INDUCTIVE LOOP DETECTORS:

Theory and Practice

Prepared by

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16. Abstract

This Implementation Package provides a users manual for design application and performance testing of inductive loop detector systems developed by the Department of Traffic, City of Los Angeles, California. It is based on a study of many of their approximately 3,000 loop detector field installations. The purpose of the study was to determine the causes of failure or intermittent operations and to develop aids for the design, test, and maintenance of these systems.

Basic theory of loop detector operation is also presented along with a discussion of loop size and shape. Installation procedures used in the Urban Traffic Control System (UTCS) in Washington, D.C., are presented with other discussions of practical ways to deal with the installation of loops across pavement joints.

A detector trouble-shooting procedure, with detail instructions and data recording forms, is presented in an Appendix in a form suitable for removal and use by individual technicians.

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SYNOPSIS

The need for an easily installed and relatively inexpensive system to provide passage and/or presence detection for traffic control purposes has led to substantial use of an inductive loop system. In the past, a lack of standardized performance criteria has hampered the design, installation, and maintenance of loop detector systems and resulted in a considerable amount of experimentation during the installation phase.

This Implementation Package provides a users manual for design application and performance testing of inductive loop detector systems developed by the Department of Traffic, City of Los Angeles, California. It is based on a study of many of their approximately 3,000 loop detector field installations. The purpose of the study was to determine the causes of failure or intermittent operations and to develop aids for the design, test, and maintenance of these systems.

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DEFINITIONS

To simplify discussion, the following definitions are used throughout this report:

1. Area Detection: The continuous detection of vehicles over a length of roadway wherein the call of a vehicle in the detection area is held for as long as the vehicle remains in the detection area. Frequently referred to as large-area detectors or "long-loop presence detectors".

2. Conduit Ground: A common reference circuit throughout the intersection formed by electrically interconnecting all conduits and the controller ground bus.

3. Detector: An electronic unit, used in conjunction with an inductive loop buried in the roadway, to sense vehicle passage or presence and transmit the information to a controller.

4. Detector System: The complete sensing and indicating group consisting of the detector unit, transmission lines (lead-ins), and inductive loops.

5. Loop System: A combination of loops of wire connected through transmission lines (lead-ins) to the detector in-put terminals.

6. Minimum Vehicle Standard: A test unit that produces the minimum change in input for which the detector system must sense and indicate passage or presence.

7. Presence: Continuous detection of a vehicle while present in the loop sensor area.

8. Point Detection: The detection of vehicles as they pass a specific point on the roadway. Detection by pressure and magnetometer detectors are typical examples. Frequently referred to as small-area detectors.

9. Presence Holding Time: The time that a detector system will continue to indicate the presence of a vehicle over one of its loops without adjusting to consider the vehicle a new environment.

10. Quality Factor (Q): A numerical index for rating the quality of a resonant circuit. A higher number indicates less losses and increased detection sensitivity in a resonant type detector system.

11. Self-tuning Detector: A circuit capable of readjusting the operating frequency to track the long-term changes in the inductance and capacitance of the loop system. May also include the adjustment of amplitude for a fixed frequency unit.

12. Sensitivity:

Loop System: The change in total inductance of a system caused by a minimum vehicle at one loop, expressed as a percentage of the total inductance.

Detector: The minimum inductance change in percent required at the input terminals to cause the detector to actuate.

13. Vehicle Standard: A test unit that produces a change in the loop inductance equivalent to a conventional American sedan.

STUDY PURPOSE AND SCOPE

General

The need for an easily installed and inexpensive system to provide passage and/or presence information for traffic control purposes has led to substantial use of an inductive loop system of several turns of wire embedded in the pavement as a means to this end.

Any traffic detection system must operate with a high degree of reliability and minimum maintenance. Within the City of Los Angeles, there are approximately 975 intersections at which vehicle detection equipment has been installed. The development of increasingly sophisticated control hardware has made the requirement for reliability a more significant requirement. The design, installation and maintenance of detector systems has been hampered by lack of physical criteria for loop performance. Additionally, early design has become standardized without reference to the physical phenomena or to the diverse locations involved. Discussion of this problem is further complicated by the lack of a standardized vocabulary and an exact description of the vehicles to be detected in terms of the specific physical phenomena used by the detection system.

The lack of specific information in this area has resulted in a considerable amount of experimentation during the detector installation phase so that loops wired to the same signal phase on different approaches will have sufficient sensitivity for the control function. In some instances, in excess of 50 manhours have been expended in "cut and try" at difficult locations.

Purpose

The purpose of this study was to determine the causes of failure or intermittent operation of inductive loop detector systems in use in Los Angeles, and to develop aids for the design, test, and maintenance of loop detectors.

The study is limited to the quantification of the critical parameters of the inductive loop system for vehicle detection so as to provide direct methods for identification of the causes of failure and borderline operation, and to provide the system designer with the necessary data for a precise design which will operate properly without field adjustment.

Out of approximately 3,000 inductive loop installations in Los Angeles, less than 100 locations have had reported failures beyond the capability of the traffic signal repairman to correct and/or identify. There is an unknown additional number of intermittent failures possibly due to borderline operation, which do not get reported. This is particularly applicable to multi-phase actuated installations. This problem becomes increasingly acute as the number of such installations increases.

To simplify the design procedure, the designers have been specifying a 6-foot loop either square, or more recently, an octagon (6 feet across flats as shown in Figure 1) at each point where detection is required. The detection area required in each through lane is serviced by two of the 6-foot loops and both approaches to an intersection are connected to a single detector unit. The connection configuration has been left to the installer to complete based on his obtaining satisfactory operation with any one of several possible combinations of series and parallel connections.

Certain vendors have provided installation design data for their particular detection equipment. These data seem to be based on successful installations of the particular hardware concerned. The systems aspect of the detector and loops has been left to the user to provide. Where several types of detectors have been purchased, the various types may not be compatible with existing installations without wiring changes. Department of Traffic experience, as well as the experience of other jurