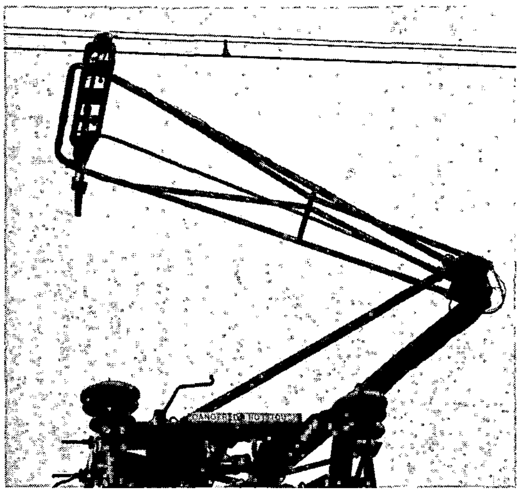
DOT-FR-80-03

FINAL REPORT

DESIGN OF DEAD-WIRE INSTRUMENTATION PACKAGE FOR USE ON ELECTRIFIED RAILROAD TEST TRACK AT TRANSPORTATION TEST CENTER



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Prepared for :

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
OFFICE OF PASSENGER SYSTEMS
WASHINGTON, D.C. 20590

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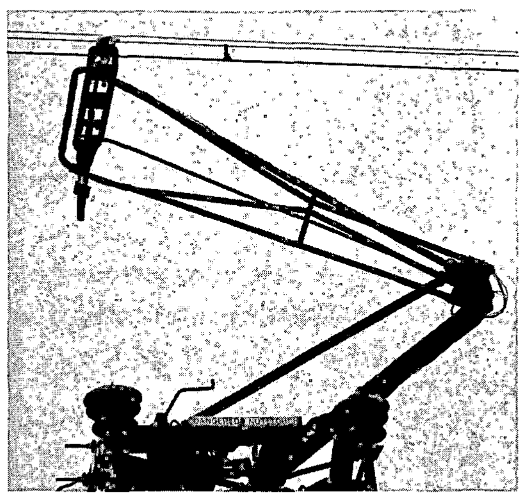

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16. Abstract

This report describes an instrumentation package designed to perform geometry measurements on a catenary system and to identify areas requiring adjustment, to perform maintenance checks on the catenary, to determine long-range stability and to provide performace data on a variety of pantograph/overhead combinations. The system measures true contact force, contact wire stagger, contact wire height, pantograph head trajectory, structure marker location and loss-of-contact.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Railroad Test Track (RTT) at the Transportation Test Center (TTC) in Pueblo, Colorado is currently being equipped with an overhead catenary system. This project has been financed by the Northeast Corridor (NEC) Project Office and administered by the Office of Research and Development as part of the NEC Improvement Project's efforts to evaluate vehicles before they enter revenue service.

1.2 FUNCTION OF DEAD-WIRE INSTRUMENTATION PACKAGE

As part of the project, a dead-wire instrumentation package was designed to be mounted on the test car shown in Figure 1-1. This instrumentation package has four primary purposes:

- To perform geometry measurements on the RTT and the catenary system and to identify areas requiring adjustment.
- To perform periodic maintenance checks on the overhead catenary system (OCS) in order to determine the long-range stability of the system.
- To provide performance data on a variety of pantograph/overhead combinations.
- To provide the data required for the various NEC tests.

1.3 ADVANTAGES OF DEAD-WIRE TESTING

The initial test series was run on a dead-wire system, i.e., with the OCS grounded which is a prerequisite to later live-wire testing, because:

- Dead-wire measurements will be used as a basis for comparison with live-wire measurements.

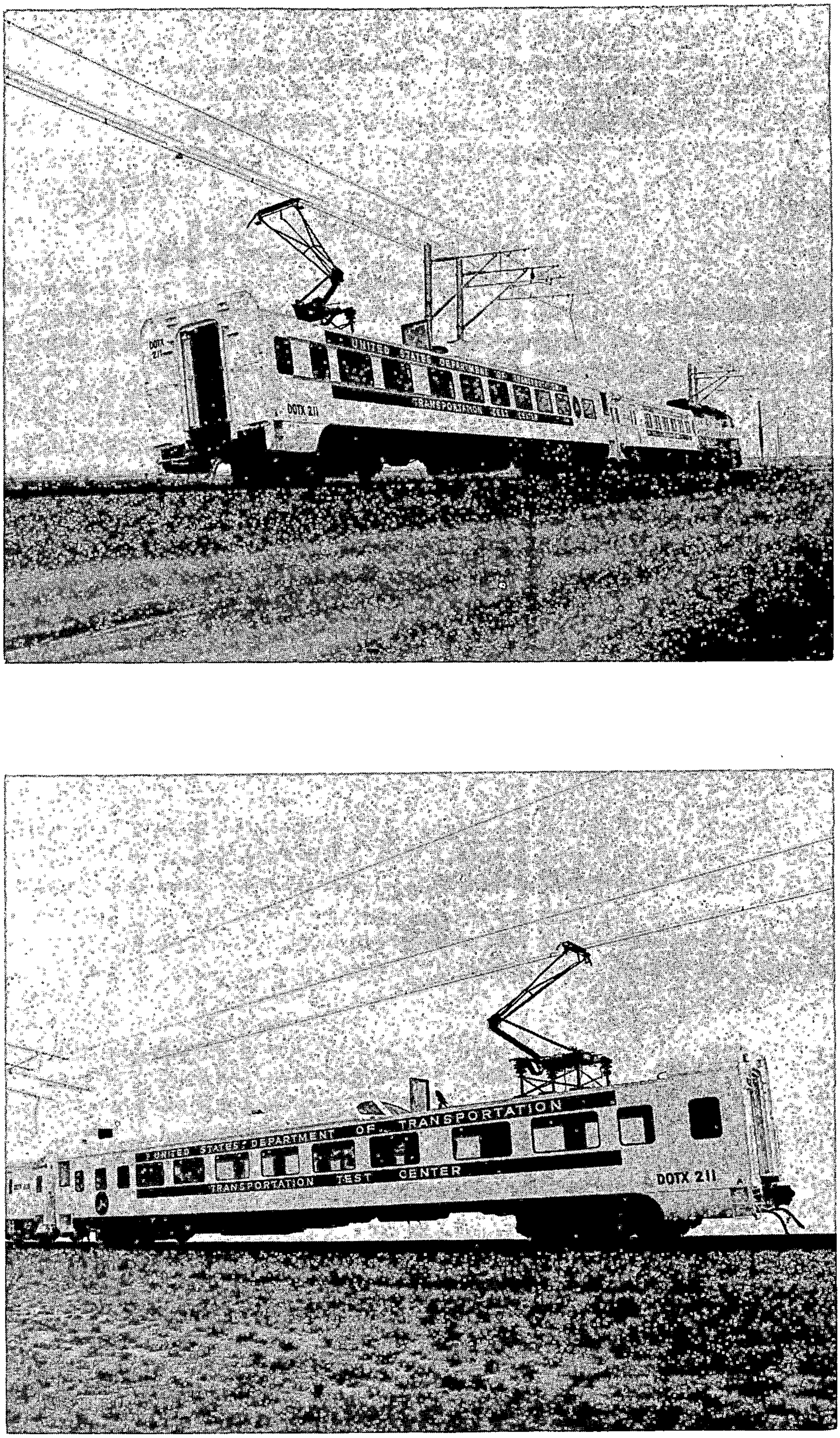


Figure 1-1. DOT Test Car Showing Pantograph

- Training of personnel is much easier without the added safety hazards involved in live-wire testing.
- The dead-wire data is much easier to analyze since it can be studied directly. Live-wire data must be filtered, modulated or demodulated, and converted to ground potential via an insolating medium.
- There is no practical limit to the number of parameters that can be monitored compared to the live-wire technique which is limited by the data transmission link.

1.4 DISADVANTAGES OF DEAD-WIRE TESTING

Dead-wire testing does, however, have disadvantages that are not present in live-wire testing, such as:

- During dead-wire testing, a thorough evaluation of the equipment at high speeds is difficult.
- The relationship between current collection and power system functions cannot be determined from dead-wire testing.
- During dead-wire testing, the correlation between current collection and radio frequency interference cannot be determined.

Therefore, the instrumentation package had to be designed for both dead- and live-wire testing. To modify the dead-wire instrumentation package to operate on a live-wire system, only the main-frame displacement transducer needed to be altered by equipping it with an insulating extension string for live-wire use. The transducers on the pantograph and the structure marker were selected with future live-wire testing in mind and will require no modification. Since the computation module accepts signals from a data-signal-conditioning system, it needs no modification for live-wire use.

1.5 CAPABILITIES OF INSTRUMENTATION PACKAGE

The instrumentation package is attached to the test car to measure pantograph (Figures 1-2 and 1-3) performance and to provide data on the following:

- True Contact Force - the dynamic force applied to the contract wire by the pantograph head.
- Contact Wire Stagger - the lateral position of the contact wire relative to the pantograph head.
- Contact Wire Height (above rail).
- Pantograph Head Trajectory - the motion of the pantograph head relative to the vehicle roof.
- Structure Markers - the locations of track structures which are recorded for subsequent data processing.
- Loss of Contact (LOC).
- Processed LOC Data - To correlate LOC to true contact force, to calculate percent LOC, and to determine LOC distribution

The overall Dead-Wire Measurement System is shown in simplified form in Figure 1-4.

1.6 SIGNIFICANCE OF MEASUREMENTS

The live-contact-force is a critical parameter in the performance of overhead catenary systems. If the contact force is too low, arcing occurs which causes damage to the current collection and overhead equipment and, in extreme cases, to the control and traction equipment. If the pantograph contact force is increased to improve current collection, this increases wear on the carbon-content strips and more importantly on the contact wire which reduces service life.

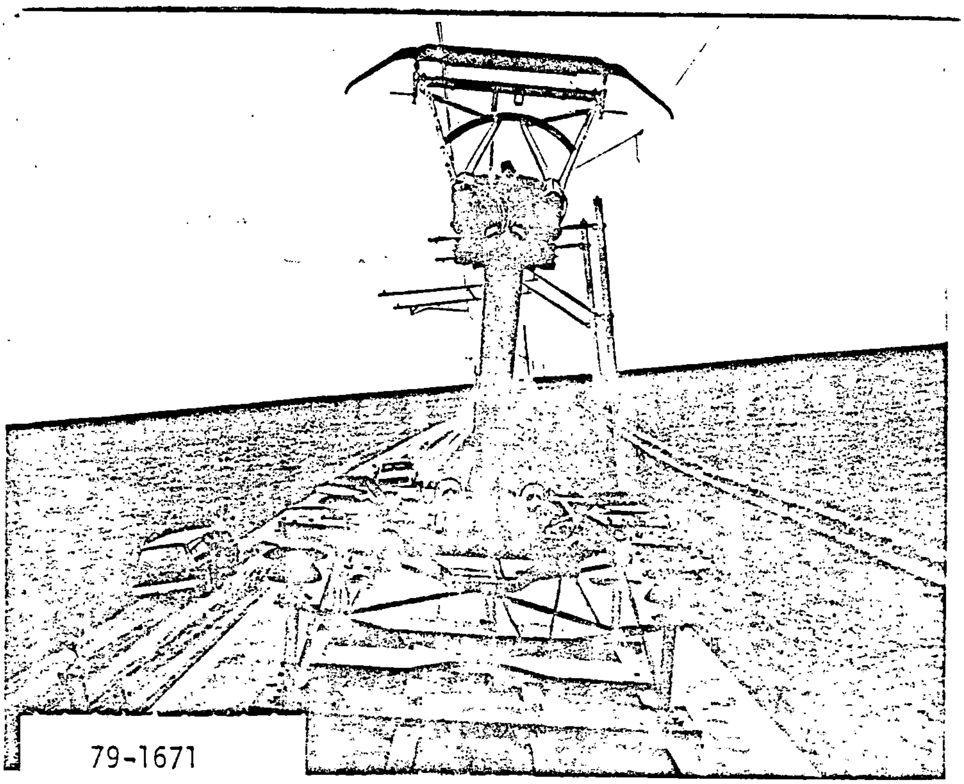


Figure 1-2. Pantograph in Up Position

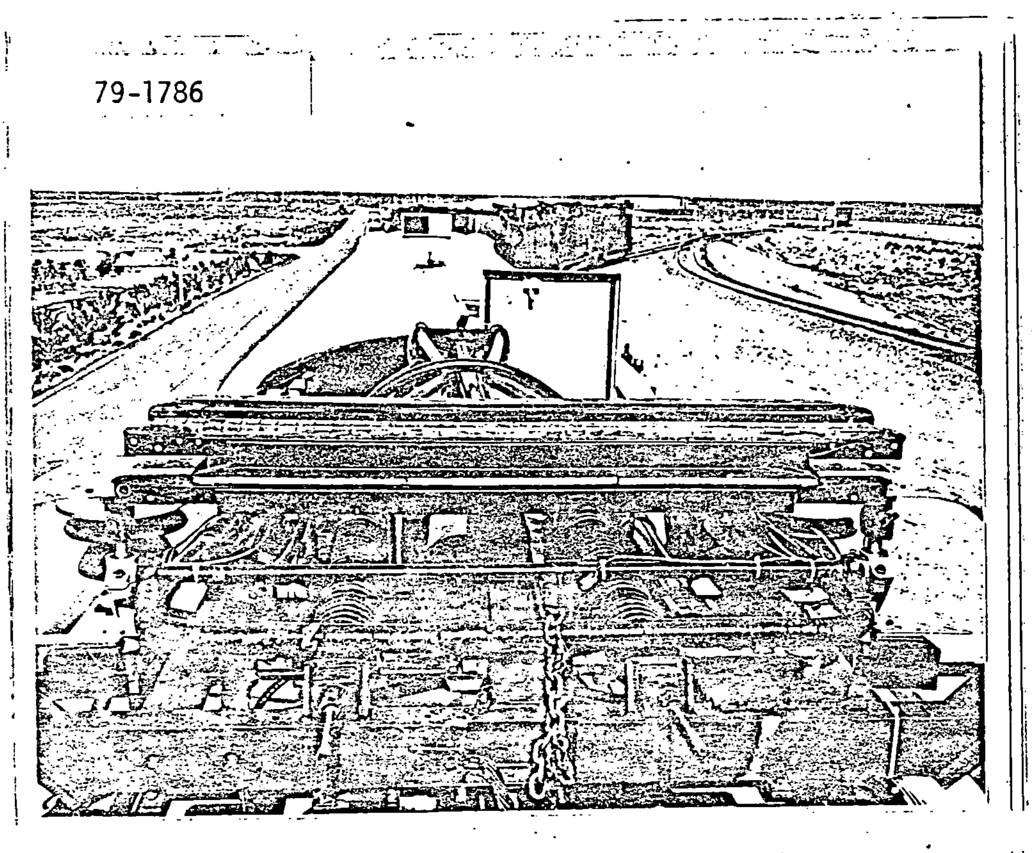


Figure 1-3. Pantograph in Retracted Position

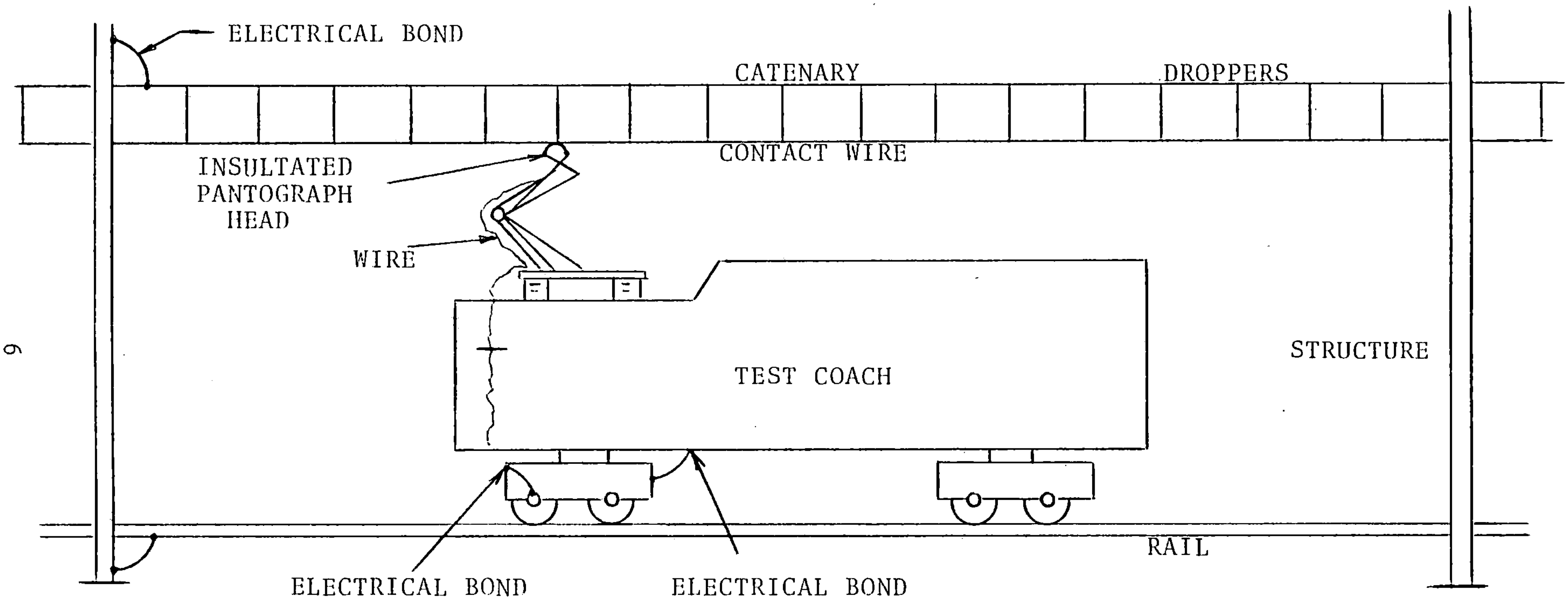


Figure 1-4. Overall Dead-Wire Measurement System

The contact wire height is an important parameter for checking the long term stability of the system and determining when maintenance should be performed.

The pantograph head trajectory can be used to determine the displacement of the secondary suspension and the frame height. The secondary suspension displacement is an important parameter; since at high speeds, limited travel of the secondary suspension can cause a dramatic increase in contact loss. Frame height affects frame stiffness and aerodynamic resistance; both of these affect pantograph performance in terms of loss of contact.

The loss of contact (LOC) and processed LOC data are important for measuring the general performance of the overhead equipment and in particular for detecting "hard spots" on the catenary. This is an important tool for maintenance planning and it can be used to indicate when maintenance is necessary.

2.0 TECHNIQUE FOR MEASURING CATENARY PARAMETERS

2.1 GENERAL

This section describes the underlying principles used in the measurement of the catenary parameters listed in Section 1.0 and describes the transducers used in the measurements.

2.2 TRUE CONTACT FORCE (F_{TCF})

The measurement of true contact force requires the measurement of two static contact forces, the pantograph head acceleration for estimating the inertial force, and an estimate of the aerodynamic forces on the head.

The true force is computed from the summation of the left and right static forces $(F_1 + F_2)$, the inertial force $F_I = m\frac{(a_1 + a_2)}{2}$ and the aerodynamic force, $F_L = \pm kv^2$.

$$\text{True force} = (F_1 + F_2) \pm m\left(\frac{a_1 + a_2}{2}\right) \pm kv2$$

Where m = the mass of the pantograph head including instrumentation

a_1 and a_2 = acceleration measured at each end of the pantograph head

F_1 and F_2 = forces measured by strain-gage force transducers

v = train speed

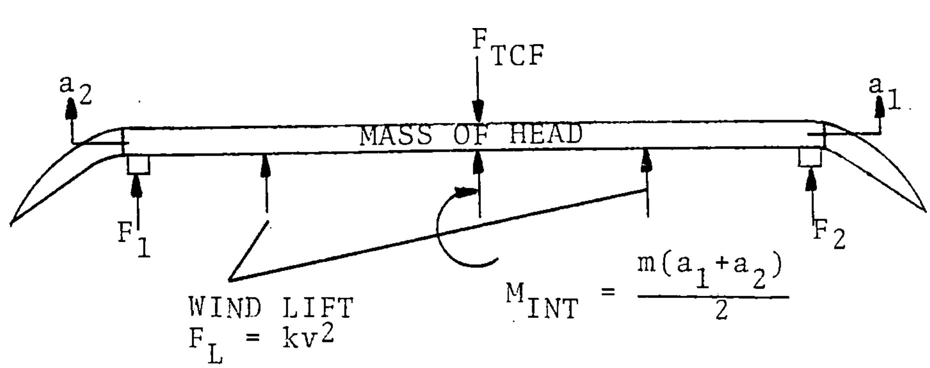


Figure 2-1. Computation of True Contact Force

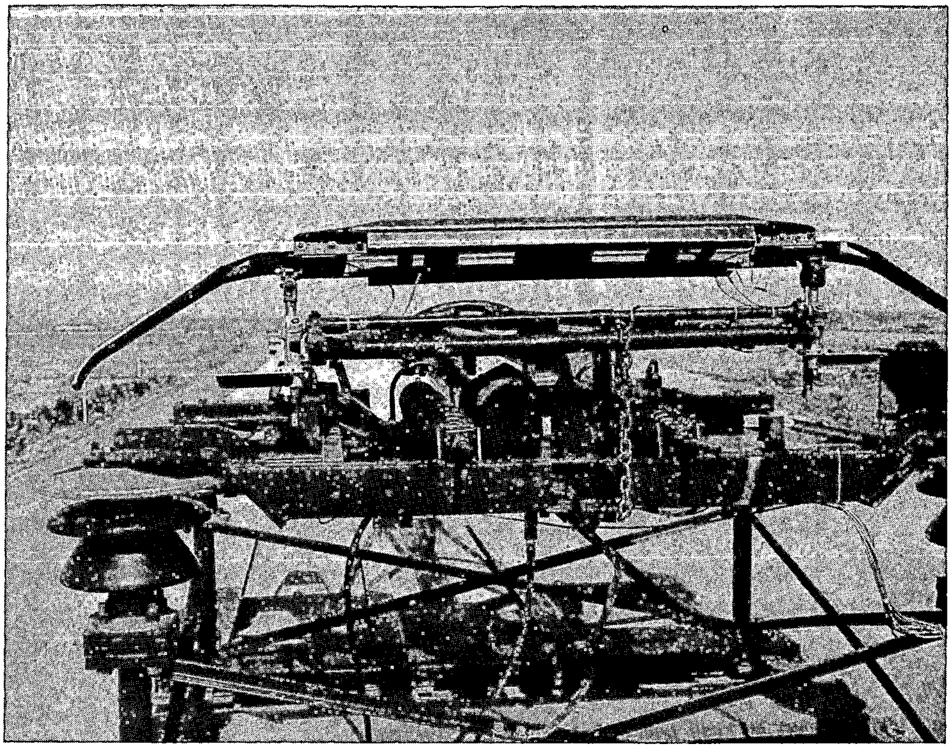


Figure 2.2 Pantograph Head and Secondary Suspension

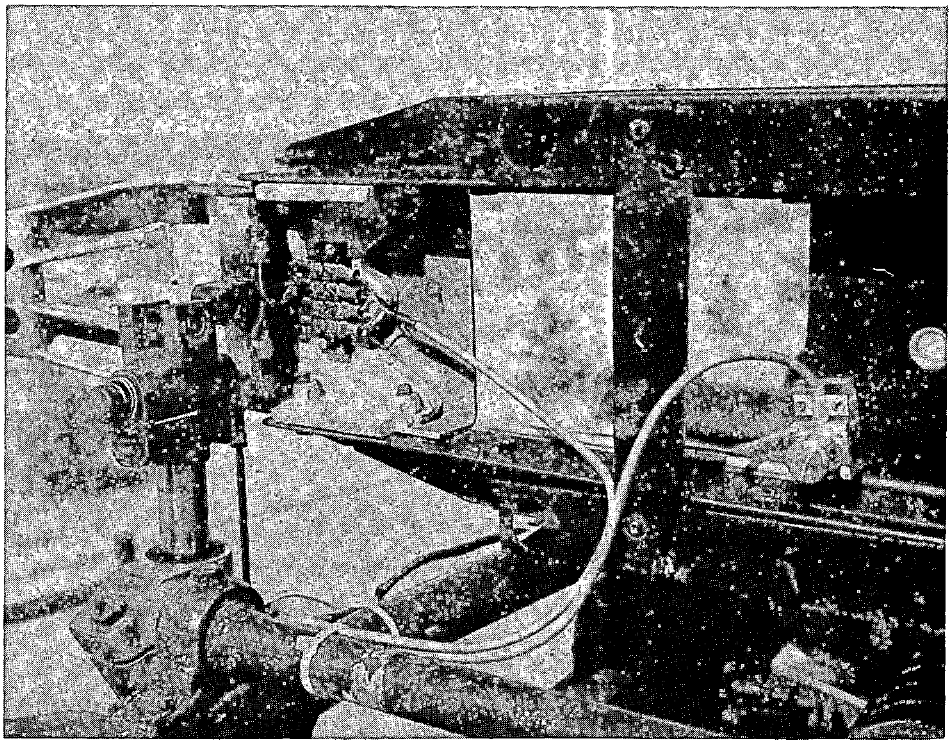


Figure 2.3 Position of Strain-Gaged Beam

2.2.1 STATIC CONTACT FORCE

To measure the static contact force, strain gaged beams were placed between the pantograph head and the secondary suspension plungers on each side of the pantograph head (see Figures 2-1, 2-2 and 2-3). The total static force exerted on the contact wire by the pantograph head is simply the sum of the two force-transducer signals. It should be noted that when the contact wire is on a horn, the force transducer on the opposite side reads negative indicating a tensile force. However, the summation still gives the contact force.

2.2.2 PANTOGRAPH HEAD INERTIAL FORCE

To compensate for the inertial effects of the pantograph head, two accelerometers were mounted on the head. Each accelerometer is offset from the center of the head by approximately one foot so that the accelerometers are diagonally opposite each other. Summing the outputs of the two accelerometers provides the average vertical acceleration, which is used for computing pantograph inertial force by multiplying by a constant which represents the pantograph head mass of 33 pounds.

2.2.3 AERODYNAMIC FORCES

The aerodynamic force (F) on the pantograph frame contributes to the contact force in a manner which is proportional to speed (v) squared, i.e., $F = kv^2$. The constant, k is computed in a preliminary test for the particular pantograph under consideration, and then inserted into the computer unit for performing the calculation of aerodynamic forces at other speeds. True force computation, therefore requires an analog, speed-related voltage with calibration facility (TTC responsibility). Since aerodynamic forces are negligible at low speeds, a calibration voltage corresponding to 100 to 120 miles per hour is required.

2.3 CONTACT WIRE STAGGER

When the overhead construction on the RTT is completed, data from the instrumentation package will be recorded at slow speeds. These data will be compared to data obtained at a few selected sites using a height and stagger gage. Limiting conditions such as the ride-characteristics of the test car will be determined to obtain a speed range where test car data are optimum. These data can be compared to other records made months or years later to establish the stability of the overhead system (assuming the track does not move). There are two approaches to the measurement of contact-wire stagger: the traditional approach based on a segmented head approach, and a second more convenient method which uses the force values on either side of the head to determine the position of the contact wire and thereby the stagger.

2.3.1 SEGMENTED HEAD

This method (Figure 2-4) utilizes a flat segmented strip mounted inside the pantograph head. As shown in Figure 2-5, the strip consists of a flat commutator having one-inch segments which are insulated by 100-ohm resistors. Passage of the contact wire along the segments and over the opposite insulator/ collector strip (wiper) provides a method for measuring stagger.

Stagger is a very important parameter to monitor, because of the height of the wire and the degree of superelevation of the rails in RTT curves. In order to facilitate movement through these curves, the segments have been extended past the normal extremities of graphite collector strips. Data are obtained for a total 20-1/2 inches to either side of the

SEGMENTED PANTOGRAPH HEAD

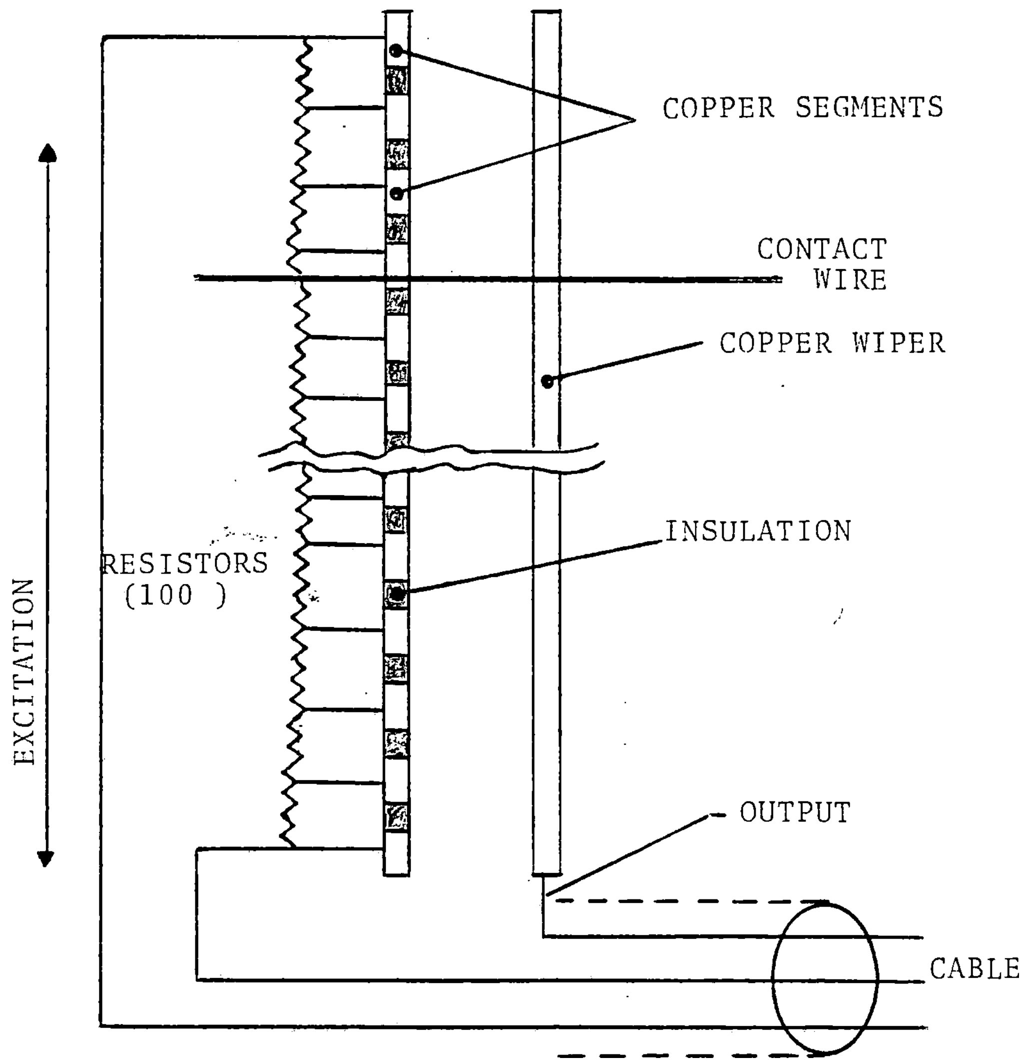


Figure 2-4. Segemented Stagger Measurement

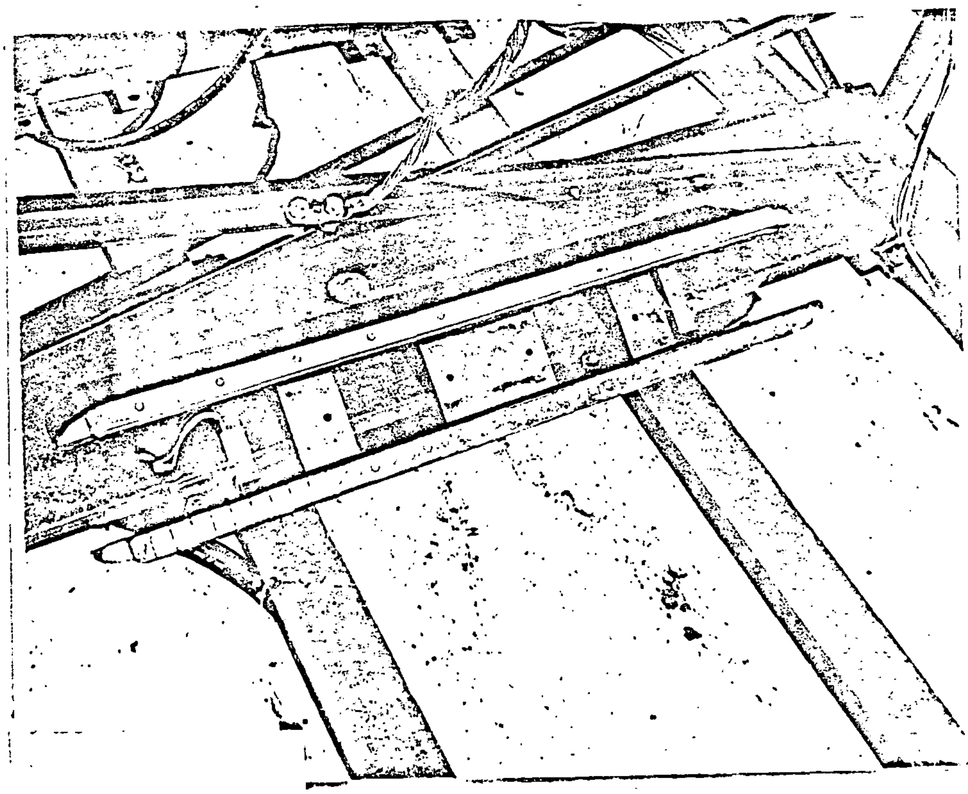


Figure 2-5. Flat Commutator Strip Inside Pantograph Head

pantograph-head centerline. Each one-inch segment is stamped with an identification number from zero to 20 each way (Figure 2-6) to facilitate calibration. This information will be lost, if the contact wire traverses the horns. Although the segmented head has been manufactured to guarantee the production of these data, it is expected to be superceded by the force processing method. Until then, both methods should be used simultaneously for purposes of evaluation.

2.3.2 INSULATION REQUIREMENTS FOR PANTOGRAPH HEAD

Each graphite collector strip (Figure 2-7) is insulated independently from the pantograph head by 1-5/8-inch wide by

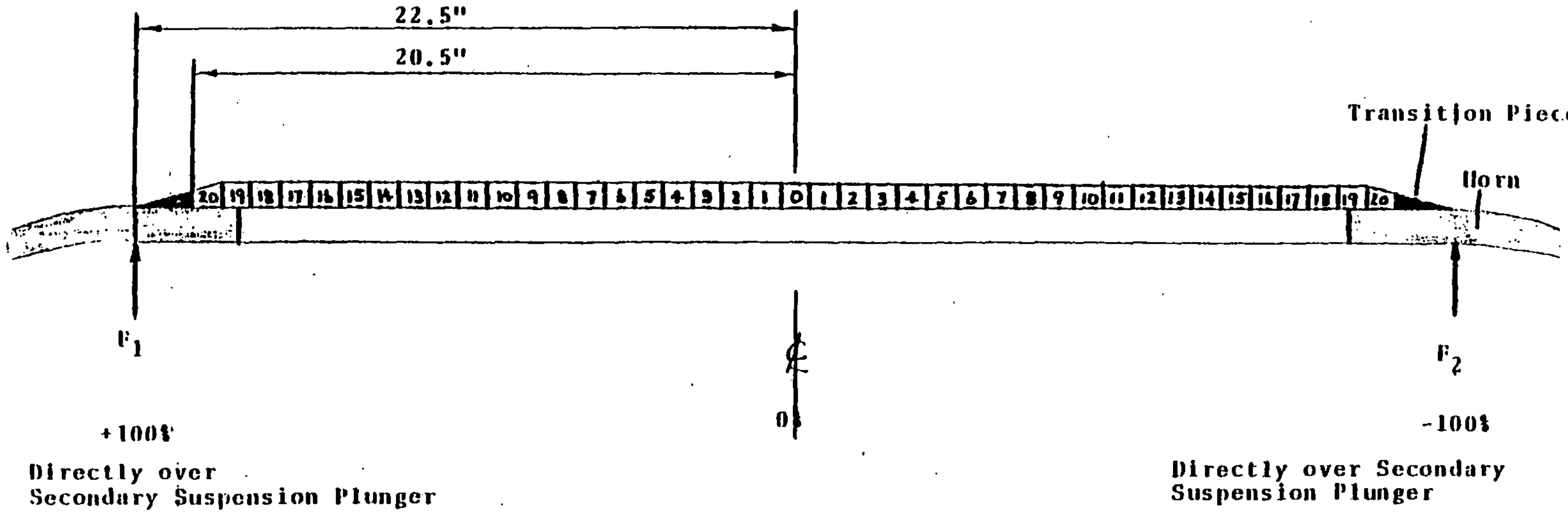


Figure 2-6. Segmented Head Dimensions

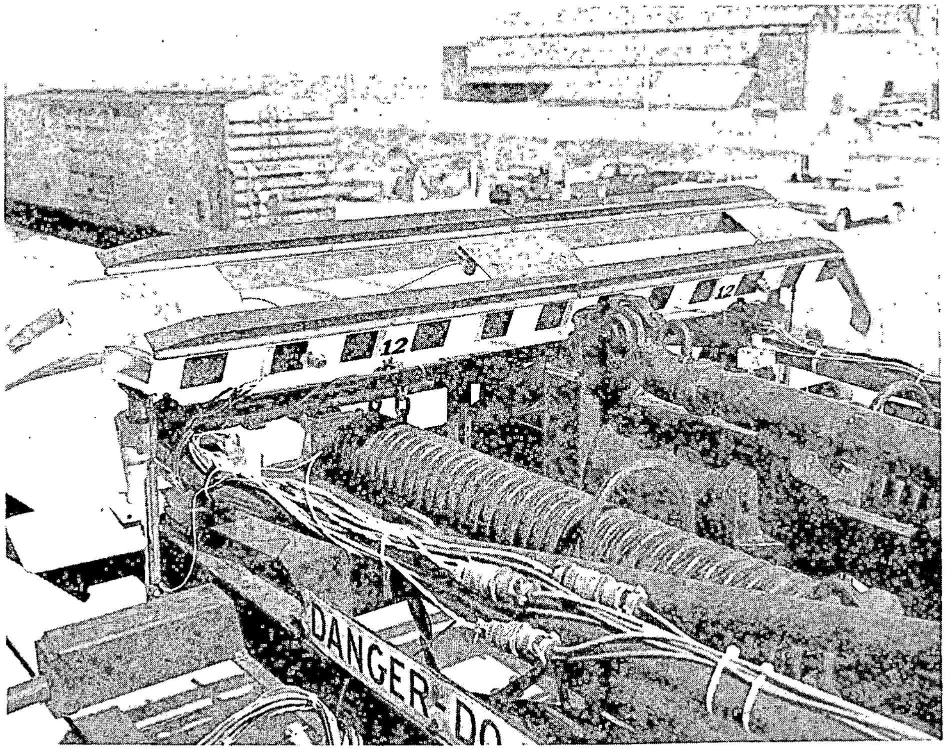


Figure 2-7. Pantograph Head Showing Graphite Collector Strips

1/16-inch thick Lexan*. The usual collector-strip fixing bolts are used but they are isolated from the pantograph head by nylon washers with shoulders that extend into the clearance holes to isolate the bolts. The bolts are tightened by nuts on the other side of the nylon washers which draw the graphite collectors towards the head and form a sandwich with the Lexan (Figure 2-8). A solder tag (Figure 2-9) is underneath

*Lexan is a General Electric trade name for apolycarbonate resin featuring high impact strength, high dielectric strength and low moisture absorption.

the nuts to ensure that all collector strips are connected electrically via an insulated wire. As a back-up, the pantograph head was insulated from the pantograph frame by nylon bushings at the hinge-block/secondary suspension anchoring points on both sides of the head.

Care was exercised to make sure that other transducers, such as accelerometers, did not have their cases grounded which would short the head to ground if they came into contact. Also, there would be a ground loop problem to consider if they were so connected.

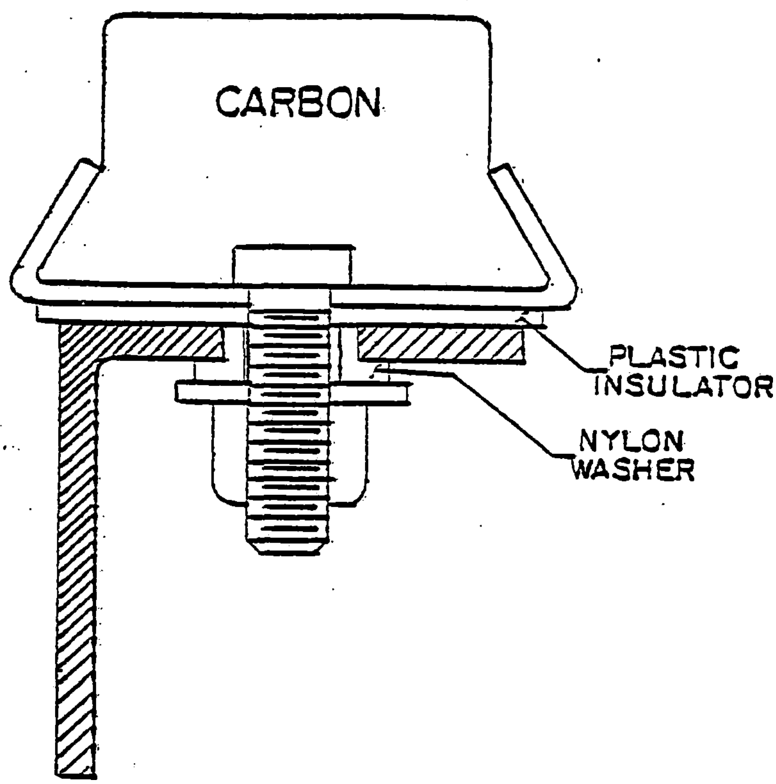


Figure 2-8. Collector Strip Insulation

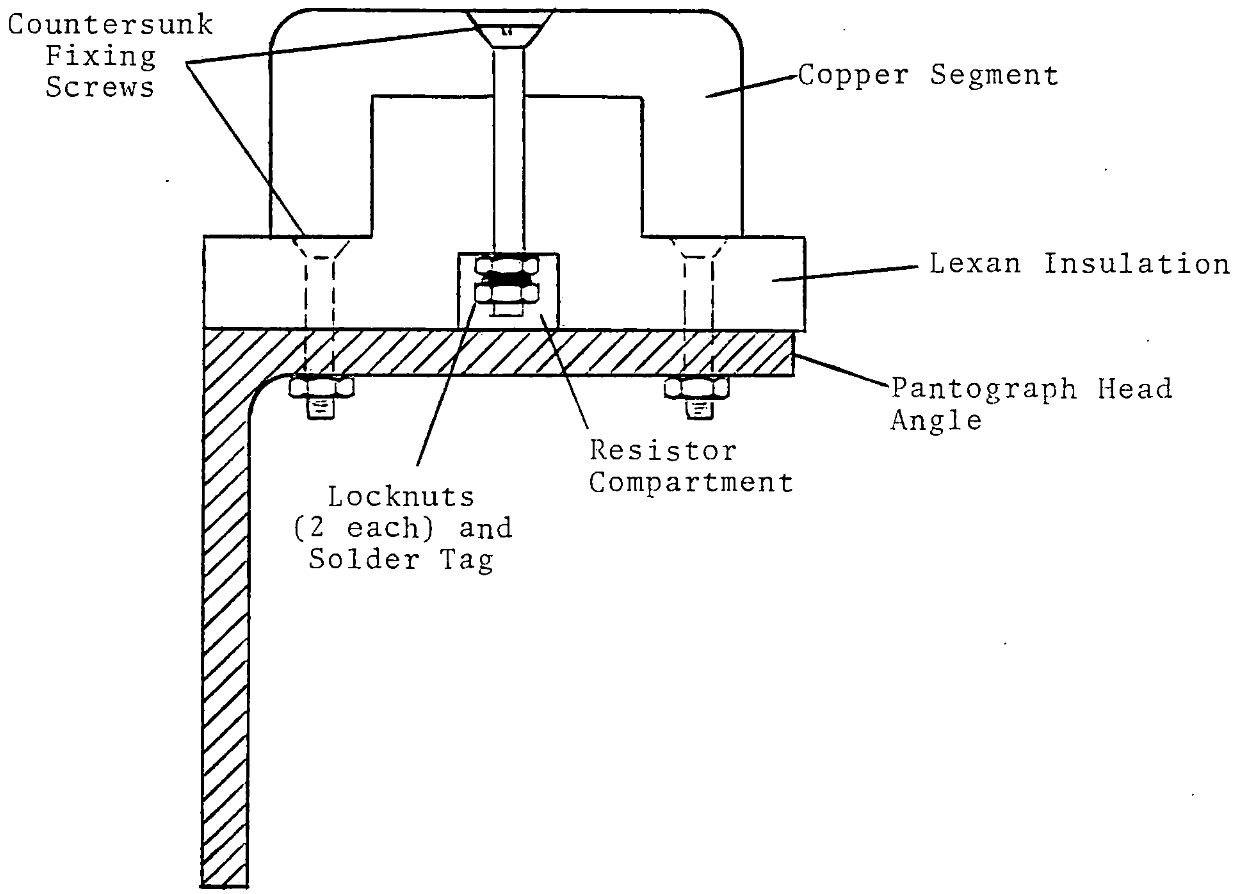


Figure 2-9. Segmented Head-Cross Section

2.3.3 MEASUREMENT OF STAGGER USING STATIC FORCE TRANSDUCERS

Another direct method for measuring stagger involves the static force transducers used in the contact force computation. If the outputs of the left and right transducers are F_1 and F_2, respectively, then a measurement of stagger is given by the ratio $\frac{F_1}{F_1 + F_2} = 0$; when the contact wire is directly over F_1 and $F_2 = 0$ and the ratio $\frac{F_1}{F_1 + F_2} = 1$. If the total distance between the transducer locations is known the $\frac{F_1}{F_1 + F_2}$ ratio can be converted directly into stagger distance.

2.4 CONTACT WIRE HEIGHT

The contact wire height can be determined by adding the effective car height to the frame height. For all practical purposes, the effective car height can be taken as the height of the car when it is stationary on level track; this is only an approximation when the car is traveling on a curve at non-balance speed.

2.4.1 PRIMARY (FRAME) DISPLACEMENT

Information on pantograph extension is important when making both performance and geometry measurements. Excessive loss-of-contact sometimes occurs before and after an over-bridge due to a steep gradient. This can be determined from the frame-height measurements and a distance counter or structure marker. At high speeds and near-maximum extension, structural flexibility is detrimental to performance. The height of the pantograph must also be considered when taking geometry measurements (such as stagger) because of the roll of the vehicle.

Frame height is measured by attaching a linear displacement transducer to the tube to which the pantograph frame is attached (Figure 2-10). An actual photograph of the installation is shown in Figure 2-11. The frame height at any instant is then determined by summing the displacement transducer output with the height of the pantograph in the retracted position. Besides being a key parameter for determining contact wire geometry, frame height is also an important parameter in determining pantograph performance.

The frame-height measurement consists of converting a rotational movement into a linear output. The operation of the pantograph frame depends on spring-pressure which acts upon a tube on the pantograph base rotating it and forcing the frame up until it comes in contact with the wire. This rotation extends the displacement transducer via a stainless-steel extension cable. Conversion to live-wire operation is usually achieved by using an insulated extension cable.

Calibration is accomplished by taking analog recordings and at the same time readings from a tape measure as the pantograph is extended.

2.5 PANTOGRAPH HEAD TRAJECTORY

This measurement indicates the motion of the pantograph head relative to the car roof. It is measured by adding the instantaneous frame height to the secondary suspension displacement.

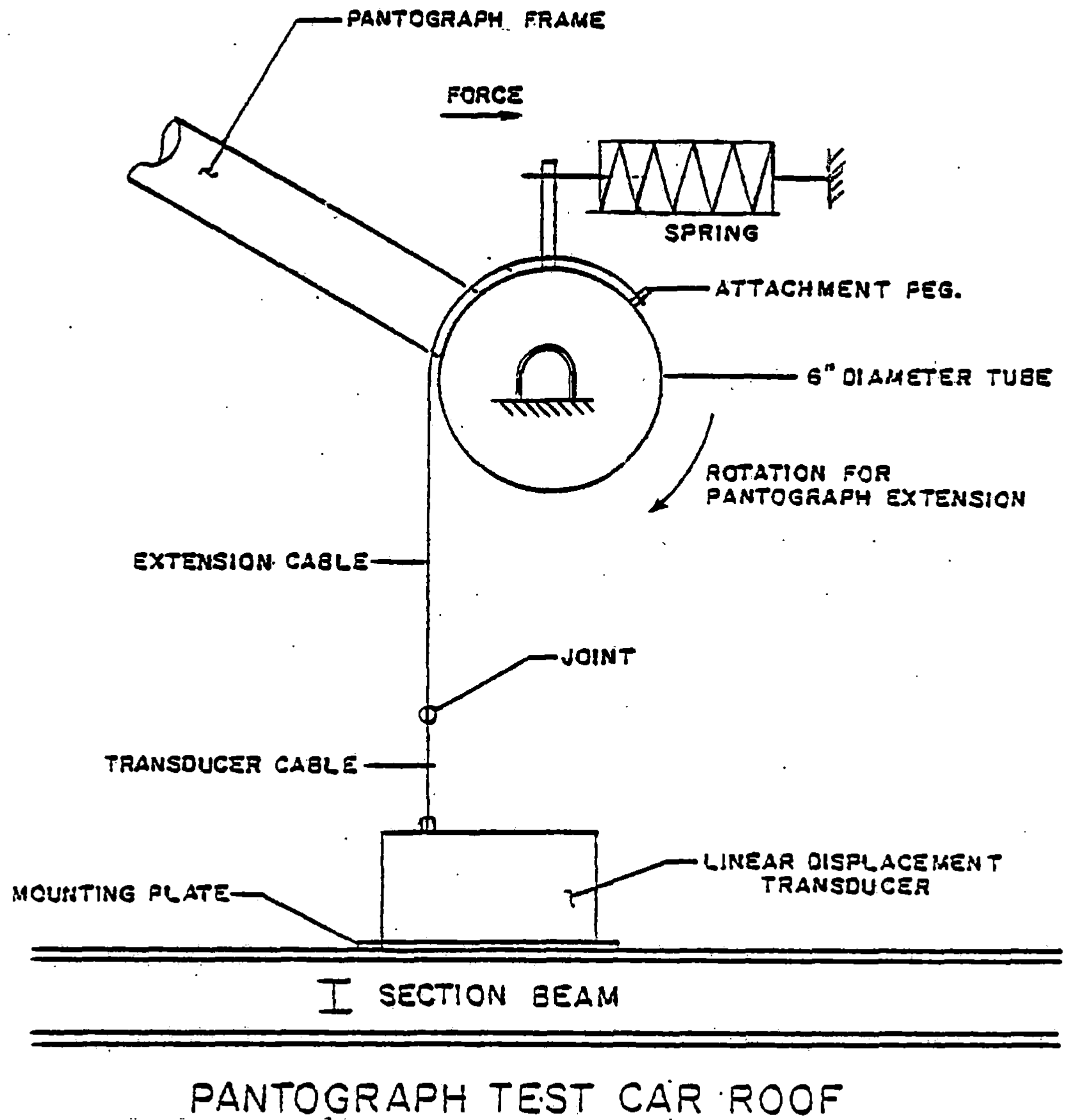


Figure 2-10. Schematic Diagram-Pantograph-Frame-Height Measurement

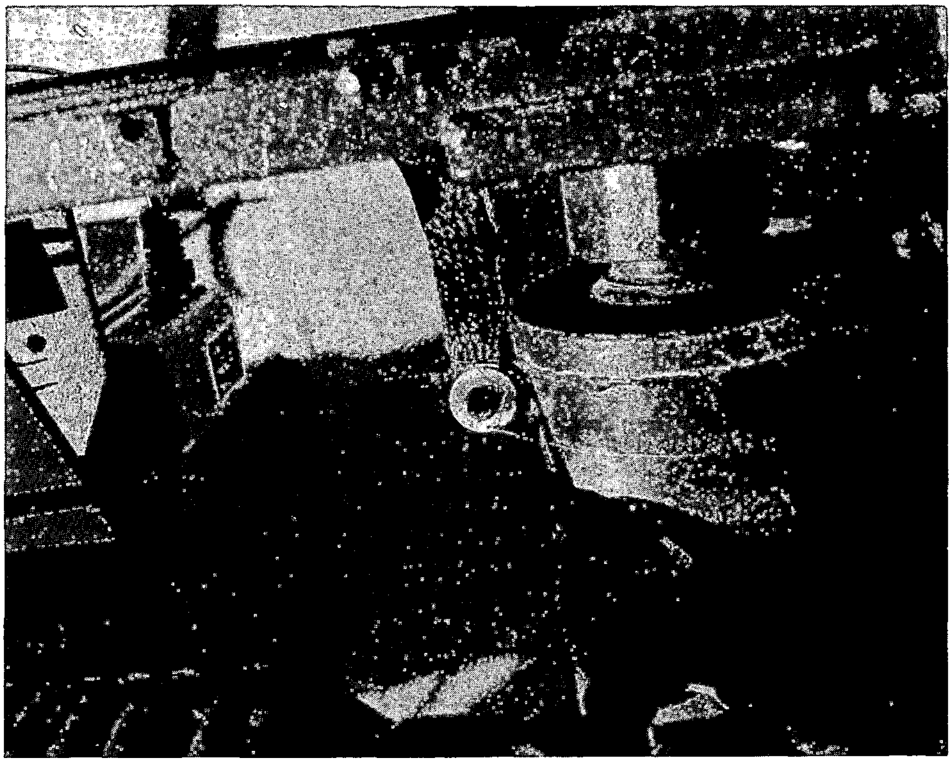


Figure 2-11. Linear Displacement Transducer for Measuring Pantograph Height

2.5.1 SECONDARY SUSPENSION DISPLACEMENTS

To achieve acceptable current collection above 70 mph, secondary suspension mechanisms are incorporated in the pantograph design. These suspension units have a different spring rate than that of the main frame so that small excursions can be encountered without losing contact with the overhead.

The secondary suspension signals yield valuable information on how a pantograph is performing, and limited travel is one reason for the exponential increase in loss-of-contact with speed.

The secondary suspension of the pantograph head, instrument for dead wire operation, consists of two hydraulic pistons to which the pantograph head is attached as shown in Figure 2-12. The displacement of the secondary syspension is measured by attaching a displacement transducer to the hydraulic piston as shown in Figure 2-13.

The range of travel of each plunger is slightly less than ± 1.0 inch. In a stationary position and with the pantograph away from the contact wire, the displacement transducers can be nulled for zero output in the signal conditioning unit.

Calibration is best achieved in the laboratory using a vernier or graduated transducer rig.

Lost of contact measurements on a dead and grounded overhead system are carried out by utilizing a low voltage (20-volt) supply to circulate a current through the system, i.e., overhead to structure, to rails, to test car ground, to LOC circuit, to pantograph head, to overhead. It is proposed to utilize a Dynamics amplifier channel for each LOC channel. While in contact with the overhead, a current flows developing a voltage across a resistor on the mode card in the amplifier. Interruption of the current flow reduces the voltage to zero. The action of the pantograph head is that of a switch in the equivalent circuit.

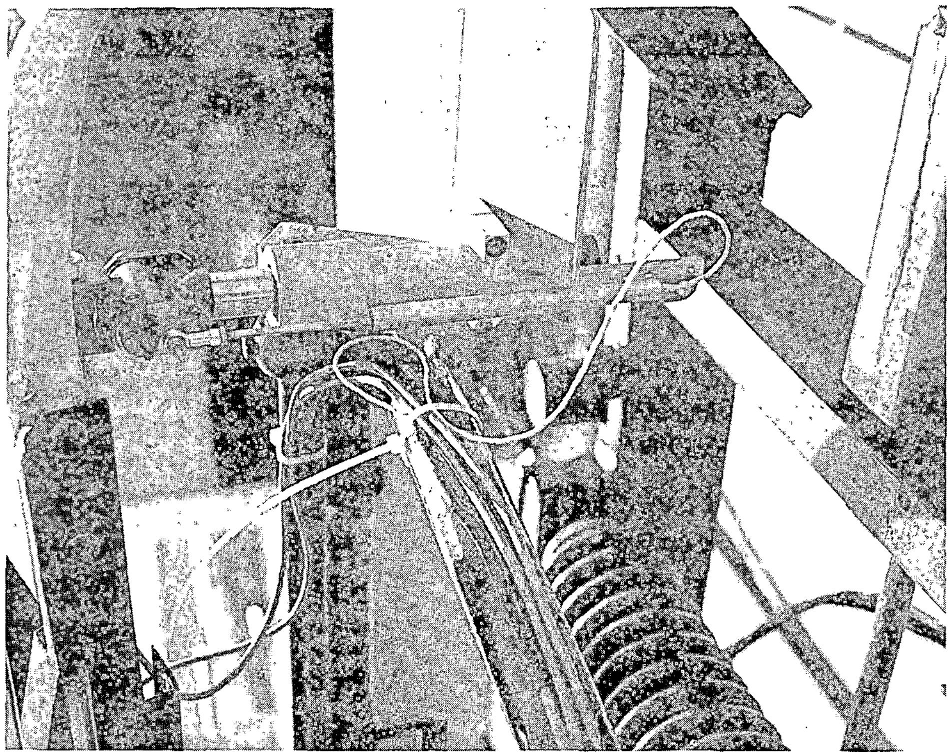


Figure 2-12. Secondary Suspension Displacement Transducers

It is difficult to measure secondary suspension displacement at the point of contact with the overhead, because the position of the wire is unknown relative to the two displacement transducers. However, by averaging the two outputs it is possible to reduce the maximum error by one-half and to obtain a good estimate of the secondary displacement.

2.6 STRUCTURE MARKER

To facilitate data interpretation, it is desirable to know the position of discreet features (insulators, droppers, etc.) so that correlations and correct assumptions about performance can be made. Structures for the support of the overhead occur

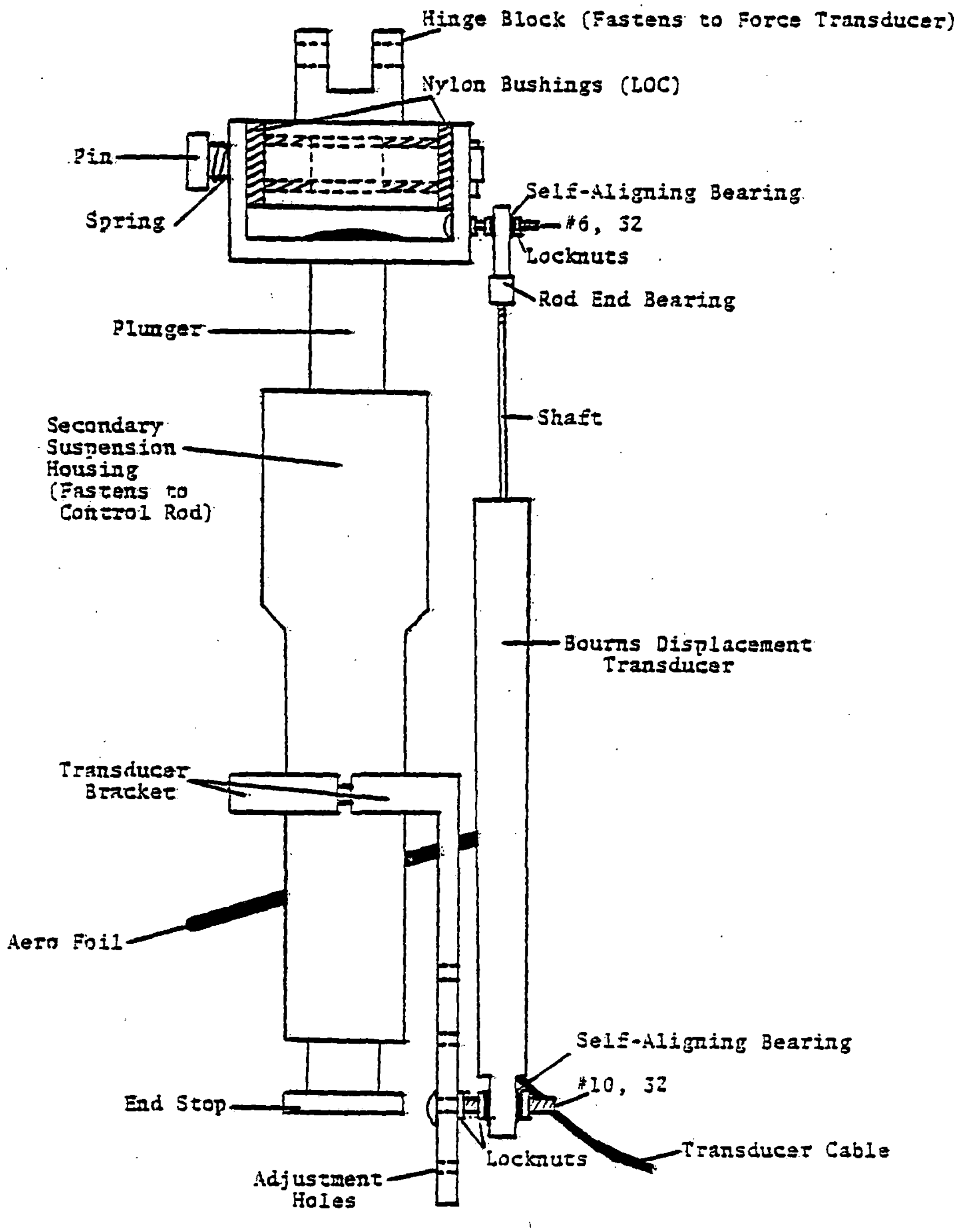


Figure 2-13. Secondary Suspension Measurement

at approximately 200-foot intervals (more frequently in curves), and they are in a position where contact losses are usually observed (change in elasticity). Once the structures are located on the record, it is a simple task to position insulators, droppers, overlaps and other discreet features.

To avoid the necessity of placing and maintaining an active system such as magnets at every structure, a prototype system has been developed that senses the change in background illumination caused by the structure obscuring the field of view of an optical device.

The prototypes consist of a 25-mm television camera lens (Figure 2-14) with variable f-number adjustment (1.4 to 22),

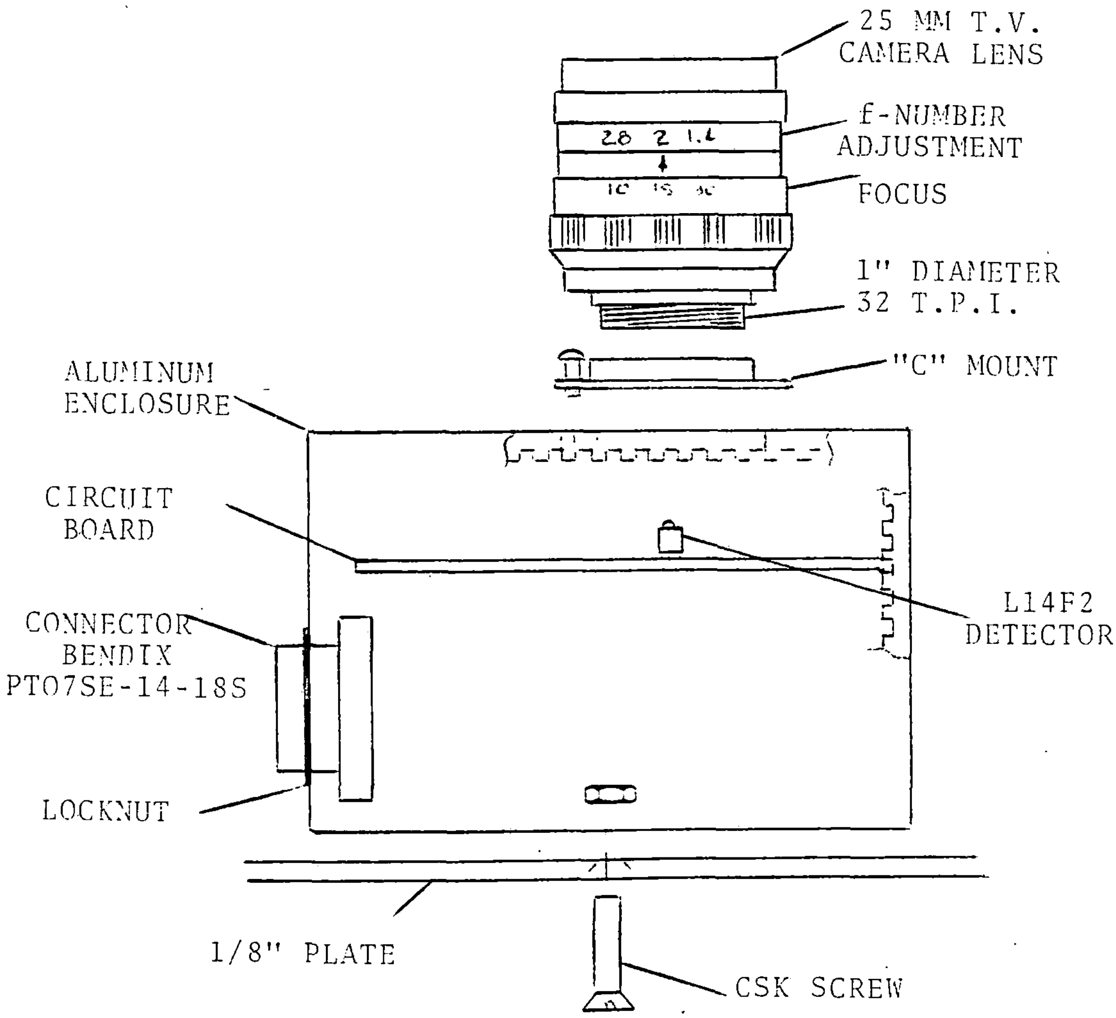


Figure 2-14. Structure Marker Arrangement

attached by a screw-in mount to a small aluminum enclosure containing the signal conditioning electronics (Figure 2-15). The sensor is mounted on one of the I-section beams on the pantograph-test-car roof, in a vertical attitude. Viewing angle is determined by the f-number setting but is in the order of a few degrees to reduce the likelihood of saturation by direct exposure to the sun. The combined effects of curves and carbody roll (above and below balance speed) must also be accounted for. The lens should not be pointed directly at the sun for any length of time as the power of the sun, magnified by the lens would quickly burn out the detector.

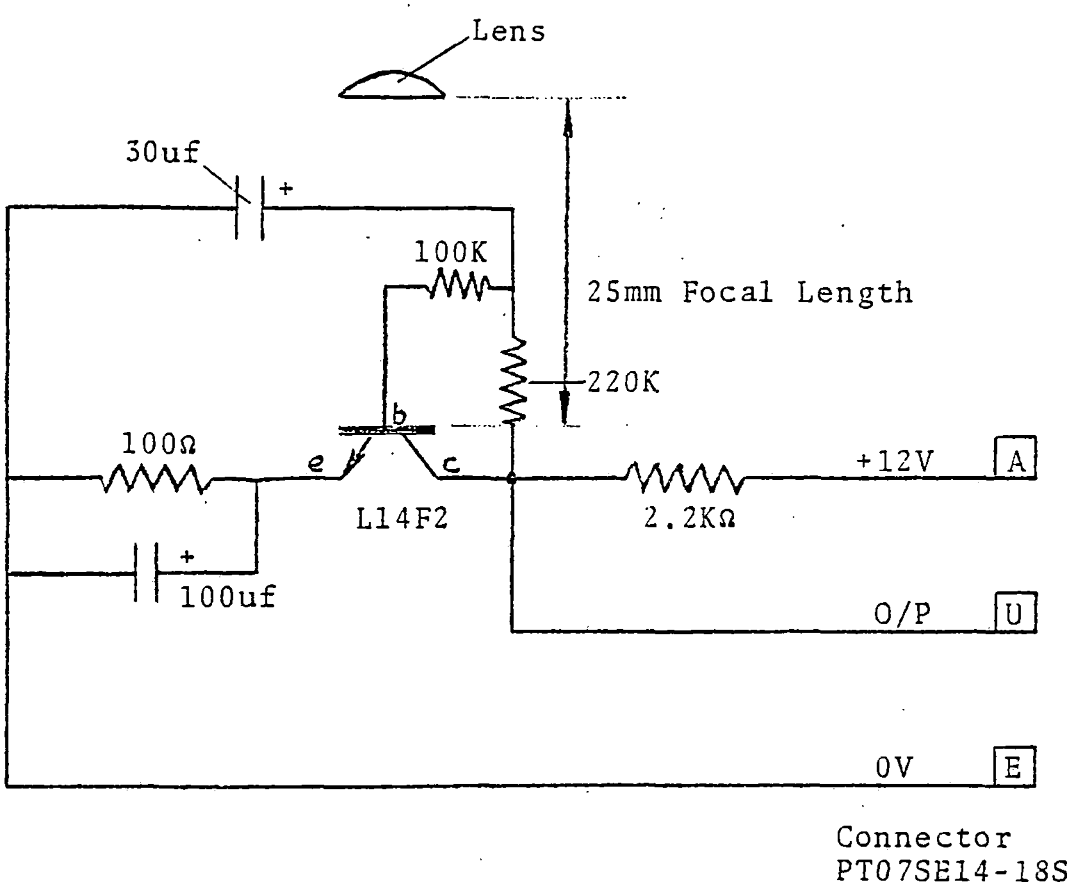


Figure 2-15. Structure Marker Circuit

The part of the structure that is sensed is sometimes referred to as the registration pole. These poles (which extend horizontally above the track) are about three inches in diameter and made of galvanized steel, but in some instances they do not extend far enough across the track to be detected by a single structure marker placed towards the outside of the test car. Unfortunately, the structure marker cannot be placed on the center line of the car as it would then detect the wires and droppers in the overhead system. Therefore, to detect all structures a separate device is required on each side of the test car.

The prototype structure marker was designed for daytime use but a demonstration was made of the structure marker working in twilight/dark conditions. A 12-volt quartz-halogen spotlight was used to illuminate the registration pole providing a diffused reflector for the structure marker to detect. In this mode of operation, the signals were observed to increase due to increased radiation; radiation normally decrease when passing under a structure. Although changes in aperture and gain have to be made for nighttime operation, night conditions are much more stable and further changes should not have to be made. Another change that will be required before live-line testing, is to shift control of the spotlights to the inside of the test car.

Positioning of the structure marker for live-line operation at nighttime may cause a conflict since it is normally placed as close as possible to the pantograph for correlation with other data channels. With it in this position, it may be susceptible to pantograph arcing.

Interface to the test car is via the normal transducer access points with a Dynamics amplifier channel assigned to the structure marker. The Dynamics amplifier supplies the power for the photo-detector (12 volts excitation voltage) and is then used as a convenient method for routing the return signal to the output.

2.6.1 PHOTO DETECTOR

A silicon photo-detector whose output is proportional to the effective radiation is used as the detector in the structure marker. The detector is placed in the approximate focal plane of a 25-mm television camera lens. The lens provides magnification and a narrow field-of-view so that small objects such as registration poles are detected at 12 feet without the sun saturating the detector. Aperture size can be adjusted manually changing the f-number from 1.4 (fully open) to 22 (almost closed) in eight steps. Each step reduces the lens area by a factor of two which decreases the radiation to the detector by the same factor. The photo-detector provides a high-level output signal which improves immunity to interference. This reduces the speed of the device, however, the speed is still more than adequate for the application.

Silicon photo-detectors have their peak output in the red or near infra-red region. The corresponding output is 80 percent less in the blue spectrum. A particular concern is what will happen to the output when the field of vew changes quickly from blue sky to bright clouds or vice-versa.

Blue skies are the result of refraction of the sun at high altitudes by small atmospheric particles. Clouds consist of much larger water droplets relatively close to the ground, and produce a much more diffused light. Also, the intensity of clouds have a large range with the cumulus (cotton wool) being much brighter than the nimbus (rain) clouds. Attempts to locate the spectra of various sky conditions have produced nothing. However, it should be possible to measure the spectra using a spectral radiometer. An attempt was made to find a wavelength having equal intensity for both blue skies and clouds. In the limited time available for this research, we have not been successful. Various passband interference filters between blue and red were tried in front of the detector so as to work on one small portion of the detector's characteristic. The relative levels obtained were very much the same with and without any one of the filters, although the absolute sensitivity decreased towards the blue end as expected. Therefore, filters are not used in the system to maintain sensitivity.

Measurements have shown that the output varies almost 20 times from early morning (0800 hours) with blue skies to noon with bright clouds during February. In July the variation could be much greater during a working day.

These variations are over a much longer period than the structure passing time and can be eliminated using feedback and/or a-c coupling the output to give rate-of-change of output. Unfortunately, the rate-of-change of output is also a function of ambient conditions, with much larger signals being seen at noon or for bright clouds than at other time of the day or for blue skies. For these reasons, a system should be designed to incorporate f-number selection and gain control from inside the test car. Automatic gain control (AGC) would of course be more complex but could be worth the effort.

However, the full range of ambient conditions has not been encountered and in particular, days of intermittent clouds and blue skies which are thought to be a possible cause of trouble.

Therefore, experience must be gained with the prototype before a system is finalized.

The final system might include the following features:

- Plano-convex lenses on the outside of the structure marker enclosures (without recesses) to prevent the accumulation of sand or water.
- Two lenses on each structure marker so that f-number can be selected from inside the test car for:
  - -- low-level signals in the winter and during twilight and nighttime operation (f = 1.4).
  - -- conditions where the sun is very high or the light is diffused by thick cloud (f = 2.8).
- Temperature control of the optical sensors for winterime operation.
- Gain control inside the test car.
- A calibration device controlled from the test car (A small solenoid could perform this function).
- An indicator on each structure marker that flashes when an object is waved across the line of sight. The indicators would be driven from the output of the system in the recording coach thus indicating that the total system is operating.

2.7 LOSS OF CONTACT (LOC) MEASUREMENT

Loss of contact measurements on a dead and grounded overhead system are made utilizing a low voltage (20-volt) supply to circulate a current through the system. As shown in Figure 2-16, the current passes consecutively through the overhead into the structure, the rails, the test car ground, the LOC circuit, the pantograph head and back to the overhead. The action of the pantograph head is that of a switch in the equivilent circuit (Figure 2-16). The loss of contact appears as a drop in voltage across the resistor in the output wireform shown in Figure 2-15.

2.7.1 DETECTION OF LOC WHEN CONTACT WIRE IS ON COLLECTOR

When the collector wire is confined to the collector area, the independently insulated strips are utilized as separate LOC circuits (leading and trailing only, the center collector is isolated from everything). Then it is possible to determine which collector loses contact first and the sequence of events thereafter. The processing module combines the loss of contact from both collector strips to provide an output when total LOC occurs.

When the contact wire is likely to traverse the horns, a true loss of contact signal is required even on the horns. With insulated collector strips, any excursion onto the horns would look like a loss of contact.

To obtain a total loss of contact for the pantograph head, the independently insulated collectors are connected to the head. One channel of the amplifer conditions the signals to be two volts = contact, zero volts = out of contact (Figure 2-17). In this method, the nylon bushings provide the isolation from the frame.

It is prudent to insulate the head from the frame even if the pantograph is initially on insulators. This eliminates having to observe the equipment on the base of the pantograph frame.

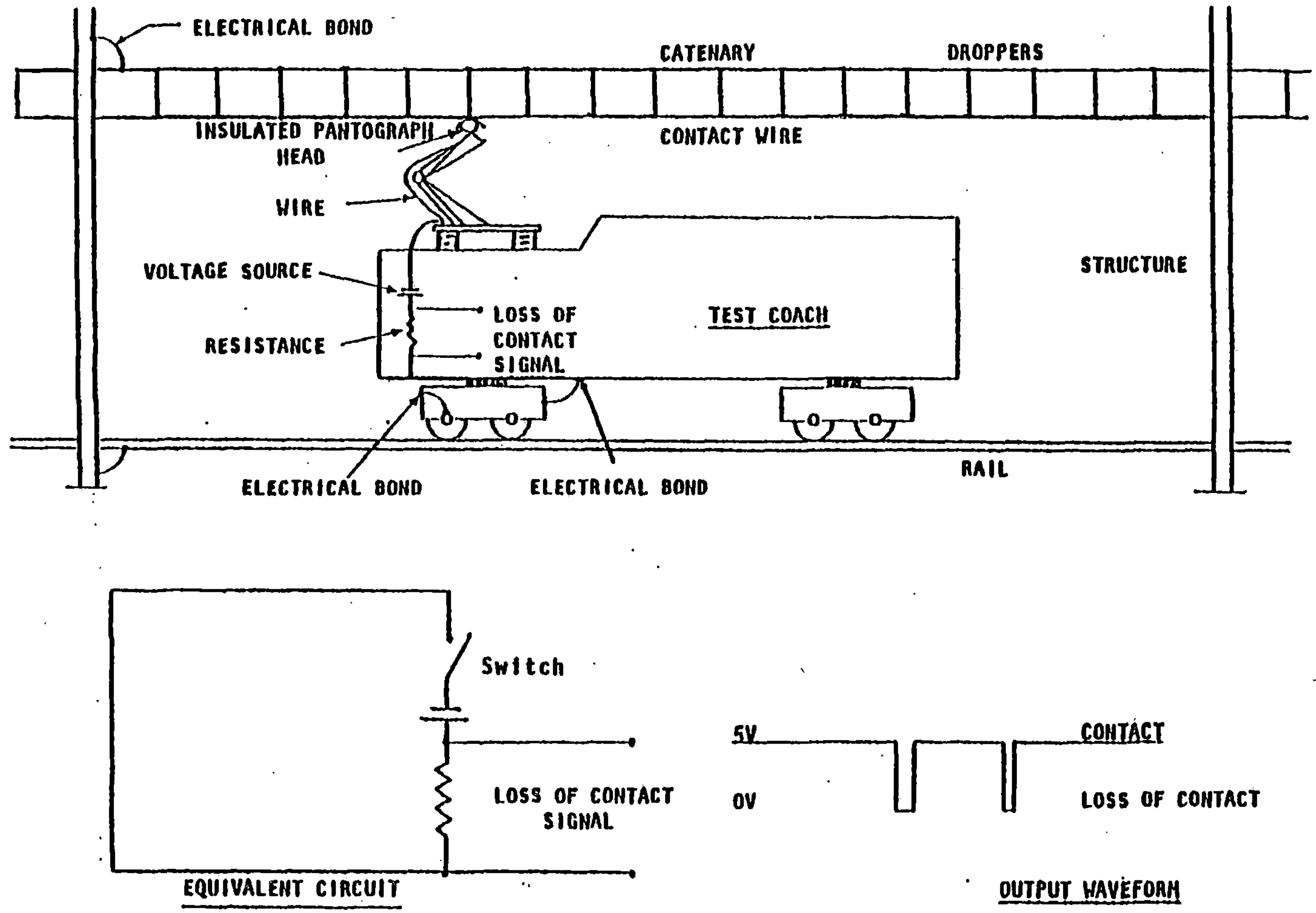


Figure 2-16. Dead Line Loss of Contact Measurements

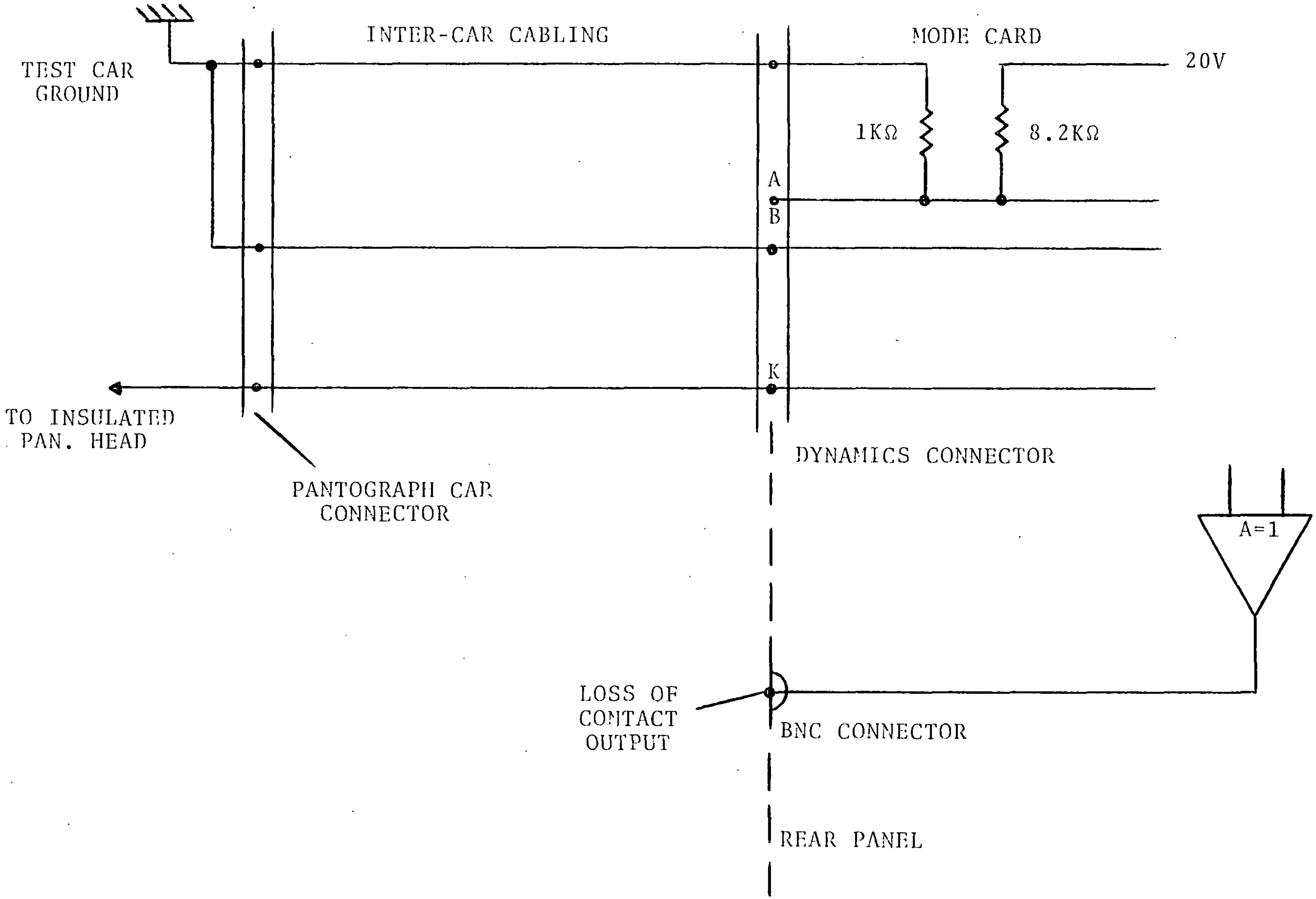


Figure 2-17. L.O.C. Test Car Wiring

2.8 PERCENTAGE LOSS OF CONTACT

In the dead wire LOC system, loss-of-contact data are produced every time a gap develops between the pantograph and the catenary. In terms of the performance of the pantograph/catenary system, not all of these data are useful. Many short duration loss-of-contacts (less than one to two milliseconds) do not represent a loss of electrical contact between the catenary and pantograph because the current would arc across during this short period. Consequently, when reporting loss-of-contact data using a dead wire package, it is necessary to reject all loss-of-contact durations below a certain level. In setting this threshold, it is most meaningful to set it in terms of the power equipment cycle time and to ignore any durations less than one-half the cycle time. Consequently for 50-Hz-power, loss of contacts less than 10 milliseconds are not too damaging.

The system described in this report has the capability of accepting variable durations for which the loss-of-contact is to be ignored. The percentage loss-of-contact is computed by scanning the total loss-of-contact (ignoring loss-of-contact less than the given threshold level) and dividing by the corresponding contact time. This percentage is then compared against a standard to check whether the catenary system is performing satisfactorily. As an example, British Rail uses a criterion of less than 0.5 percent LOC as being acceptable when all loss-of-contacts less than four milliseconds are rejected.

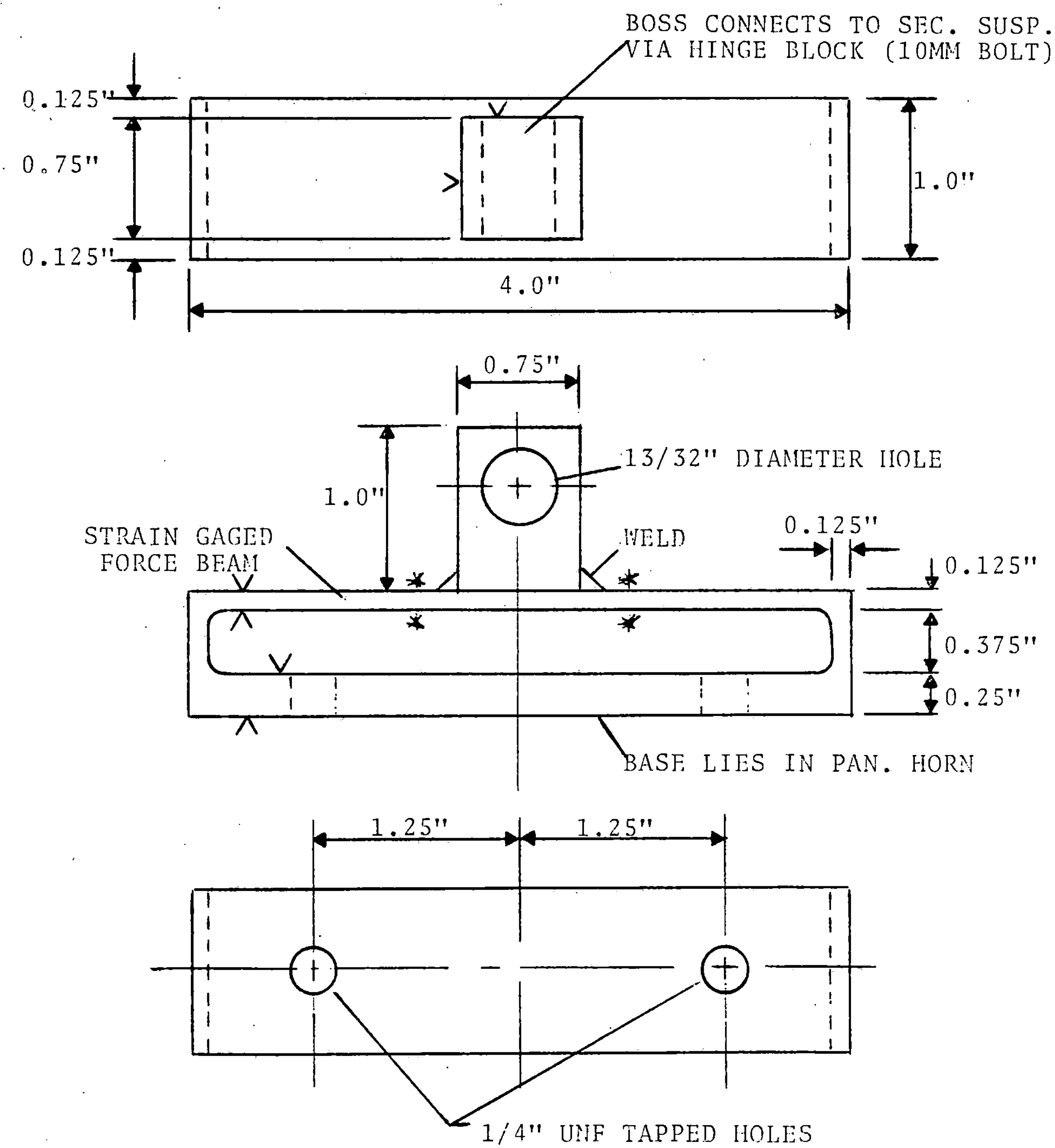
3.0 TRANSDUCER DETAILS

3.1 TRANSDUCERS FOR TRUE FORCE MEASUREMENT

Four transducers are used in the measurement of true force: two force transducers for measuring the static forces on each side of the pantograph head, and two accelerometer transducers for measuring the average acceleration of the pantograph head used in computing the inertial force.

3.1.1 FORCE TRANSDUCERS

The force transducers are based on a strain gage concept. The metal blocks to which the strain gages are attached (Figure 3-1) have been machined out of solid blocks of mild steel and a boss has been welded in the center of the force beams through which the load is applied. They are designed to fit into the space between the pantograph horns which have been modified to accept the force transducers. The bases of the force transducers are mounted on the secondary suspension through large blocks as shown in Figure 3-2. The positioning is such as to make all the components vertical above the secondary suspension plungers. To accommodate the strain gaged beams (Figure 2-2), the standard attachment points on the aluminum horns were removed, filled with weld and then machined flat inside. This machined surface supports the strain-gaged beams and is held in place by countersunk screws from the top side of the horns. Pivot attachments were provided in the center of each strain-gaged beam to give the pantograph head the same longitudinal freedom as the instrumented version. To connect the pantograph head to the secondary suspension plungers, hing-block spacers (which allow for the differential action of the spring plungers) were used. Thick side-walls (0.125 inch) support the strain gaged beams efficiently without significantly reducing the effective beam length (important for sensitivity). The thickness of the strain gaged beam



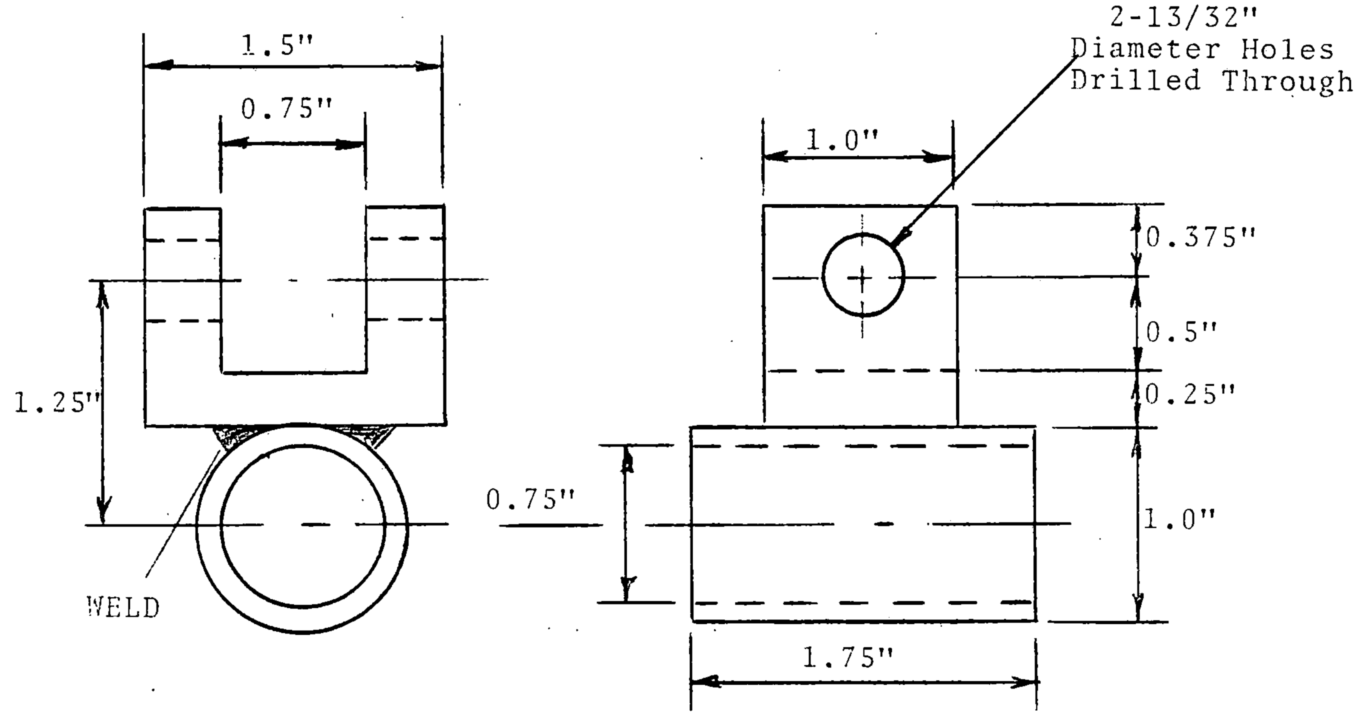
MATERIAL MILD STEEL

ALL MACHINING TO BE DONE AFTER WELDING

MACHINED SURFACE MARKED >

POSITION OF STRAIN GAGE *

Figure 3-1. Force Transducers



MATERIAL MILD STEEL
ALL MACHINING TO BE DONE AFTER WELDING

Figure 3-2. Hinge Block

is a little under 0.125 inch (the amount being that required to obtain a polished surface on which to bond the strain gages).

Strain gages have been placed as close as possible to the central boss on the top side (compression) and directly below the inside (tension) to obtain maximum sensitivity. Gages (350 ohms) with a grid area of approximately 0.05 square inches were used. Butyl rubber and aluminum tape were used to provide environmental protection.

Measured sensitivities were less than calculated. Hence, it should be possible to reduce the beam thickness even more without nearing the yield point. Higher sensitivities will increase the computational accuracy, especially for stagger computations. The range of the system is 100 pound feet with a sensitivity of 0.43 microvolts/volt/80-pound feet.

3.1.2 ACCELEROMETERS

Two accelerometers are attached to the pantograph head to obtain the average acceleration.

The accelerometers are Setra (model 141A) with a range of 8.0g. Frequency response is flat to 220 Hz with a sensitivity of 5.7 microvolts/volt/g. The non-linearity over the range 0-4 g is ± 0.5 percent.

3.1.3 VELOCITY SIGNAL

In order to account for the aerodynamic-force component on the catenary (which is proportional to the velocity squared) it is necessary to monitor speed. The equipment for this measurement was supplied by TTC and involves a rear panel BNC connector with 10 microvolts/mph scaling.

3.2 TRANSDUCER RANGE SETTINGS (Dynamic Outputs)

Force No. 1 and No. 2: 1.4 volts = 80 pound feet

Accelerometers No. 1 and No. 2: ±1.4 volts = ±3 g

Frame Displacement: 1.4 volts = 10 feet

Secondary Suspension No. 1 and No. 2: ±1.4 volts = ± 1 inch

LOC 1 and LOC 2: +2 volts = Contact
zero volts = LOC

Segmented Stagger: ±100 percent stagger = ±1.4 volts (An attenuator is provided to reduce the output to 1.4 volts for recording on magnetic tape.)

3.3 EXCITATION VOLTAGES

Transducer	Recommended	Maximum	Dynamics Amplifier Gain Setting
F_1 and F_2	10 volts	25 volts*	325
A_1 and A_2	10 volts	25 volts	8.2
X_A and X_B	5.6 volts**	50 volts	1
X_1	3.2 volts***	25 volts	1
Segmented Stagger Head	16.85 volts ****	120 volts	1
Structure Marker	12 volts	25 volts	1

*It is recommended that Micro-measurements technical note TN-127-2 be read before voltages above 10 volts are applied to the force transducers. The increased sensitivity could be more than offset by zero drift and hysteresis effects which should both be minimized for true force and stagger computations.

**Since this is a high level output, the excitation voltages could be trimmed to obtain 1.4 volts from the dynamics amplifiers with a gain of unity for a one-inch extension of the transducers.

***The excitation voltage can be trimmed to obtain 1.4 volts = 10 feet with an amplifier gain of unity.

****Similarly, the segmented-stagger-head excitation voltage can be adjusted to give 100 percent = 1.4 volts with a short circuit applied between the last segment and the wiper.

4.0 GENERAL DESCRIPTION OF COMPUTATIONAL UNIT

4.1 RACK UNIT

The computational modules are mounted in a standard 19-inch rack. The rack has a front-panel height of seven inches and extends to a depth of 14.1 inches as shown in Figure 4-1.

There are seven modules, each with a front panel width of 2.4 inches nominal. The modules must be placed in the order shown on the front panels, one to seven from left to right. Failure to keep the modules in the correct order will result in two or more modules not functioning. Incorrect placement of the power supply module would keep all units from working. Although there is no mechnical interlock to prevent placing the modules in incorrect order, no harm will come to the equipment if a mistake is made. The power input can only feed the power module; all power supply lines are common to each module and input and output lines are separated to opposite sides of the module connectors. Also, logic inputs have protective diodes to guard against signals of negative polarity.

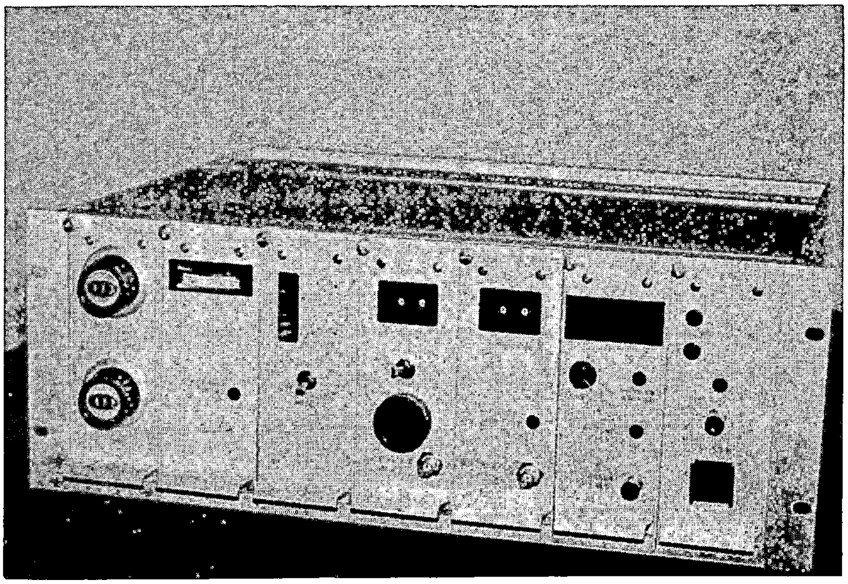


Figure 4-1. Computational Unit (Front View)

All data inputs to the computational unit are via BNC connectors on the rear panel as shown in Figure 4-2. These are connected using standard BNC/BNC cables to the outputs of the appropriate signal conditioning/amplification channel.

It was thought unlikely that all of the outputs would be used simultaneously but it was considered useful to have intermediate outputs available. It is usual to record the raw data on magnetic tape for future use while observing processed data on oscillographic or Brush recorders.

4.2 POSITION OF MODULES

The modules are designated from left to right:

No. 1 - True Force
No. 2 - Stagger
No. 3 - Trajectory
No. 4 - Loss of Contact (LOC) Duration
No. 5 - Loss of Contact (LOC) Delay
No. 6 - Loss of Contact (LOC) Percentage
No. 7 - Power Supplies

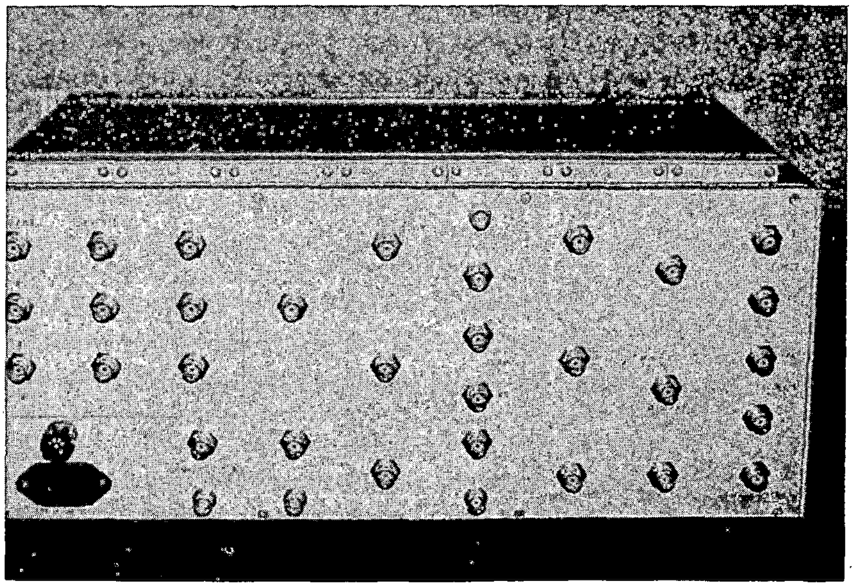


Figure 4-2. Computational Unit (Rear View)

Module No. 5 also contains the Gated LOC computer output and the time base circuits required by the Gated LOC and the Percentage LOC modules.

Module No. 6 provides the controls to the Tektronics counter (Method A) and displays directly percentage LOC (Method B).

The Power Supply module contains the calibration reference voltage circuit and the controls to activate the calibration relays in the True Force and Trajectory modules.

4.3 DESCRIPTION OF MODULE FUNCTIONS

4.3.1 TRUE FORCE

This module receives inputs from force transducer No. 1 (F_1), force transducer No. 2 (F_2), accelerometer No. 1 (A_1), accelerometer No. 2 (A_2) and a speed input (V). It produces the sum of F_1 and F_2, i.e., $(F_1 + F_2)$, which is the static contact-wire-force. While stationary and for relatively slow speeds, this would be a good approximation to the true force between the pantograph head and the contact wire.

When subjected to acceleration, the pantograph head produces another force resulting from the mass times the acceleration. Accelerometers A_1 and A_2, which are placed on opposite sides of the center on the leading and trailing collectors, respectively (to cancel longitudinal and lateral motions) are averaged to find the average vertical acceleration of the head mass, i.e., $\frac{(A_1 + A_2)}{2}$.

The head mass is also scaled in this stage and a digital dial is provided on the front panel to select any value between 0 and 100 pounds. An exact value for M, the mass, can be obtained by weighing the pantograph head. Because of the difficulty in calibrating accelerometers to an exact "g' value equal to a precise number of volts, it is necessary to do a cynamic calibration. Initially, each accelerometer requires a scale factor of ± 3.0 g = ± 1.4 volts to make the scaling of the dial correct. The scale factor was arrived at by assuming 1.4 volts = 80 pounds for F_1 or F_2. The intermediate output - $M \frac{(A_1 + A_2}{2}$ is also brought out to a rear panel connector (- denotes a reversal of polarity).

Every attempt was made to contend with possible polarity variations in the transducers and it was assumed that similar transducers, i.e., F_1 and F_2, or A_1 and A_2 would be mounted in the same axis.

The sum (or difference) of the static force $(F_1 + F_2)$ and the mass times acceleration of the head produces another output:

$$(F_1 + F_2) \pm M \frac{(A_1 + A_2)}{2}$$

Sum or difference is selectable on an internal circuit board switch denoted (+, -) to take account of accelerometer mounting direction.

Another internal switch is marked (dc, ac). This allows for either d-c or a-c coupling of the average accelerometer signal to the force summation. The time constant of the a-c signal must be less than 10 seconds (0.1 Hz) to pass without attenuation. This should be satisfactory since the structure-passing time is approximately one second at 100 mph and usually the higher frequency effects are the ones of interest. A-C coupling may prove useful if zero offset shift due to temperature effects is experienced on the accelerometers. (Bearing in mind that 0.1 is very significant with a head mass of 35 pounds and that only ± 3.0 g of a ± 8.0 g range accelerometer is being used.)

The second digital dial allows a number between zero and 10 pound feet to be selected as the velocity squared aerodynamic force. This number must be obtained experimentally. Scaling sets the selected value at a force produced at 100 mph. Corresponding increases or decreases in speed, increase or decrease the computed value on a square law relationship. The input voltage is 10 millivolts/mph, i.e., 1.0 volt = 100 mph. Again for scaling, 1.4 volts = 80 pounds has been assumed for F_1 and F_2. An output $(-KV^2)$ has been brought out for scaling validation checks. Also, the aerodynamic force can be selected by an internal switch for either increasing or decreasing upward force depending on the pantograph head configuration.

The sum (or difference) of the static, dynamic and aerodynamic forces produce the true force output.

$$\text{True Force} = (F_1 + F_2) \pm M \frac{(A_1 + A_2)}{2} \pm KV^2$$

SUMMARIZING

Inputs	Outputs
Force No. 1 (F_1)	$(F_1 + F_2)$
Force No. 2 (F_2)	$-M \frac{(A_1 + A_2)}{2}$
Accelerometer No. 1 (A_1)	
Accelerometer No. 2 (A_2)	$(F_1 + F_2) \pm M \frac{(A_1 + A_2)}{2} - KV^2$
Speed (V)	
	$-KV^2$

$$\text{True Force} = (F_1 + F_2) \pm M \frac{(A_1 + A_2)}{2} - KV^2$$

Where M is selectable from 0 to 100 pounds and $(-KV^2)$ is selectable from 0 to 10 pound feet at 100 mph.

4.3.2 STAGGER

This module processes one force transducer input (F_1 or F_2) and the sum of F_1 and F_2 to produce stagger of the contact wire relative to its center position (when $F_1 = F_2$). Neglecting the scaling, which is necessary to obtain optimum results from the analog divider, stagger = $\frac{F_1}{F_1 + F_2}$.

Therefore, when $F_1 = 0$ (contact wire directly over F_2) the output is zero. When F_1 is maximum (contact wire directly over F_1) the output is one, since $F_2 = 0$.

Using the offset control (set at zero) the condition of zero volts output is moved to equal -1.0 volt with a corresponding meter indication of 100 percent to the left hand side of zero.

The gain control allows the maximum signal to be shifted to equal 100 percent in the opposite direction (meter only).

When $F_1 = F_2$, the output voltage is zero which does not drive the meter but gives an indication of zero percent stagger.

To further facilitate this function, an indicator is provided to warn of wrong polarity signals from the force transducers. This is because the analog divider only works in two quadrants so the denominator must be positive. A negative signal on the denominator input lights the indicator (REVERSE DENOM). A switch is provided on the internal circuit board to change denominator polarity. However, once selected correctly the setting will be correct as long as the force transducers remain in the same orientation or until they are replaced by other force transducers.

It should be noted that this method is experimental and still requires evaluation to determine limiting factors and possible improvements.

4.3.3 TRAJECTORY

The inputs to this module are: main frame extension (X_1), second stage displacement (X_2), No. 1 secondary suspension displacement (X_a), and No. 2 secondary suspension displacement (X_b).

Scaling is provided to sum X_1 and X_2 on the assumption that X_1 = 1.4 volts = 10 feet and X_2 = ± 1.4 volts = ± 6.0 inches. The second stage is for future use with the two stage Faiveley pantograph. When not in use, the X_2 input should be connected to ground. Provision is made for second-stage polarity via an internal switch. The front panel meter provides an indication of the pantograph head-height above the vehicle roof (neglecting secondary suspension displacements). A reverse meter-switch accommodates reverse-polarity, main-frame signals.

An intermediate output is the average secondary suspension displacement and is denoted $\frac{X_a + X_b}{2}$. Scaling of ±1.4 volts = ±1.0 inch is assumed. Average secondary suspension movement is summed (or differenced) with the second stage output. Sum or difference can be selected by an internal switch. To obtain the dynamic response, this output is summed to an a-c coupled output of the main frame. A time constant of 10 seconds (1/10 Hz) should ensure that the dynamic response is observed above 30 mph. It will be necessary to verify the dynamic response by looking at the main frame output with scaling on the Dynamic amplifiers to look at one-foot of travel. This will entail balancing this transducer channel with the pantograph against the wire. Once verified, this tedious procedure can be dispensed with.

SUMMARIZING

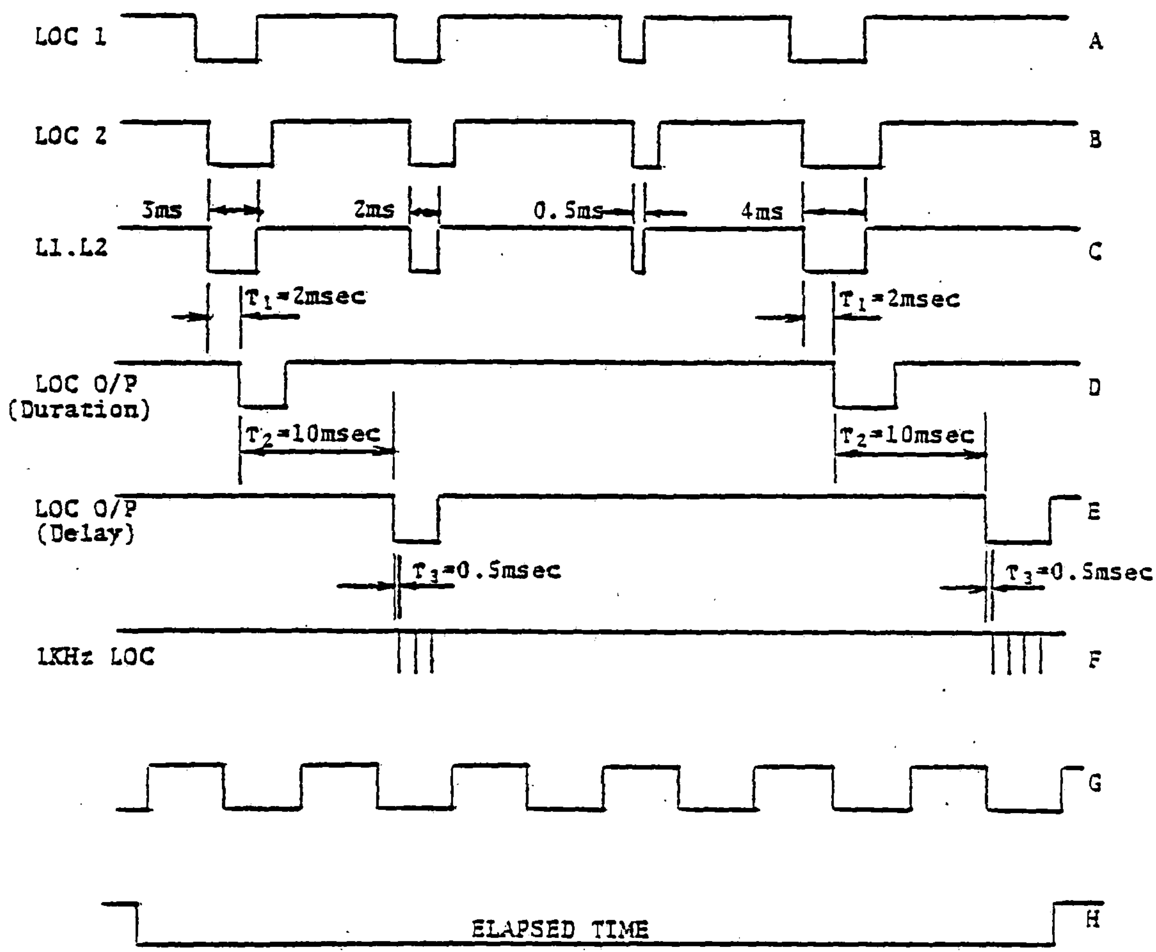
Inputs	Outputs
Main Frame X_1	$X_1 + X_2$
Second Stage X_2	
No. 1 Secondary Suspension, X_a	$\frac{X_a + X_b}{2}$
No. 2 Secondary Suspension, X_b	Dynamic Response $= X_1 \pm X_2 \pm \frac{X_a + X_b}{2}$

4.3.4 LOSS-OF-CONTACT DURATION

Inputs are provided for the independent loss of contact signals from the leading and trailing collector strips. These are shown in Figure 4-3. It is hoped that by collecting LOC as separate data for each collector strip, valuable information can be gained on the longitudinal effects of the Northeast Corridor pantograph heads which are free to rotate longitudinally in the direction of the contact wire.

The separate LOC signals are combined by this module to produce a total LOC output. This is designated $(L_1 . L_2)$ since they are logically 'AND' gated.

The loss of contact signal now passes through the "duration" section of the module. For any thumbwheel switch setting greater than zero, a discriminator ignores those occurrences less than the pre-set duration. Occurrences greater than the pre-set value are allowed to pass through to the next stage. These outputs have the same pulse widths as their respective inputs but they are delayed by an amount equal to the thumbwheel setting. This is insignificant compared to the delay experienced by the analog channels which would probably be



A = LOC LEADING COLLECTOR
B = LOC TRAILING COLLECTOR
C = TOTAL LOC
G = 100 Hz TIME BASE
H = TEST ZONE

Figure 4-3. Loss of Contact Processing

filtered at 30 Hz. A thumbwheel setting of zero routes the signals directly to the next stage without any appreciable modification as shown in Figure 4-3.

Although duration settings of greater than eight milliseconds are not expected, the full range of 79 milliseconds could prove useful for analyzing distribution when a computer is not available. In this mode, the same data is played back from tape through the LOC duration module and, for each pass, a different setting is selected. The percentage LOC in distinct bands can thus be evaluated.

An audible alarm has been included on the front panel, driven by the LOC signal. It is hoped that the frequency and duration of LOC occurrences will give an indication of the performance to test personnel. It may be a further advantage to have a similar alarm in the observation dome of the pantograph test car so that short duration LOC signals can be heard even though they may not be seen. An on/off mute switch has been incorporated so that it can be turned off when the pantograph is retracted.

4.3.5 COMPUTATION OF PERCENTAGE LOC

Two methods are available for computing the percentage loss of contact.

Method A

This method utilizes two counter modules, the timing diagram is as shown in Figure 4-4. Events generated by Automatic Location Detectors (A.L.D.'s) on the track (or manually applied events) are used to define a test zone where it is required to know percentage LOC. Elapsed time between the two events, controls two counter modules external to the unit. Counter A is started and stopped from counting by the loss-of-contact

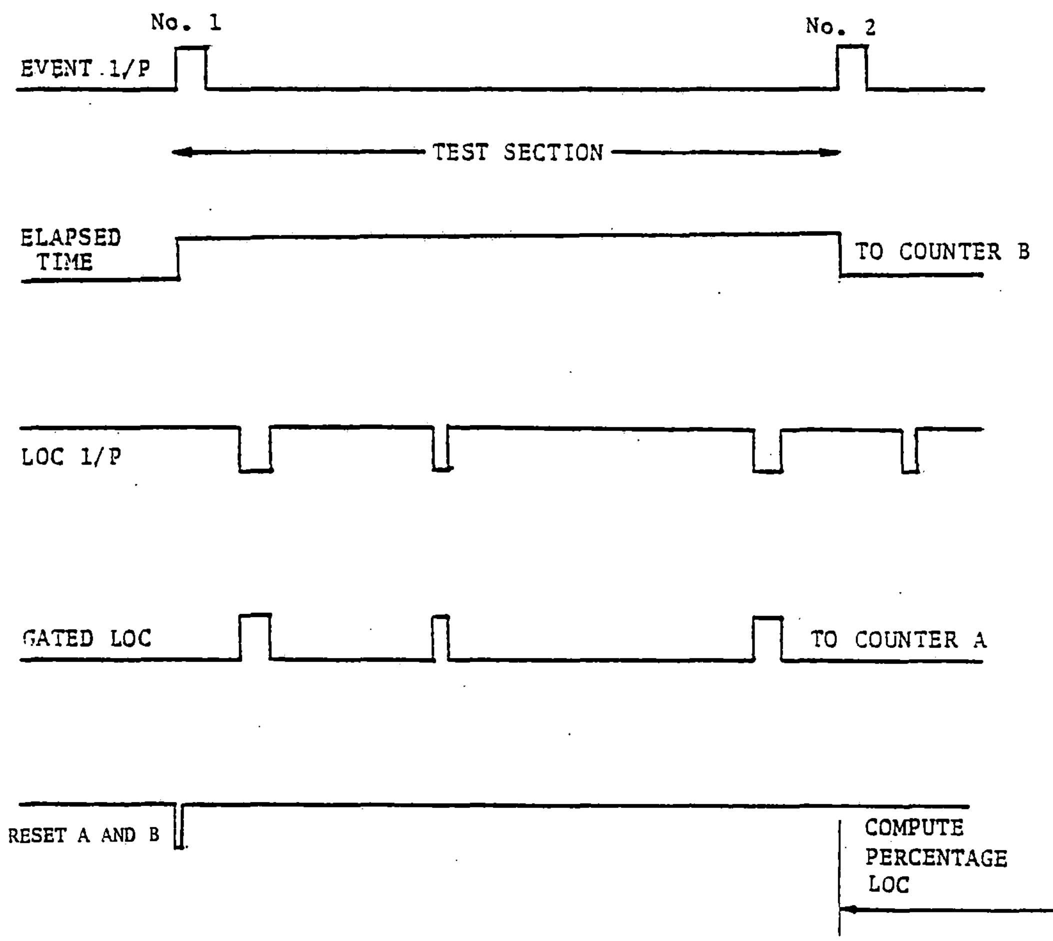


Figure 4-4. Percent Loss-of-Contact (Method A) Timing Diagram

signal which is in turn controlled by the elapsed time signal. Counter B is started and stopped from counting by the elapsed time.

Although the event input can be either normally low or normally high since it operates on positive edges, normally high events will produce an elapsed time delayed by the time to cross the ALD. However, the total elapsed time is unaltered. Also, when using the manual event, the event input on the rear panel should be connected either high or low to prevent noise spikes from being picked up. The sequence of events is as follows:

- Set Counter A time base at 10 KHz (maximum count = 999.9999 seconds). Set FUNCTION switch to TIME MANUAL.
- Set Counter B time base at one KHz (maximum count = 999.999 seconds). Set FUNCTION switch to TIME MANUAL.
- Observe TEST ZONE indicator, it should be out. If it is on, push the MANUAL EVENT button once to return the bi-stable to the correct initial conditions.
- Run through the test zone passing magnets No. 1 and No. 2. (These could be manually applied events. The TEST ZONE indicator should light while the vehicle is in the test zone.
- Displays will be frozen until reset is activated by passing another magnet.
- Divide the output of Counter A by the output of B to obtain percentage LOC.

The display counters are automatically reset to zero at the start of the elapsed time.

The disadvantantages of this method are:

- There is room for human error when dividing the contents of Counter A by the contents of Counter B, especially since there are seven digits to contend with.

- It uses two expensive DC 503 modules ($870 each) that would be better suited to other work instead of being fixed in a one-function role.

Method B

This method computes percentage LOC directly (refer to Figure 4-5). Before accumulating data, the TEST ZONE indicator is out. Ignore the reading in the display and the OVERFLOW indication which may be spurious data. (The overflow indicator will amost certainly be on if the equipment has not been used recently.)

When an external or a manually applied event is acquired, the TEST ZONE indicator will come on. Simultaneously, the display and the OVERFLOW indicator will be reset to zero and extinguished, respectively. At the end of a designated test zone, another event is required to turn off the TEST ZONE indicator. Almost immediately, the percentage LOC is displayed. If the OVERFLOW indicator comes on before the end of a test zone, there are three possible causes.

- The Test zone duration is longer than the indicated time in Table 4-1 for the range selected.
- Percentage LOC is worse than predicted and requires the higher range. (LOC greater than 10 percent would not be expected but Method A could be used in such an eventuality.)
- A break in continuity occurred somewhere in the system resulting in a false indication of 100 percent LOC.

If the OVERFLOW indicator appears after the second event is applied, it can only mean that the percentage LOC is greater than anticipated. However, a break in continuity should only be discounted if the test zone time exceeded the time to

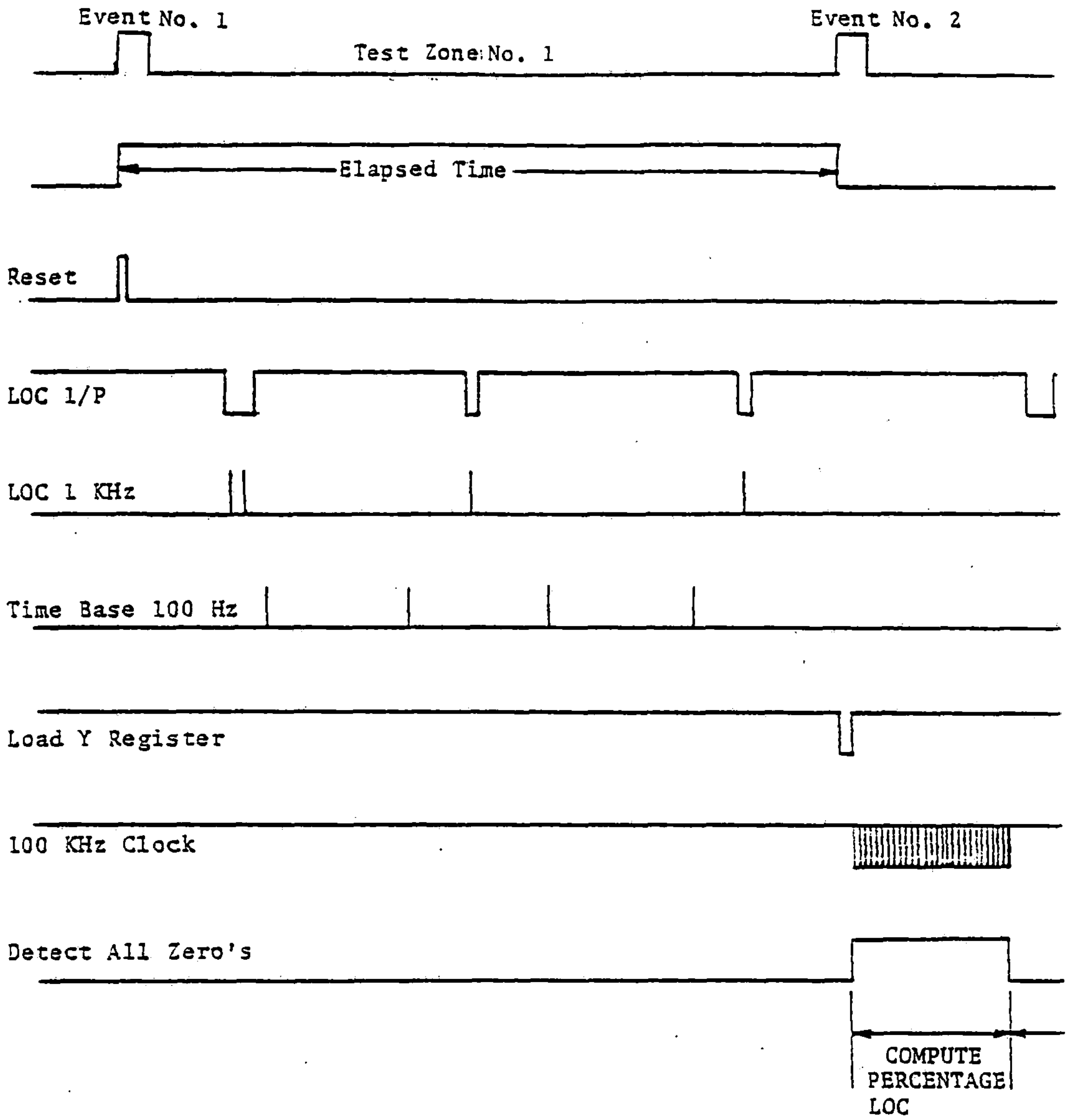


Figure 4-5. Percentage Loss-of-Contact (Method B) Timing Diagram

TABLE 4-1

PERCENTAGE LOSS-OF-CONTACT
(METHOD B) RANGE TABLE

Parameter	Condition 1	Condition 2	Condition 3	Condition 4
LOC	1 KHz	1 KHz	100 Hz	100 Hz
Timebase	100 Hz	10 Hz	10 Hz	1 Hz
Percentage LOC	9.999	0.9999	9.999	0.9999
Test Time (seconds)	99.99	999.9	999.9	9999.0

obtain an overflow prior to the second event. In the previous example overflow occurs in 10 seconds for 100 percent LOC. If the test length exceeds 10 seconds and overflow does not occur until the second event, a discontinuity in the signal can be discounted.

Results for percentage LOC using this direct method will depend on the waveform of the LOC signal. For instance, a waveform containing only losses greater than six milliseconds will give a more accurate result than one containing many short duration losses. This is because of the slow sampling rate (one KHz) and the results will be consistently lower than the actual value. More accurate and repeatable results will be obtained by accumulating data over as long a period as possible.

Although Table 4-1 gives the LOC for range 3 and 4 as 100 Hz the sampling rate is one 1 KHz and the 100-Hz rate is produced by a decade counter.

This method which displays percentage LOC directly should be a valuable tool in assessing the dynamic performance of pantographs. Even with a computer calculation available, this method can be used to increase the confidence factor in the results.

4.3.6 POWER SUPPLY MODULE

This module provides +5 volts at 2 amperes for a logic supply in the LOC processing modules and ± 15 volts at 300 milliamperes for the other modules. Power input is 110 volts, 60 Hz via an interference filter on the rear panel. A fuse post is provided for protection. Power enters the power supply module via the module connector on the rear of the plug-in module. Accidental insertion of any other module in the power supply slot will cause no damage since the corresponding pins on all other modules are not connected.

A front panel push-on/push-off, double-pole switch with an indicator lamp controls input power to the power supplies.

A CALIBRATION switch with an indicator lamp activates reed relays in the True Force and Trajectory modules when pressed and held in. This applies 1.4 volts to all inputs in both modules. The calibration voltage is a precision 2.5-volt reference signal having a maximum drift of 10 millivolts over the temperature range 0-70 degrees centigrade. This is divided down to 1.4 volts by a front panel control with test points. In practice 1.4 volts is never experienced on F_1 and F_2 simultaneously, since the sum of F_1 and F_2 is 1.4 volts full-scale deflection. A series resistor is provided in the calibration circuit to divide F_1 and F_2 in half. With 1.4 volts applied to all inputs, the scale factors can be measured or adjusted on the recorders. Stagger will indicate zero since $F_1 = 0.7$ and $(F_1 + F_2) = 1.4$ which is half-scale and corresponds to zero percent stagger. The trajectory-module meter will indicate 10 feet ± 6 inches depending on the setting of the second stage polarity switch. If the second stage proves inconvenient, it can be easily disconnected.

A calibration switch that must be held in was chosen as it cannot be accidentally left switched on.

4.4 REQUIRED ADDITIONAL INPUTS TO COMPUTATIONAL MODULE (TTC Responsibility)

The following inputs must be supplied to the computational module:

- Speed: A rear panel BNC connector with 10 millivolts/mph scaling. A calibration facility for speed only would be a requirement with a calibration equivalent to say 100 mph.
- Event: Rear panel BNC connector. These are to locate test sections for percentage LOC calculations. Logic signals are required; either polarity can be utilized.

5.0 DETAILED THEORY OF OPERATION

5.1 GENERAL

This section describes the circuits that have been designed to implement the operations required for computing the various parameters.

The Burr-Brown 3510 operational amplifier has been adapted to perform inverting, summing and difference functions in all of the analog modules. It has all the qualities required of a high-grade summing amplifier, i.e., high-gain, high-input resistance, low-output resistance and the input offset-voltage is trimmed at the manufacturing stage. Also, special precautions with layout are not required as they are with other operational amplifiers. Output short circuits to ground can also be tolerated. In other applications, output noise may be a limiting factor but in this case, high frequency noise is still below one percent of full-scale reading. Integrating capacitors have been included across the feedback resistors of some amplifiers to reduce the bandwidth (3dB) to about 320 Hz and hence the noise.

Amplifiers marked by an asterisk (*) on the circuit diagrams in this section, or with painted black tops in the circuit are 3510CM amplifiers, replacing the standard 3510AM. These amplifiers were substituted because of the high value of the feedback resistor in that particular stage and because they have lower bias current requirements. Closed loop frequency compensation, in the form of a capacitor from Pin 5 to ground has been applied to all amplifiers. However, in some cases the recommended value of 4700pf was found to be insufficient and hence increased. For complete information consult the manufacturers data sheet.

The fixed resistors are all highly stable (50ppm or 100ppm) with one-percent maximum tolerance. They were also selected using a laboratory standard bridge and the values used were between nominal and +0.5 percent. It should be noted that more than one resistor is used from Pin 3 to ground on a number of amplifiers because of the limited selection of precision resistors and the need to balance each input to the amplifier and thereby prevent offset.

5.2 TRUE FORCE CIRCUIT (Figure 5-1)

Input resistances for F_1, F_2 and V have been fixed at 100 K ohms but A_1 and A_2 will be some value less than 100K ohms as dictated by the available values of digital readout potentiometers and the scaling requirements.

A scale factor of 80 pounds = 1.4 volts was chosen to allow for all the load to be taken on one side of the pantograph head, and for excessive forces at incorrectly-set insulators. Therefore, $F_1 = F_2$ = 80 pounds maximum = 1.4 volts and $(F_1 + F_2)$ = 80 pounds maximum = 1.4 volts. Each accelerometer A_1 and A_2 has a scale of $\pm$ 3g = $\pm$ 1.4 volts. The average vertical acceleration is $(A_1 + A_2) / 2$.

To obtain the dynamic force which equals mass times acceleration, a scaling potentiometer accounts for the mass. Force = $M(A_1 + A_2) / 2$. The scaling potentiometer is a 100K-ohm digital readout potentiometer and forms the feedback resistor to amplifier No. 2. Any value from 0-100K ohms corresponding to head masses from 0-100 pounds can be selected with a linearity of 0.1 percent of reading.

To calculate the value of input resistors A_1 and A_2, assume the head mass potentiometer is set at 50K ohms with a corresponding reading of 5000 (50 pounds) in the digital readout.

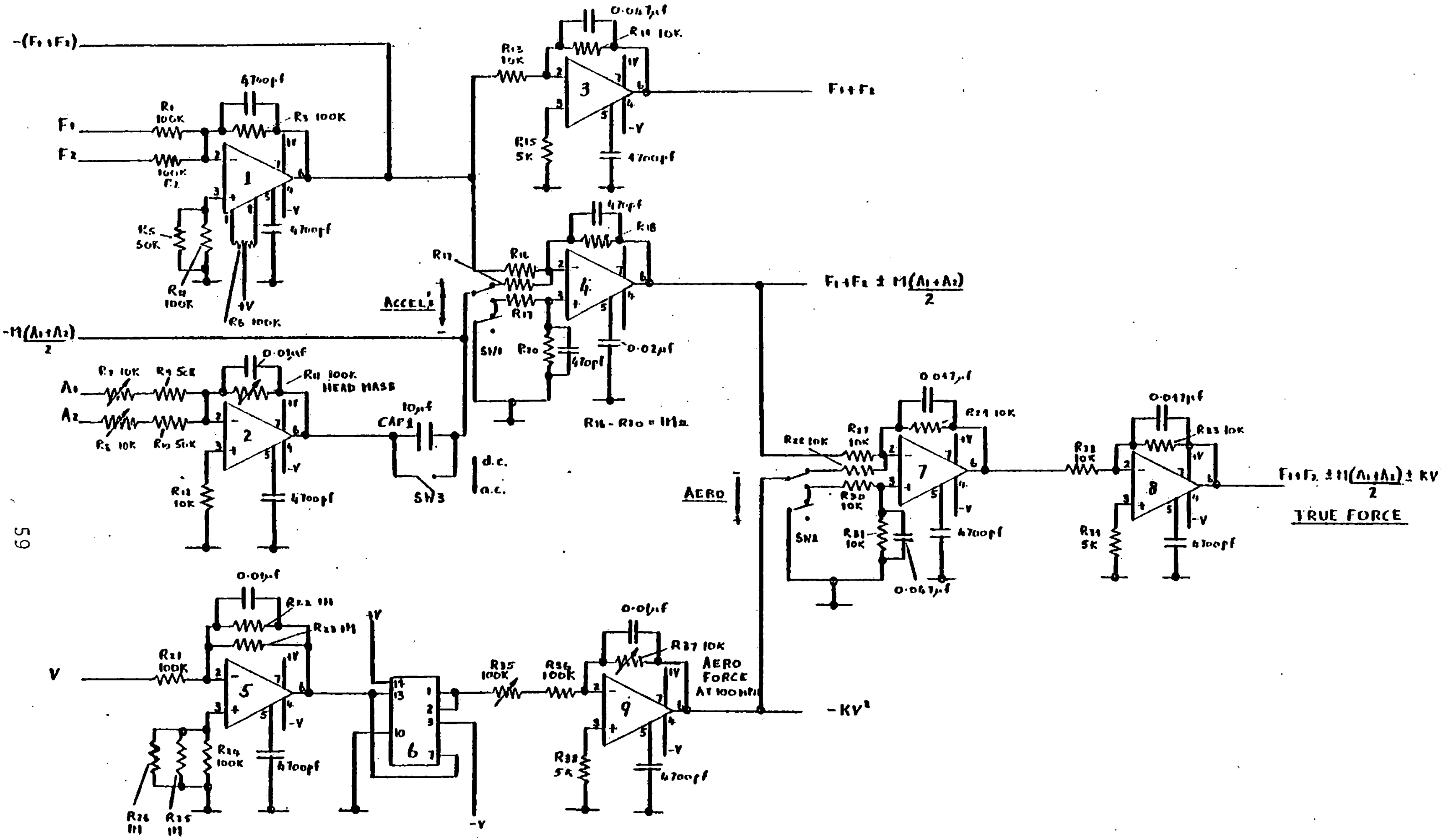


Figure 5-1. True Force Measurement Circuit

If $A_1 = A_2 = 1.4$ volts = 3g and $(A_1 + A_2/2 = 3g$, then 3g x 50 pounds = 150 pound feet. Now 80 pound feet = 1.4 volts from $(F_1 + F_2)$. Therefore, gain = 150/80 x 2 = 0.9375. If rf = 50K ohms, R_{input} = 50K ohms/0.9375 = 53.3K ohms.

Each accelerometer has an input resistance consisting of a 50K-ohm resistor in series with a 10K-ohm potentiometer. These potentiometers are adjusted during calibration using 1.4-volt inputs. The output can be monitored on the rear panel BNC connector designated $-M(A_1 + A_2)/2$. For static (d-c) calibration inputs, the a-c/d-c coupling switch should be in the d-c position.

Inverting Amplifier No. 3 is used to obtain the sum of F_1 and F_2 with the same sense as the inputs and is also taken to the Stagger module to ensure that either $(F_1 + F_2)$ or $-(F_1 + F_2)$ is negative.

Amplifier No. 4 is a sum or difference amplifier depending on the setting of the switch marked ACCEL's +, - on the circuit board. This allows for transducer mounting polarity as it may not be possible to instrument all pantographs identically. During calibration, a full scale signal is applied to all inputs simultaneously, i.e., $(F_1 + F_2) = 1.4$ volts and $A_1 = A_2 = 1.4$ volts.

Therefore, it is a simple matter to calculate the output at $(F_1 + F_2) \pm M(A_1 + A_2)/2$ for each of the switch postions, i.e., if the pantograph head weighs 33 pounds, set the head mass to this value:

$$3g \times 33 \text{ pounds} = 99 \text{ pound feet} = \frac{99}{80} \times 1.4 \text{ volts} = 1.7325 \text{ volts}$$

The outputs will be 1.4 + 1.7325 = 3.132 volts and 1.4 - 1.7325 = -0.332 volts.

The speed signal routed to the computational unit comes from the test coach (TTC responsibility). It has a calibration of 10 millivolts/mph. Therefore, 1.4 volts = 140 mph.

To increase the signal to the squaring device, a gain of five produces a maximum signal of 7 volts (Amplifier No. 5). The square function is accomplished by a Burr-Brown 4206K multiplier (Package No. 6). No external components are required to obtain an accuracy of 0.25 percent.

$$\frac{Ex \times Ey}{10} = Eout$$

$$\frac{7 \times 7}{10} = 4.9 \text{ volts}$$

This voltage can only have a positive value.

To produce an aerodynamically-scaled force from the velocity-squared signal requires another scaling amplifier (No. 9). This amplifier uses a 10K-ohm digital readout potentiometer as the feedback resistance. A typical figure of 5 pound feet a at 100 mph has been used for some pantographs, so a range of 0-10 pound feet at 100 mph was convenient and appears to satisfy most requirements.

Ten pound feet at 100 mph is 10×1.4^2 = 19.6 pound feet at 140 mph, assuming a square law relationship. Scaled to the force transducers (19.6/80) x 1.4 = 0.343 volts. If the output of the multiplier is 4.9 volts at 140 mph, an attuenuator is required having the value 0.343/4.9 = 0.07. Since R_f = 10K ohms for 10 pound feet, R input = 10K/0.07 = 141K ohms.

A 100K-ohm fixed resistor in series with a 100K-ohm potentiometer provides the required scaling.

Because the output from the multiplier has to be positive, the output KV^2 must be negative, i.e., $-KV^2$. To allow further flexibility, an internal switch is provided so that decreasing up-lift can be programmed.

Amplifier No. 7 sums or differences the dynamic and aerodynamic forces while Amplifier No. 8 is an inverter which produces the true force in the same sense as the force transducers.

5.3 STAGGER CIRCUIT FUNCTION (Figure 5-2)

The heart of this module is a Burr-Brown analog divider type 4291K (package No. 3). It produces the quotient $E_o = 10N/D$.

Where E_o = output voltage
N = numerator voltage
D = demoninator voltage

In this particular case, the numerator is force transducer No. 1 (F_1) and the denominator is the sum of the force transducer signals ($F_1 + F_2$).

F_1 and ($F_1 + F_2$) have maximum values of 1.4 volts. In order to obtain maximum accuracy from the divider, gain stages are required for both inputs. A gain of 5 for both inputs gives maximum signals of 7 volts. F_1 has an input resistance of 100K ohms since it could conceivably come from a tape recorder output and still not load that output appreciably.
The $\pm(F_1 + F_2)$ signals are buffered outputs from the true force module. Therefore, input resistance is not critical and is 10K ohms.

The divider will only function with a positive denominator voltage (2 quadrants). Therefore $+(F_1 + F_2)$ or $-(F_1 + F_2)$

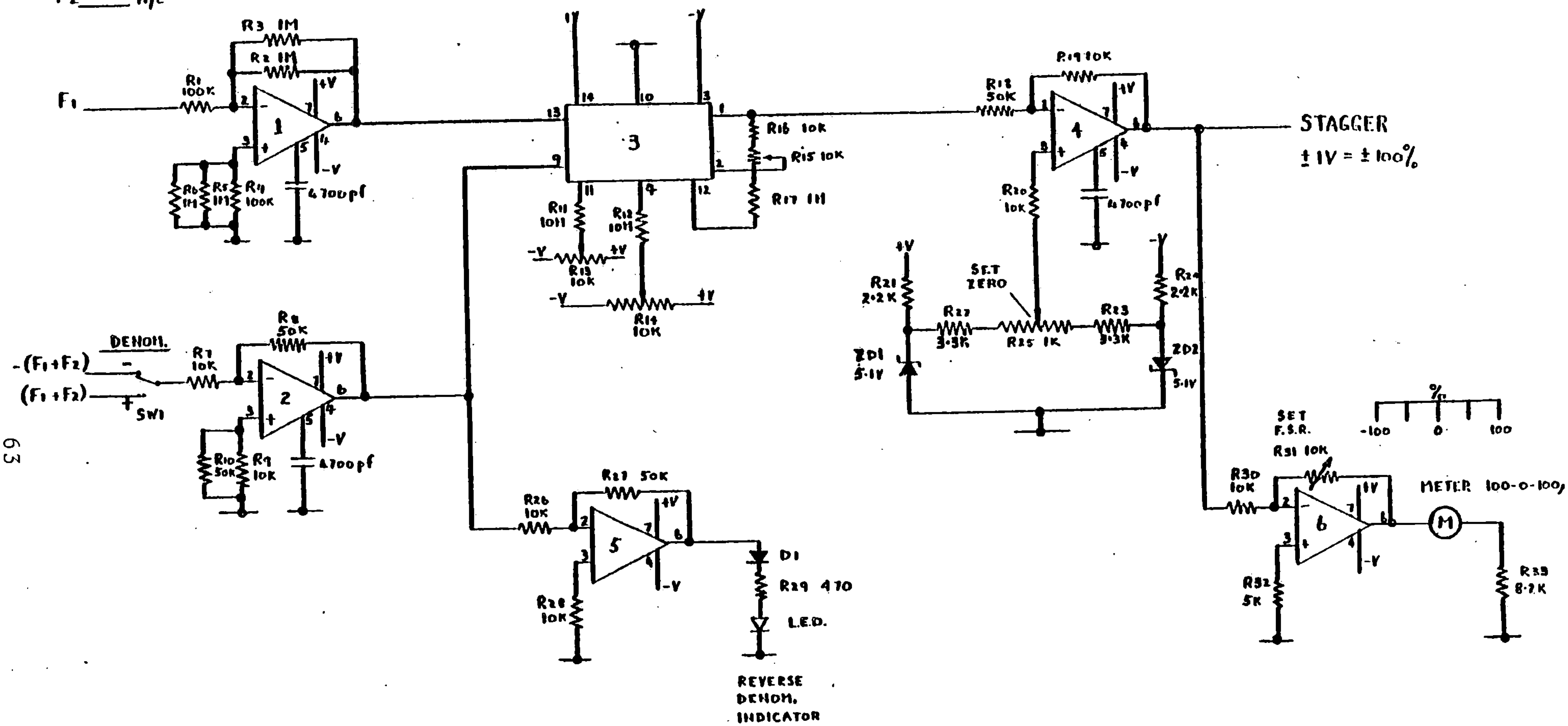


Figure 5-2. Stagger Circuit

is switch selectable to allow for transducer mounting position. To warn of negative denominator voltages, an amplifier and an LED indicator are provided (package No. 5). The diode in series in the LED protects the LED against harmful reverse voltages.

Assuming F_1 and F_2 to be positive signals, the maximum signal at the X input (numerator) will be -7 volts while $-(F_1 + F_2)$ will give a maximum of +7 volts at the Y input (denominator). The output (quotient) can therefore have a value between - 10 volts for maximum signal and zero volts for minimum signal.

The manufacturer specifies a minimum denominator voltage of 100 millivolts with no external components. With scaling, 7 volts = 80 pounds; hence, 100 millivolts represents about one pound. This would appear to be adequate for geometry-type measurements at comparatively slow speeds, even with a reduced upward force of only 5 pounds.
However, transducer offsets and drift combine to reduce the accuracy at low upward forces. For this reason, the manufacturers recommended circuit was added so as to work with denominator voltages of less than 100 millivolts. Considerable difficulty was experienced in following the manufacturer's procedure to null the gain and offset errors. This was partly because of the offsets in the amplifier producing $-(F_1 + F_2)$ in the True Force module and partly because of the single turn potentiometers used for nulling. However, some improvement did result with a denominator voltage of 50 millivolts being quite easy to achieve. Good accuracy was obtained doing a static calibration with a 5-pound weight but was not too accurate at 2.5 pounds for the above reasons.

Experience and possible improvements in the zero drift of the force transducers will refine the method further. Following the analog divider is a divide-by-5 attenuator giving a maximum output signal of 2 volts (package No. 4). To enable zero percent stagger (center of head) to be zero volts and since it is half-scale a level shifting network offsets amplifier No. 4. Therfore, if $F_1 = 0$ and F_2 = maximum, stagger = -100 percent; if F_1 = maximum and $F_2 = 0$, stagger = +100 percent; and if $F_1 = F_2$ then stagger = zero percent.

An output voltage of ±1 volt for ± 100 percent stagger was chosen to suite the available values of precision resistors.

A type 741 amplifier stage with gain control to adjust full scale range is provided to drive the indication meter (No. 6). The gain is adjusted until 100 microamperes is obtained for a one-volt input. R18 is a current limiting resistor.

To reduce the output noise of the output stage (No. 4), an integration capacitor shunts the feedback resistor. This is wideband noise and would not be seen by the recording device but the capacitor has been included to improve the appearance of the output (approximately 5 millivolts noise). This capacitor gives a 3dB bandwidth of about 20 Hz which is more than adequate for this purpose. An external filter and some experimentation will be used to determined the optimum cut-off frequency.

5.4 TRAJECTORY CIRCUIT FUNCTION (Figure 5-3)

This module has two main functions: (1) to produce the contact wire height above the roof of the test car, and (2) to produce the dynamic response (rate of change of pantograph height).

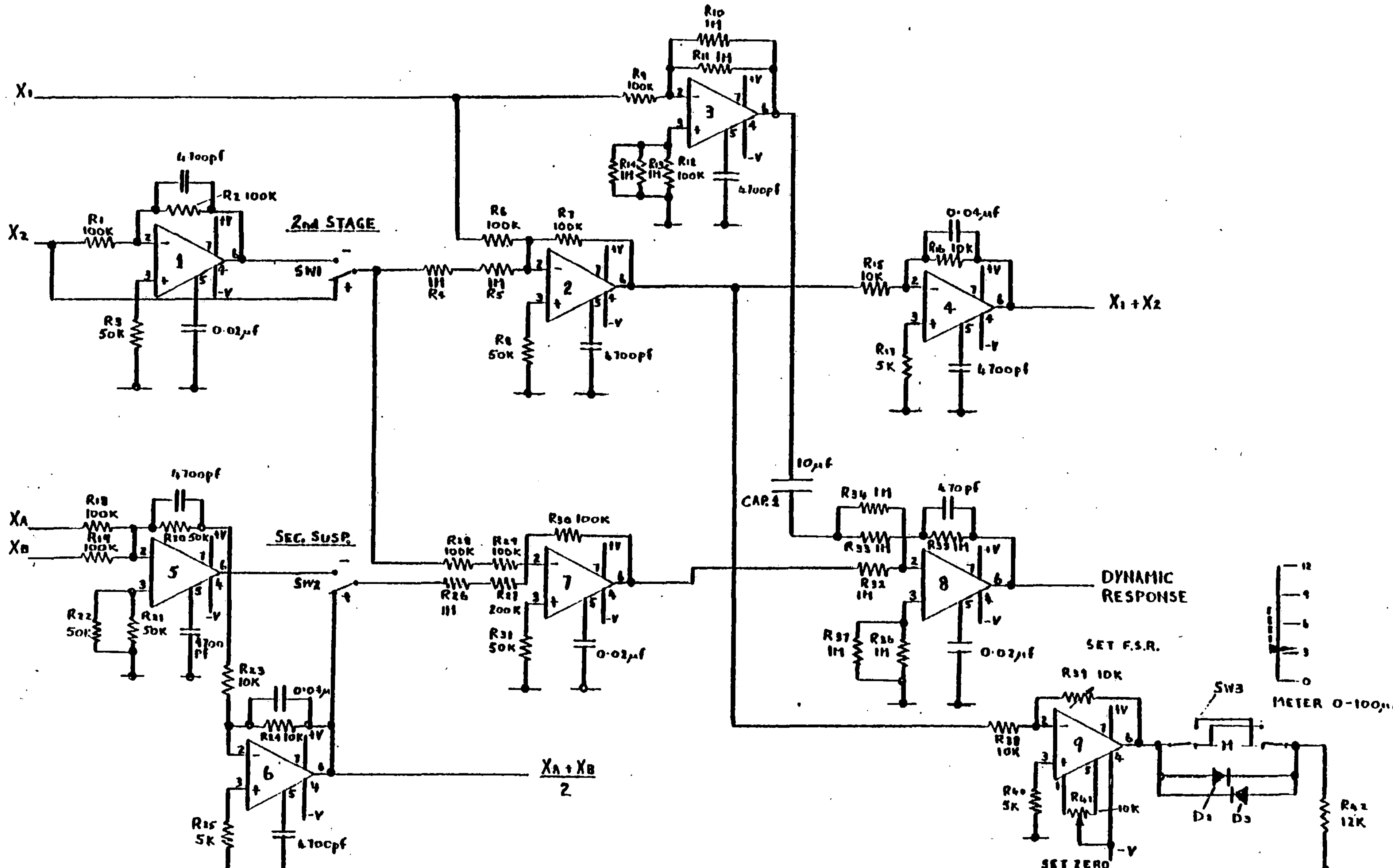


Figure 5-3. Trajectory Circuit

To produce the first output, the secondary suspension displacements are neglected and the sum of the main and second stage displacements only is considered. Amplifier No. 2 has scaling of 2 megohms and 100K ohms corresponding to 6 inches and 10 feet extension of the second stage and main frame, respectively. Amplifier No. 4 provides a signal in the same sense as the main frame input. Output here is still 10 feet = 1.4 volts. To allow for the mounting polarity of the second stage displacement transducer, a circuit board switch is provided to select either polarity signal. Amplifier No. 1 is simply an inverter.

To provide an indication of wire height directly, a meter scaled from 0-12 feet is included on the front panel of this module. Provision for reversal of the main frame signal is made by a reverse meter switch. Amplifier No. 9 drives the 100-microampere meter via a 12K-ohm current limiting resistor (R42). Full-scale range is adjusted by the 10K-ohm feedback resistor R34. The zero offset control (R41) compensates for only 30 Millivolts of offset but this should be sufficient.

The $\pm (X_A + X_B)/2$ signal (average secondary suspension displacement) is produced by amplifiers No. 5 and No. 6. Although this signal is not particularly useful, it is required for calculation of dynamic response. Again, a switch is provided on the circuit board to ensure that displacements in the same direction on the pantograph are summed together and not differenced.

Amplifier No. 7 has input scaling resistors of 200K and 1.2M ohms for the second stage and the secondary suspension, respectively (corresponding to six inches and one inch). With the 100K-ohm feedback resistor R30, the output of amplifier No. 7 is scaled at 1.4 volts = 1 foot. To scale the main frame in the same manner requires a times-ten amplifier. To accomplish this, a times-five gain is configured in amplifier No. 3 (R_f/R_{in} = 500K/100K = 5) and a gain of two after the capacitor

(C-1) in amplifier No. 8 ($^{R}f/^{R}in$ = 1M/500K = 2). A gain of ten in amplifier No. 3 would result in that amplifier saturating when the input voltage reaches about 1.2 volts. The a-c coupled output of the main frame (1.4 volts = one foot) summed to the combined second stage and average secondary suspension displacements (1.4 volts = one foot) gives the dynamic response.

5.5 LOSS OF CONTACT (LOC) DURATION MODULE

For convenience this module can be split into two separate circuits:

5.5.1 LOSS OF CONTACT DURATION CIRCUIT (Figure 5-4)

The dual ganged digital potentiometer may be considered as two potentiometers (ganged together for purposes of explanation) and controlling the two monostable periods in package No. 9.

Capacitors C_1 and C_2 are padded to obtain a calibrated period for each position of the potentiometer. The specification for the 74L123AN for timing resistance is 5K - 400 ohms which would correspond to a timing range of 1 to 80 milliseconds. Actually, a range of 1 to 79 milliseconds simplifies the design and was adopted.

Inputs to the module are from the Dyanmics amplifiers for loss-of-contact leading collector (LOC 1) and loss-of-contact trailing collector (LOC 2). Also a front panel BNC connector is provided for calibration from a pulse generator. The first stage is transistor switch (T_1) which conditions the signals. A threshold voltage of approximately 0.7 volts is expected for a silicon transistor. Laboratory tests confirm this transistor to be fully saturated at 0.8 volts. Diode D_1 protects against

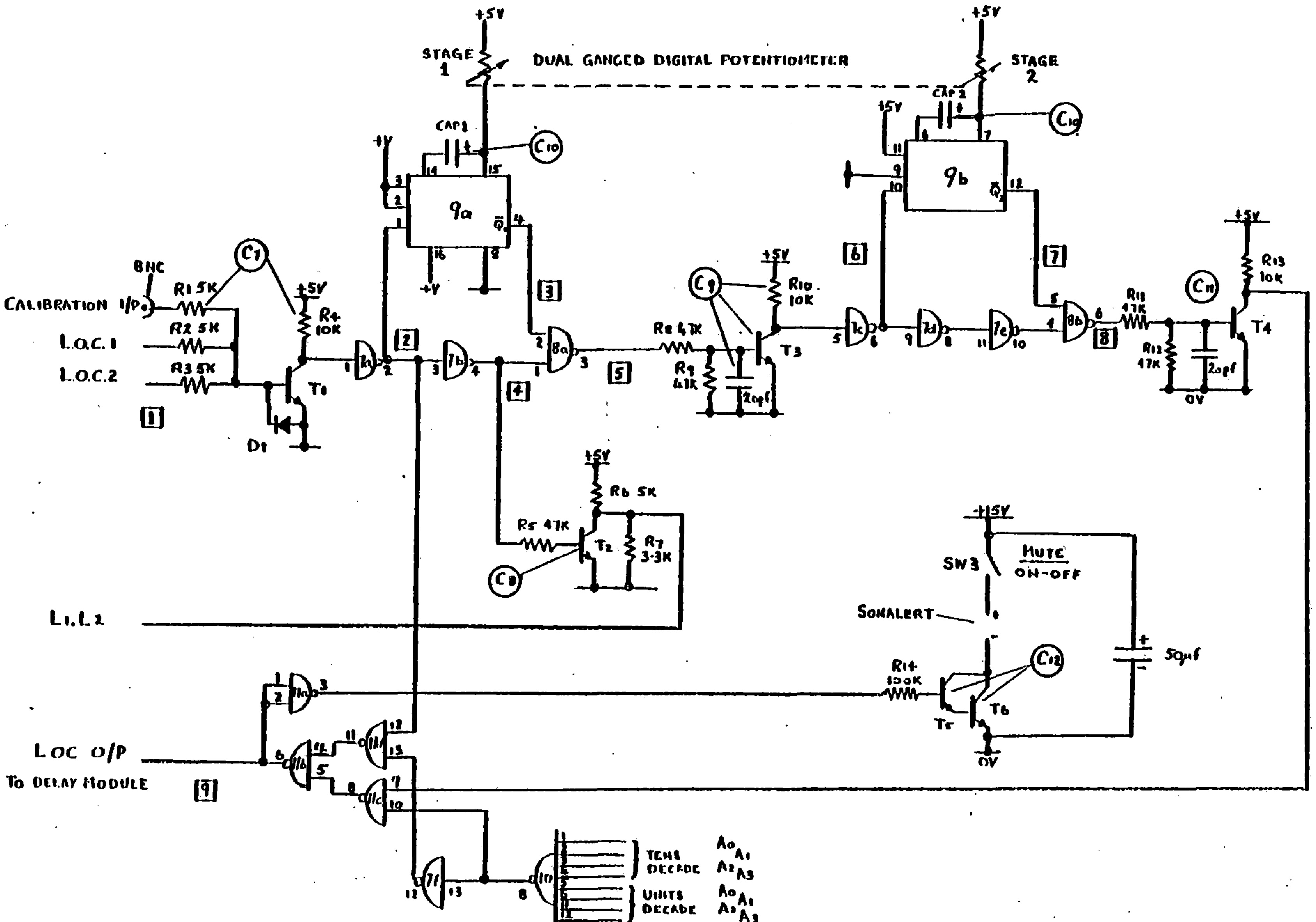


Figure 5-4. Loss-of-Contact Duration Circuit

reverse voltages. The calibration input must be disconnected from the pulse generator before data processing is started.

If LOC_1 or LOC_2 is high (0.8 volt) T. will be saturated. Therefore, both inputs must be low (_ 0.6 volts) i.e., out of contact for T_1 to be high. By inverting the signal at T_1, and "AND" function is obtained when both collector strips have lost contact, i.e., when $LOC_1 = 0$ and $LOC_2 = 0$, $L_1 . L_2 = 0$.

The collector for T_2 and the 5K/3K ohm attentuator provide a suitable signal for recording.

Until contact is lost the input on package No. 9, pin No. 1 is high and also $\bar{Q}_1$ is high. A low-going signal triggers the monostable, setting $\bar{Q}_1$ low for the selected period. This low inhibits the signals from passing through gate 8a for the timed period. Immediately (as the period finishes) the LOC signal is permitted to pass. Obviously, if the signal has returned to high before the timing period has finished, the net output will be zero. The resultant output at pin 8a is a waveform similar to the input but with the first few milliseconds missing (equal to the duration setting). See Figure 5-5.

The components on carrier No. 9 (C9) contain a filter and an interface to the next stage. A time constant of one microsecond insures that short duration pulses caused by unequal propagation delays do not trigger the next stage.

The second half of the circuit adds a period to the waveform equal to that lost in the first half. The net result is a waveform of equal duration to the input but delayed by an amount equal to the duration setting. Package No. 9 pin 10

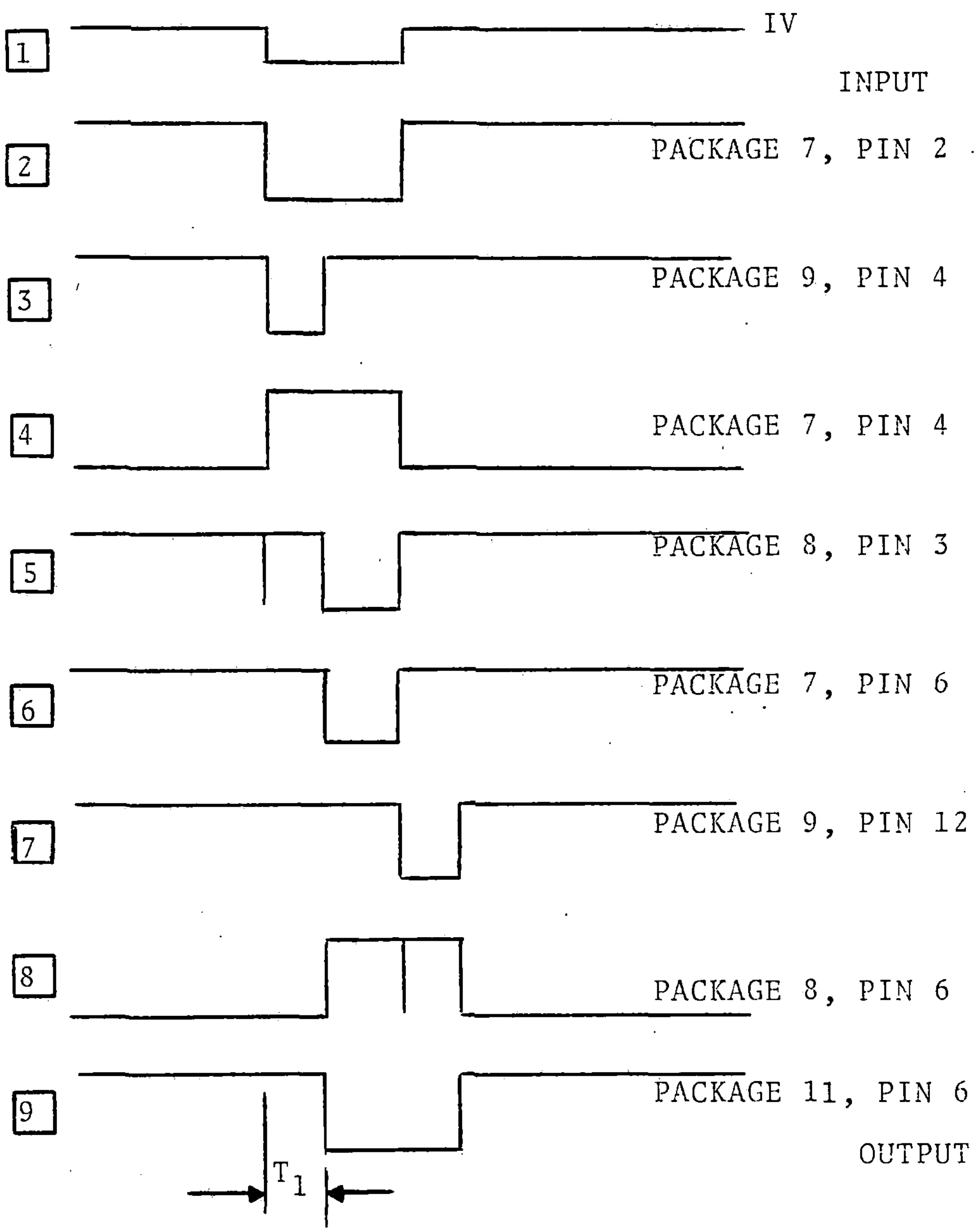


Figure 5-5. Loss-of-Contact Duration - Timing Diagram

is triggered by the rising edge of the waveform, setting $\overline{Q}_2$ low for the selected period and forcing the output of pin 8b high. Component carrier No. 11 serves a similar function to C_9. The output at T_4 is the true loss of contact signal.

Provision has been made for a setting of zero milliseconds (zero). Package No. 10 detects the condition of all 1's corresponding to a setting of 00 milliseconds. It should be noted that the logic signals from the thumbwheel switches are negative logic convention.

Package No. 10 output will then be low and will allow the input siganl to reach the output via pin 11c without being modified in any way. Propagation delays are negligible.

Any other setting but 00 milliseconds (zero) will force package No. 10 high and inhibit pin 11c. The output for any other setting than zero will have arrived via the duration circuit. The LOC Duration output does not appear directly as an output but is fed to the LOC Delay modules. Consequently, logic levels are all that are required.

Gate 11a and the components on C_{12} switch the Sonalert on and off in step with the LOC signal. A mute switch is provided.

NOTE

The +15-volt supply is from a different fuse than that used for the analog supplies as the Sonalert was found to cause crosstalk due to the high resistance of the fuse and the impulsive current requirements of the Sonalert.

5.5.2 DUAL-GANGED DIGITAL POTENTIOMETER (Figure 5-6)

Highly stable (100 ppm), 4.99K-ohm and 49.9K-ohm, one percent resistors are used in the units and tens decade, respectively. Additionally, the resistors were selected using a standard laboratory bridge and resistors whose values were between 4.99K and 5K and 49.9K - 50K were used. The "on" resistance of the analog switches ensures that the lowest value of timing resistor is not lower than 50-ohms. To compensate for the "on" resistance, a large resistor could be used to shunt the first resistor in the units and tens timing chains.

Each of the two halves of the monostable package (No.9) in the LOC duration circuit requires identical circuits so they are designated Stage 1 and Stage 2. The timing resistors between the positive supply (5 volts) and the timing resistors between the positive supply (5 volts) and the timing resistor ports on the monostables were replaced by the dual-ganged digital potentiometer. Each units decade has nine 4.99K resistors while the tens decades have seven 49.9K resistors each. Therefore, a range of 1 - 79 milliseconds is possible.

Packages Nos. 1 and 2 decode the inputs from the thumbwheel switches from 0 - 9, while Package No. 3 provides the decimal conversion for the tens decade. The thumbwheel switches have a common terminal for connection to zero volts while the outputs are all tied to 5 volts via pull-up resistors to obtain a good high signal for a particular switch in the open position. It should be noted that the thumb wheel switches are designated for negative-logic-level signals, i.e., for positions zero, A_0, A_1, A_2, A_3 the signals are all high while for $\overline{A}_0$, $\overline{A}_1$, $\overline{A}_2$ and $\overline{A}_3$ the signals are all low.

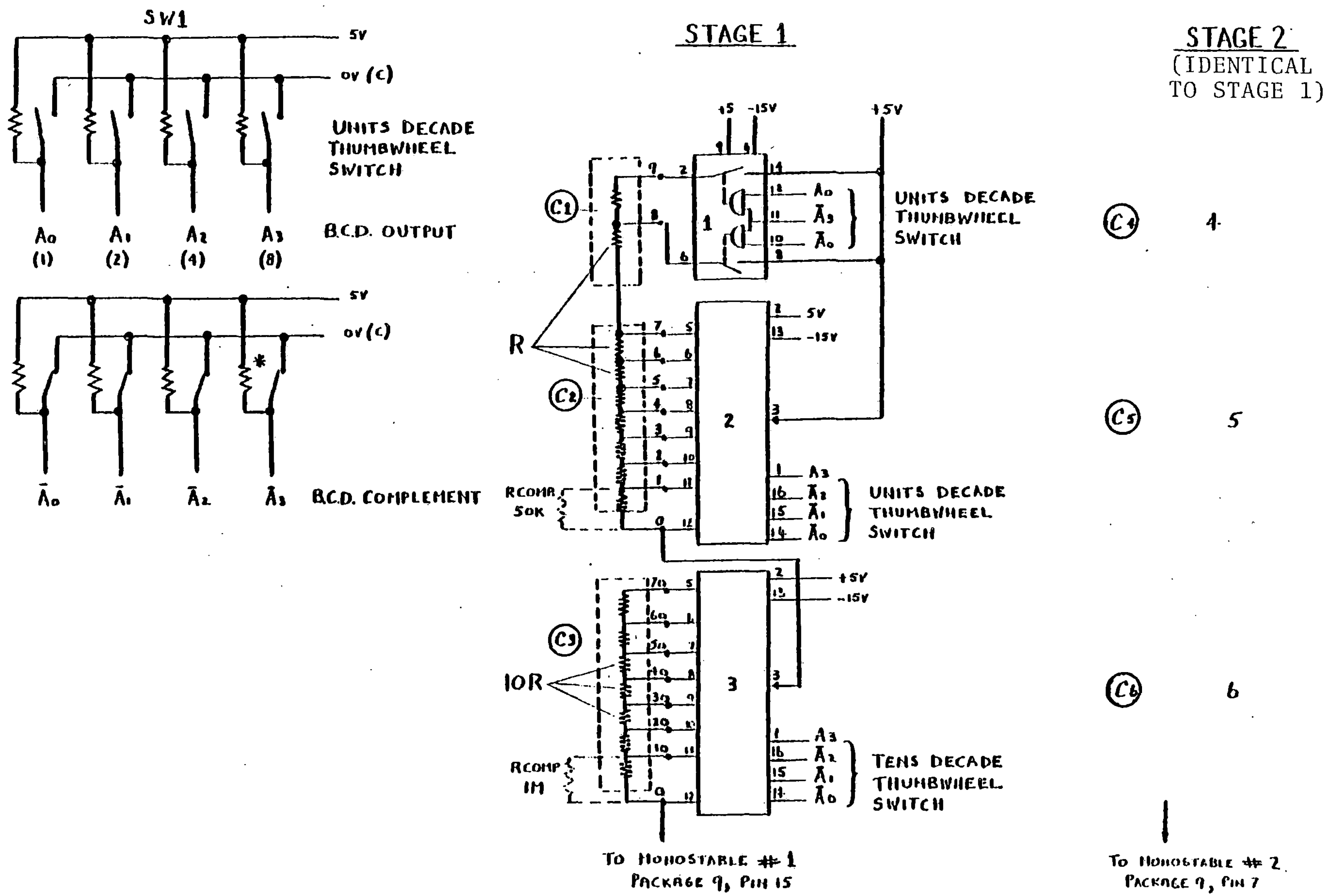


Figure 5-6. Dual-Ganged Digital Potentiometer

Available values for pull-up resistors close to 10K ohms are used; i.e., 8.2K or 12K but the A_3 input must not be higher than 5.6K ohms.

5.5.3 LOSS-OF-CONTACT DELAY CIRCUIT (Figure 5-7)

A Motorola crystal oscillator provides a 16 MHz highly stable square waveform, package No. 1. Package No. 2 contains a divide-by-8 and divide-by-2 circuit, while package No. 3, contains a divide-by-5 and divide-by-2 circuit. By cascading the divide-by-8 with the divide-by-5, a 16 MHz ÷ (8x5) = 400 KHz signal is obtained at pin No. 11 of package No. 3. Further division using the divide-by-two functions of packages Nos. 2 and 3 produces 400 KH_z ÷ (2x2) = 100K H_z. The 100 KHz signal feeds the LOC percentage module and is also taken to the rear panel so that crystal oscillator operation can be easily checked.

Clock pulses at 400 KHz are divided by the number set in the thumb wheel switches for delay, i.e., for a 10-millisecond second: Output frequency = 400KHz/10 = 40 KHz. Packages No. 4 and No. 8 provide this function. A divide-by-2 is performed by package No. 11 to obtain a symmetrical waveform with: Output frequency = 200 KHz/N, where N = the number set in the thumb sheel switches from 1 - 99. Packages No. 16, No. 17 and No. 18 are 64-bit serial shift registers and package No. 19 is an 8-bit serial shift register. The cascaded total is a 200-bit serial-in/serial-out shift register. The cascaded total is a 200-bit shift register and gives a delay of one millisecond at a clock rate of 200 KHz. For a variable clock rate from 200 KHz to 200 KHz ÷ 99, delays are possible from 1-99 milliseconds. The LOC input from the duration module is applied to the shift register input and and digitized by the clock signal. The output is an identical waveform delayed by the period selected by the thumb wheel switches.

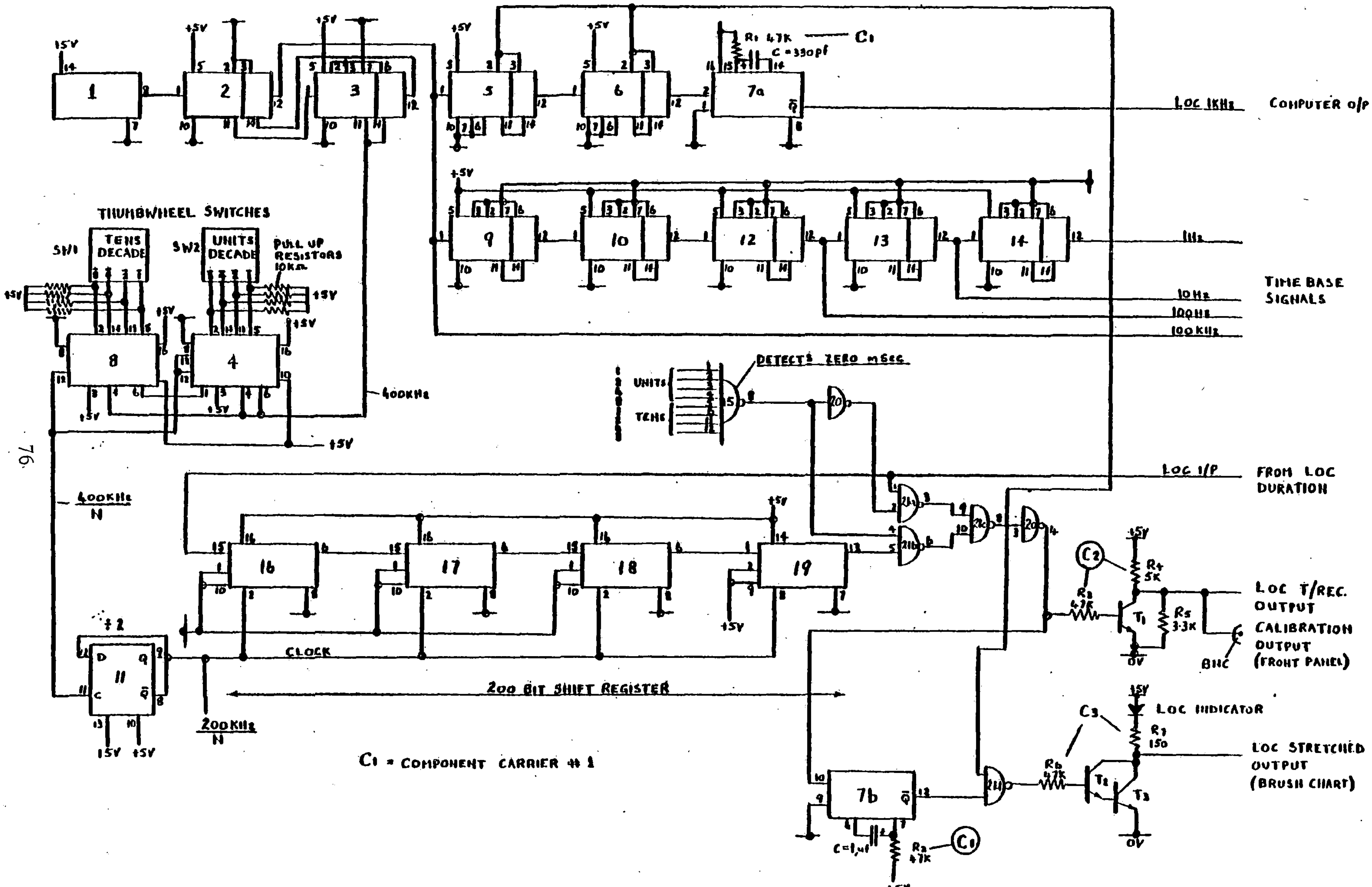


Figure 5-7. Loss-of-Contact Delay Circuit

Package No. 15 detects a setting of "00" milliseconds delay to enable gate 21a and allow the input to reach the output without delay. All other settings route the input through the delay register, to the output. It should be noted that the logic signals from the thumb wheel switches have a negative convention.

Component carrier C_2 has a transistor output stage and an attenuator for driving magnetic tape recorders (1.4V, 1/P). A front panel BNC connector is provided for monitoring calibration signals.

In addition to the tape recorder output, an output is provided to give a loss-of-contact indication on slow response recorders such as Brush charts. Any loss-of-contact appearing at the input (i.e., greater than the duration setting) triggers the monostable No. 7b) to give a 12-millisecond pulse. Therefore, all inputs of less than 12-millisecond period have an output pulse width of 12 milliseconds. Any input greater than 12 milliseconds is unaffected by this circuit. Package No. 21c provides an "or" function for the LOC input and the 12-millisecond stretched pulse.

An LOC INDICATOR is provided in the form of a light-emitting-diode (LED) which also flashes for a minimum of 12 milliseconds when contact is lost.

The 100-KHz singnal is further divided by 10 in packages No. 5 and No. 6 each time to arrive at a 1-Khz-signal. However, the circuit is not free running and is only allowed to divide during loss-of-contact periods. The result is a 1-Khz-wave train during LOC and a low-signal during periods of contact since the reset lines are activated (i.e., reset on pins 2 and 3 = logic high). Gate No. 21c provides the reset to the counters so that an account of any delay setting is included for possible correlation.

The 1-KHz square wave pulses (last stage is a divide by 2) trigger the monostable No. 7a on the rising edge and since each rising edge is central to each pulse, an output is obtained 0.5 millisecond after the loss-of-contact (LOC) signal appears. A time constant is selected giving a pulse period of approximately 4-5 microseconds. This facility has been provided for interface with a computer and is also normally high ($\bar{Q}$ output) so as to feed interrupt inputs.

Although two connectors are provided on the rear panel and designated COMPUTER O/P, the other output has not been connected because future computer input requirements are not known.

Free running decade counters (packages Nos. 9, 10, 12, 13 and 14) divide the 100 KHz-waveform down to one Hz (5 decades). One-Hz, 10-Hz and 100-Hz square waves feed the LOC percentage module range control.

5.5.4 LOSS-OF-CONTACT PERCENTAGE CIRCUIT (METHOD A)

External event inputs are conditioned by the transistor switch T_1 to provide compatible signals. Either normally high or normally low signals can be used since the circuit is edge sensitive, but when not in use it should be tied to one or the other to prevent noise spikes from triggering the circuit. Diode D_1 protects against reverse polarity signals. The "on" threshold is approximately 0.7 volts and laboratory checks show it to be fully saturated at 0.8 volts. Thus, the circuit can be activated from an analog tape recorder channel (1.4 volts). Manual events are generated by the push button switch on the front panel and the bounce free circuit 4a and 4b (Figure 5-8).

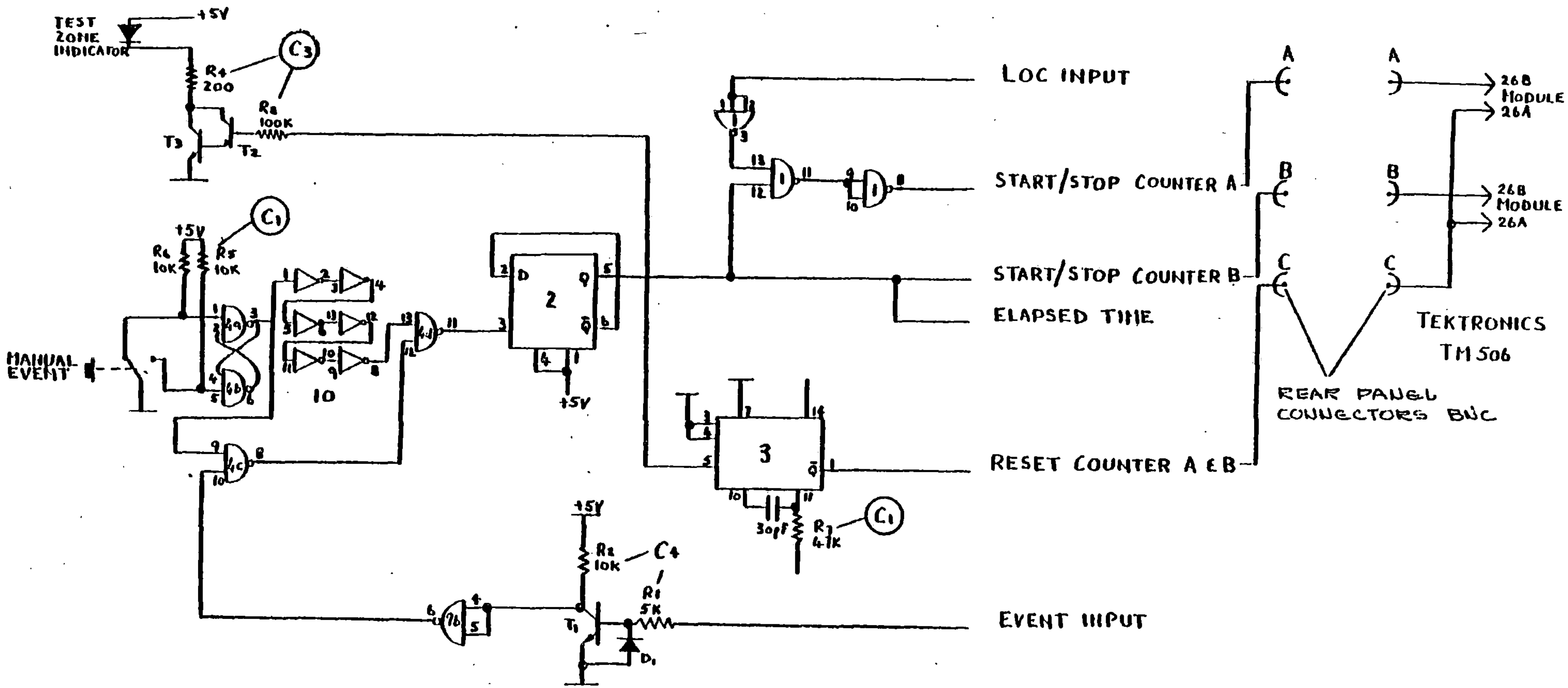


Figure 5-8. Loss-of-Contact Percentage Circuit (Method A)

For external event inputs, circuit 4a is normally high and therefore gate 4d is enabled. Events reach the D-type flip-flop, package No. 2, in phase with the input so that normally low signals trigger that device immediately as the input goes high. The event is a pulse, but on returning to low it does not affect the output of the flip-flop. Another low to high transition is required to return the flip-flop to its original condition. The output of package No. 2 pin 5 is therfore an elapsed time indication between two events.

For manual events there are two cases to consider:

External event = normally low
External event = normally high

With the external event low, gate 4c output is forced high, enabling gate 4d. Gate 4a going low is inverted by 4d to produce a rising edge to the flip-flop thus starting the elapsed time. A further push of the button returns the flip-flop to the original condition. With the external event high, gate 4c is enabled and the output of 4c is determined by the other input from 4a. Gate 4a going low forces 4c high, enabling 4d.

The six inverters of package No. 10 ensure that 4d is enabled before the pulse edge from 4a arrives at 4d. Therefore, a pulse is generated at the output of 4d equal to 5 propagation delays (60 nanoseconds which is ample to trigger the flip-flop.

No provision has been made to determine the position of the flip-flop at power switch ON. However, one push of the MANUAL EVENT switch would correct this if thw wrong state were chosen.

A light emitting diode (LED) indicates a test zone. The diode is driven from the flip-flop output (package 2 pin 5) by a Darlington transistor connection (T_2 and T_3).

Elapsed time is brought out on BNC - B on the rear panel and interfaces with BNC - B on the Tektroics TM506 rear panel. By controlling the start/stop count functions of the internal counter in the Tektronics module, an elapsed time is generated.

Counter A in the Tektronics rack is controlled from BNC - A on its rear panel via BNC - A on the computational Unit rear panel. The signal to start/stop this counter is derived by gating the elapsed time and LOC input together. A high count is generated when both conditions are right, i.e., elapsed time = high, LOC = two.

Counter A fits in the extreme left hand side module of the Tektronics rack, while Counter B is adjacent. BNC - C on both the Computational Unit and the Tektronics rack has the reset facility to set all digits to zero at the start of a test zone. A reset pulse is generated by monostable package No. 3 (one microsecond).

5.5.5 LOSS-OF-CONTACT PERCENTAGE CIRCUIT (METHOD B) - COMPUTES LOSS-OF-CONTACT DIRECTLY

This method (Figure 5-9) requires the circuitry of Method A to define the location of test sections, the time base circuit of the LOC delay and the LOC signal at one KHz, a range control circuit (Figure 5-10) and a circuit to count two input data

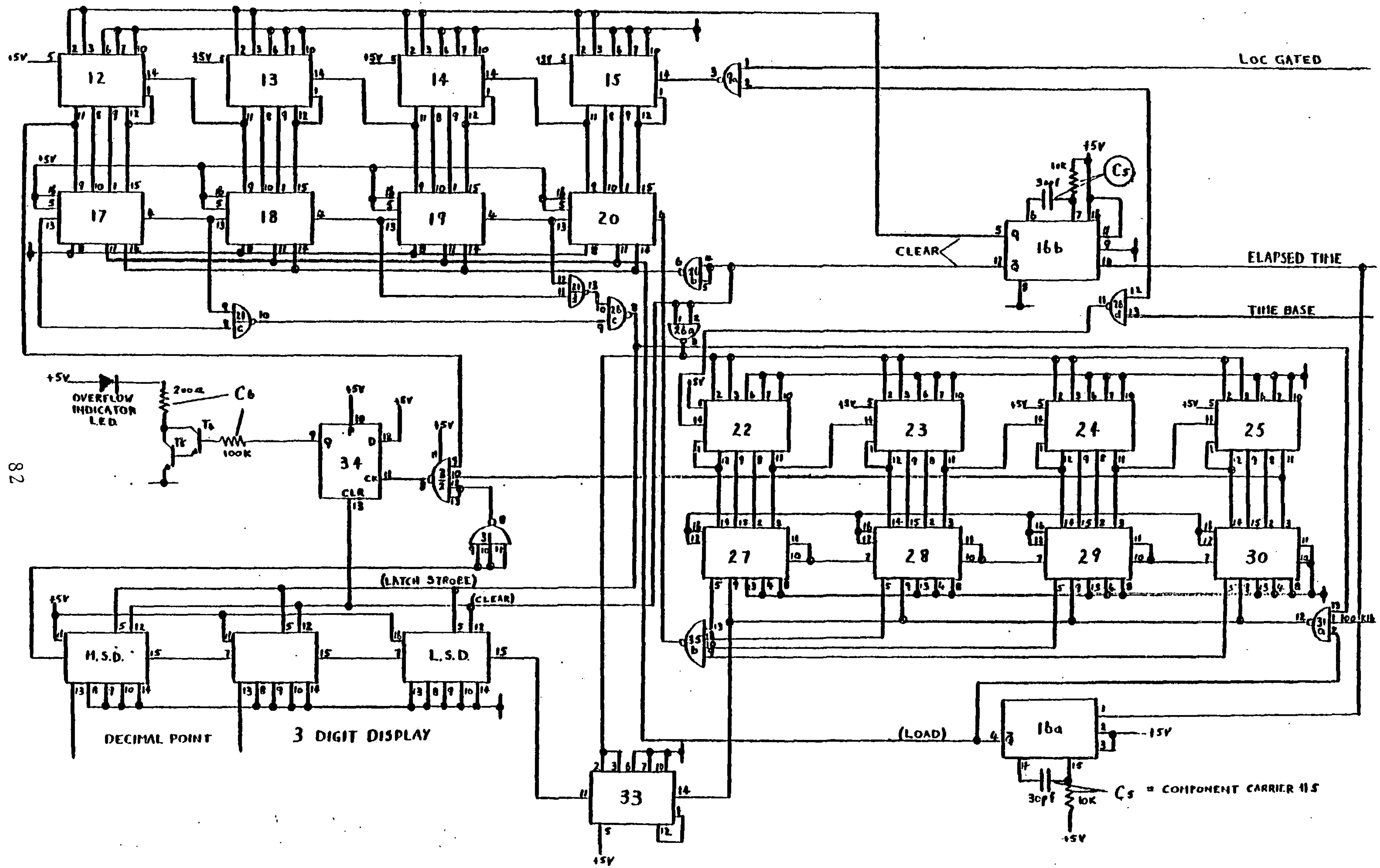


Figure 5-9. Loss-of-Contact Percentage Circuit (Method B)

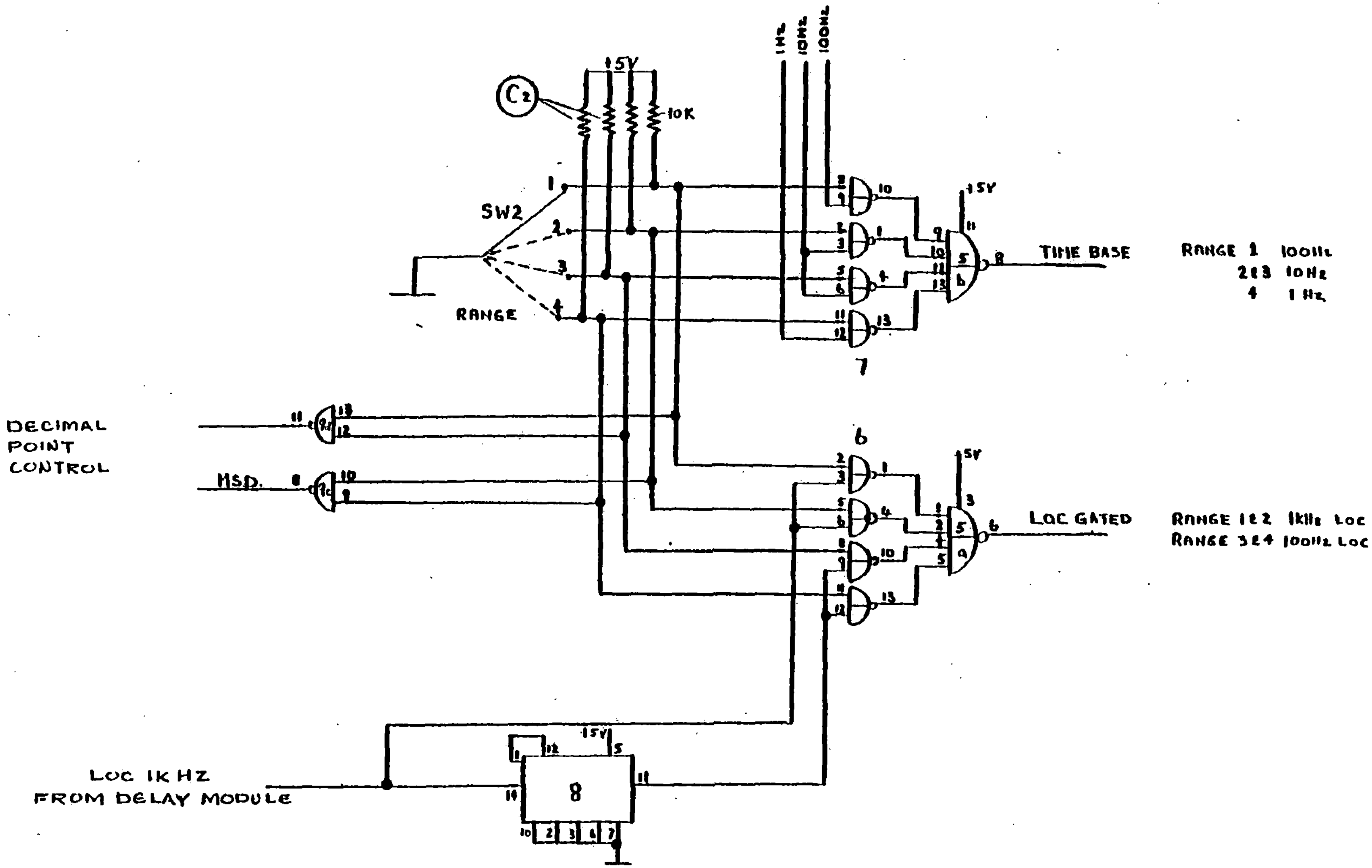


Figure 5-10. Range Circuit-Percentage Loss-of-Contact (Method B)

streams during the test zone and then divide one number by another before displaying percentage LOC.

The range control switch has four settings, designated simply 1, 2, 3 and 4. This enables time base signals of 1, 10 or 100 Hz to be selected and for LOC signals at either a one-KHz or 100 KHz rate to be used for processing percentage LOC according to Table 4-1 for elapsed times and percentage LOC expected. The decimal point on the display is also controlled by the range switch. Packages No. 5b and No. 7 decode the time base requirements while the LOC signal at one KHz or 100 Hz is generated by packages NOs. 5a and 6. A decade counter package No. 8 divides LOC at 1 KHz to obtain LOC at 100 Hz. Gates 9c and 9d detect a logic low in range position 2 or 4 and 1 or 3, respectively. A low on 2 or 4 enables the decimal point on the most significant digit with a corresponding full scale reading of 0.000 while a low on 1 or 3 enables the decimal point on the center digit with a corresponding full scale reading of 9.99.

For purposes of explanation, suppose that range 1 is selected with corresponding LOC data at 1 KHZ and a time base of 100 Hz. Therefore, for 10 percent LOC averaged over a sufficiently long period the X and Y registers have equal counts.

The elapsed time of the test section is generated by the event inputs to the control module (Method A). This serves to allow pulses into the X and Y registers only in a test zone. On entering a test zone, a reset pulse is generated to clear the X, Y and Z counters to zero. At the completion of a test run, the X and Y registers contain numbers they obtained in the test zone. The elapsed time signal going low generages a load command to the Y register which in turn clears the "all zeros" detector and allows the 100-KHz clock to run. Reset is generated by monostable No. 16b for a period of approximately one microsecond. Inverters are used to increase the fan-out capability and obtain the correct phasing. Time base pulses enter the cascaded combination of packages 22, 23, 24 and 25 via gate 26d during the test zone (X register). LOC gated data at one KHz enters the Y register (12, 13, 14 and 15) via gate 9a during the test zone.

Load command is generated on the falling edge of the elapsed time by monostable No. 16a (1 microsecond).

Instead of trying to explain how this circuit works, suppose we have a hypothetical number in each register. Remembering that X was at 100-Hz input rate and Y at 1-KHz input rate so there is a factor of 10 to include in the answer.

The X register controls a four decade rate multiplier. It has a base frequency of 100 KHz/10^4 = 10 Hz. It also has an output which is equal to the input decade number times 10 Hz, i.e.: 0 through 999 times 10 Hz, therefore the maximum frequency output = 99.99 KHz. This frequency counts down the number in the Y register until it reaches zero. Suppose: Y = 9000 and X = 9000, this would correspond to a percentage LOC of 10 remembering we have a scale factor 10 to apply to the answer. Y is clocked down at 90 KHz so for 9000 pulses it takes 9000/90 KHz = 1/10 second.

Now, in 1/10-second the Z register, which is clocked at 100 KHz, has advanced to 10000 which with suitable placement of the decimal is the answer we require. (Actually 9.999 is the largest percentage LOC that can be accomodated, but such a figure would be intolerably large anyway.) An overflow indicator is incorporated in case the dynamic performance deteriorates more rapidly than can be predicted, or the test duration has been miscalculated. At 100 Hz time base, the maximum count occurs in 99.99 seconds in the X register and also in the Y register for 10-percent LOC.

The down counter for the Y register is formed by packages 17, 18, 19 and 20, and the "all zeros" detector by gates 21c, 21d, and 26c. A condition of "all zeros" produces a low on 26c to inhibit the 100-KHz clock at 31a and to transfer counter information in the Z register through to the display (latch strobe).

The four decade, rate multiplier is formed by packages 27, 28, 29, 30 and gate 35b to make the clock for the Y register down counter. Pulses can be observed at the output of 35b, pin 8 for a short time only during each percentage LOC calculation.

Since only a three-digit display would fit the available front panel space on the percentage LOC module, a decade counter was required to buffer the display units (package 33).

Overflow of the X, Y or Z registers produces a clock pulse to set the D-type, flip-flop output high (34). The light-emitting-diode (LED) indicator is driven by the Darlington-connected transistors T_4 and T_5.

Fault finding on this circuit is fairly difficult and time consuming, and in some cases, it will be necessary to "break the loop" and check each register systematically; e.g., to check the X register and the four-decade, rate multiplier.

The "all zeros" detect line to 31a pin 13 should be disconnected, thus allowing continuous 100-KHz clock pulses to the decade rate multiplier. Using a stop watch, allow pulses into the X-register for a pre-determined period of time (say 50 seconds). After 50 seconds, check the contents of the X register. Accuracies of about 0.1 second should be expected. Then measure the frequency appearing at the four-decade, rate multiplier output (gate 35b pin 8. In this example we expect 5000 (50 seconds x 100 Hz) x 10 Hz = 50 KHz. Check the frequency for various time intervals. If a fault is evident, individual stages can then be checked, i.e., let the number in the X register = 3691, then measurments of 30 KHz, 6 KHz, 900 Hz and 10 Hz respectively should be observed at each output.

5.5.6 POWER SUPPLIES

The LOC processing modules draw 1.4 amperes from the 5-volt logic supply via a 2-ampere fuse which provides short circuit protection.

The analog circuits draw 80 milliamperes at ± 15 volts including the power-on light on the main switch (28V lamp). This drain increases to approximately 200 milliamperes when the calibration relays are activated and the Sonalert is on continuously. The relays and the Sonalert have separate fuses to avoid crosstalk problems due to the high resistance of the fuses and the impulseive nature of these devices. Fuses for the ±15-volt supply should be chosen accordingly but the total for each supply should not permit more than 300-milliamperes to flow.

5.5.7 CALIBRATION

The relay coil in the True Force module has one side taken to +15 volts while one side of the trajectory relay coil is taken to -15 volts. Calibration is implemented by applying zero volts via the calibration push switch to the other side of the relay coils. The coils operate reed contacts which disconnect the normal inputs and apply the reference voltage of 1.4 volts. To compensate for the change in load, resistance seen by the reference supply, i.e. infinity when deactivated and all inputs in parallel when activated, an 8.2 K-ohm resistor is taken from the reference supply to ground thorugh the calibration switch. When calibration is pushed, the 8.2K ohms is disconnected and replaced by the input resistance of the amplifiers. The reference supply will then be constant (within 2 millivolts) whereas it would have changed by 40 millivolts. To obtain a calibration on the Stagger module without using more reed relays, the circuit of Figure 5-11 was adopted. F_2 has an equivalent calibration of 0.7 volt since the 100K-ohm series resistor effectively halves the 1.4 calibration voltage since it is in series with the 100K-ohm input resistor F_2 on the True Force module. To obtain F_1 = 0.7 volts requires a series resistor of 50K-ohms since F_1 is fed to the True Force module and the stagger module (both 100K-ohms input resistance). However, the F_1 signal to the stagger module must come from the common side of the reed relay, hence the terms F_1 in and F_1 out.

5.5.8 STRUCTURE MARKER CIRCUIT (Figure 5-12)

Light perpendicular to the test car roof is focused onto the silicon photo-darlington (L14F2) by the television camera lens arrangement. With an open circuit base connection, the output voltage across a collector load resistor is proportional to the light flux, until saturation occurs. The load resistor,therefore,is a compromise to obtain sufficient signal early

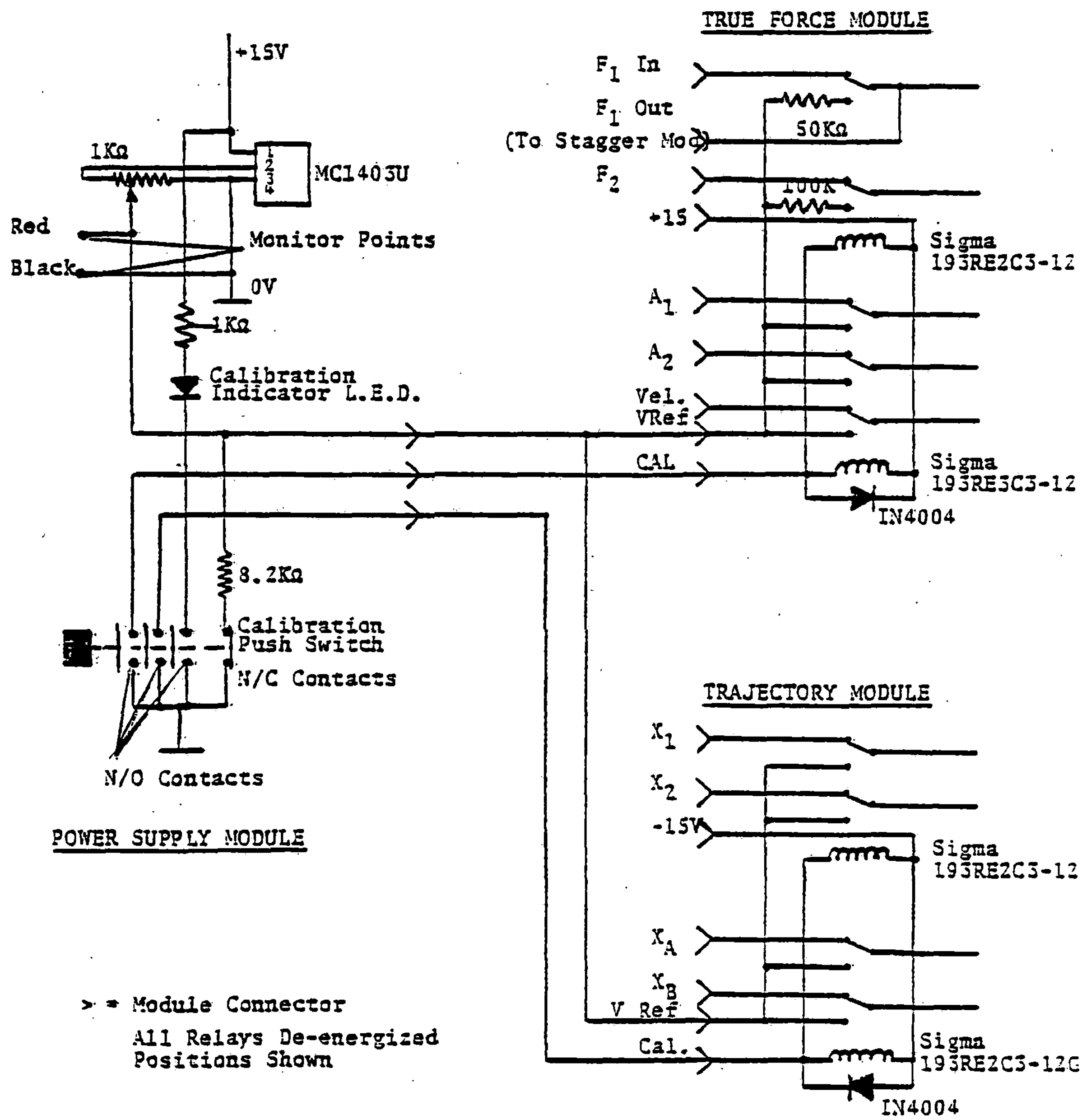


Figure 5-11. Calibration Circuit

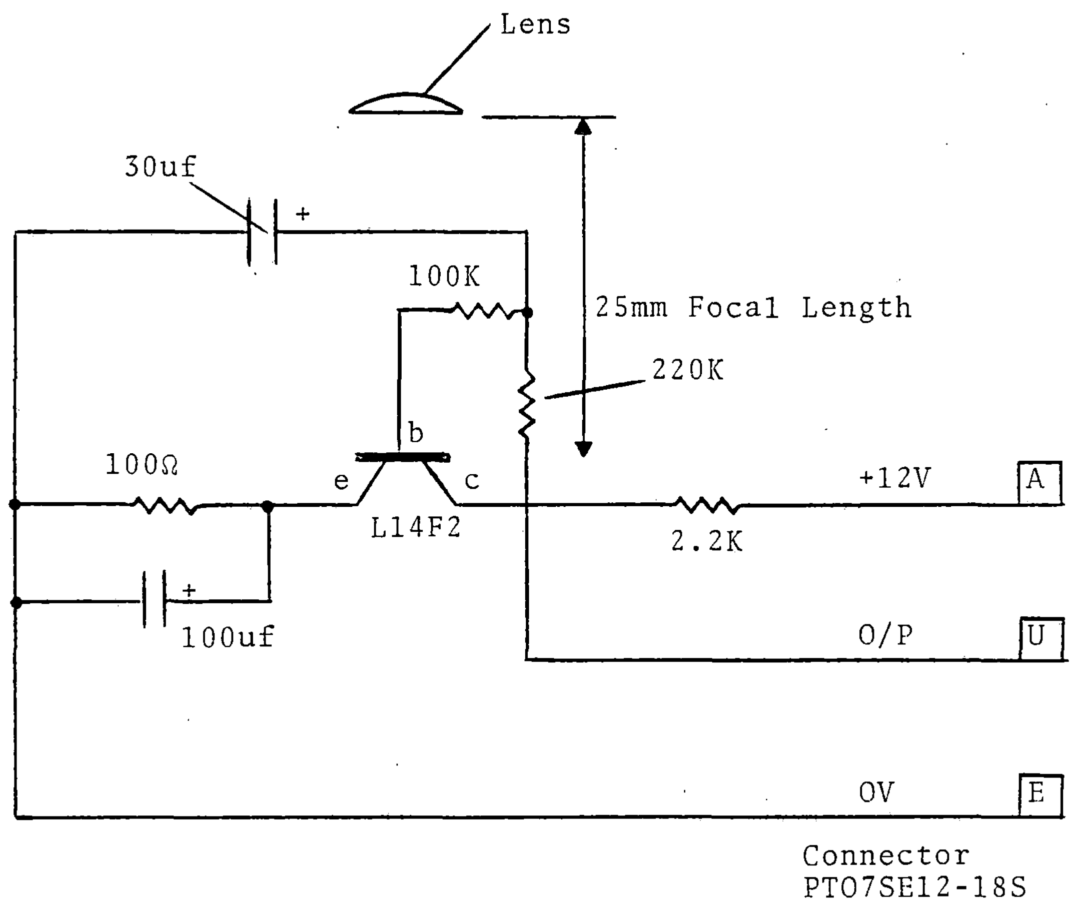


Figure 5-12. Structure Marker Circuit

and late in the day, without saturating in the middle of the day. Larger supply voltages allow for greater changes in the ambient conditions before saturation occurs, since the detector is a current-operated device. This particular circuit does work but the output level can vary anywhere between the power supply rails. This would make it difficult to observe on a recorder and impossible to amplify further without a-c coupling.

With the addition of a few components, it is possible to bias the detector using the base connection to maintain a reasonably constant output. Therefore, part of the output at the collector is fed back to the base in anti-phase. Changes in the base current caused by an increase or decrease in the ambient conditions are accompanied by a corresponding decrease or increase in the self bias applied to the base. The result is a much more constant output voltage. Further negative feedback is applied by the emitter resistor. If the circuit was to remain this way it would also try to compensate for the change in light detected at a structure. To avoid this, decoupling capacitors are required in the feedback networks which allow fast changes (structures) to occur while compensating for the slow (ambient) conditions. The time constant selected is, therefore, a compromise between being able to see the structure at slow speeds and being able to cancel the ambient changes. The prototype has a time constant of approximately one second which could easily be reduced to 100 milliseconds by reducing the base de-coupling capacitor to one microarad if problems occur.

If the transition from blue skies to clouds causes problems, a speed-controlled rate of change circuit could be designed. This would have a time constant of one second for slow speeds (0-10 mph) where train velocity is not likely to produce fast changes in output. At 100-150 mph the time constant would be reduced to 20 milliseoncds to detect structures and reduce ambient changes due to train velocity. Obviously, a velocity input would be required from the test car.

Some variations due to ambient changes can still be seen but these are limited to less than one volt. The saturated output level is about one volt while the dark level is approximately two volts. The f-number selection (with a little experience) will keep the detector in the linear operating region. A rule of thumb that could be adopted is:

> f = 1:1.4 for early and late in the day or for blue skies during the wintertime. (Collector load = 2.2K ohms)
>
> f = 1:2.8 for cloud and overcast conditions and near mid-day (Collector load = 2.2K ohms)

NOTE

For night operation f = 1:1.4 is required and an increased collector load (20K ohms).

A Dynamics amplifier supplies the power to the structure marker via the standard instrumentation cabling. The return signal (collector of L14F2) is routed via the mode card through the amplifier and the output appears on the BNC connector of the Dynamics rack for that particular channel. By using the offset facility on the signal conditioning module it would be possible to move the saturated level to correspond to zero volts. It would then be possible to provide extra amplification in this stage if necessary. Similarly, the dark level could be offset to zero volts for night operation and a gain of ten used to dispense with the necessity of changing load (collector) resistors in the structure marker.

Shadows cast across the structure marker from objects not directly in the field of view are generally not a problem. They are always several times smaller than an object directly over the field of view. However, these shadows on a very bright day could give larger signals than the structures under less favorable conditions. A comparator circuit was considered for the output stage which would only give an output when a pre-determined level has been exceeded. This again would have required adjustment to suit the conditions, i.e., a variable threshold to exclude shadows on a very bright day or to include the structures at other times. Therefore, to keep the prototype as simple as possible, this was excluded. Besides the structures should stand out from other incidents and the structures on the Railroad Test Track will give a regular though speed-dependent pattern.

On the question of birds overhead being detected, these again should appear as quite small occurrences compared to the structures.

Although it was though that a diffuser would help to overcome cloud edge problems by integrating the light, it is difficult to say if the experimental diffusion obtained improved matters. The output of the detector was taken to a differentiating circuit so that rate of change could be observed when moving the detector through an angle from clouds to blue skies. Although the detector was moved manually with and without the diffuser, which could account for some error, about the same results were obtained for each test. Again this has been omitted from the ptototype system.

For night operation, a suitable spotlight and increased gain is all the modification necessary. The aperture should be fully open f = 1:1.4 and the load resistor 20K ohms. In the initial tests a separate circuit board was used. This consisted of the open-circuited base detctor and a load resistor. In the dark, the collector load could be increased to almost infinity without saturating but a value of 10-20K ohms was satisfactory in the dark without being oversensitive at twilight. This particular circuit is difficult to use as the output is referenced to 12 volts (the supply) instead of zero volts. Therefore, it would seem logical to use the daytime circuit at night but with an increased collector load. A shunt resistor could be placed on the mode card, and operated by the calibration switch.

Calibration of the daytime system could be simply checked by waving a hand across the structure marker. (This may not be possible with energized overhead.) For night operation a flashlight could be waved across the structure marker but actually aligning the spotlight so that the sillumination on the pole is seen by the detector will be the most time-consuming activity.

5.5.9 MODULE INTERCONNECTIONS

The modules in the Computational Unit are interconnected as shown in Figure 5-13.

Design of Dead-Wire Instrumentation Package for Use on Electrified Railroad Test Track at Transportation Test Center (Final Report), US DOT, FRA, D Allen, R Scofield, 1980 -13- Electrification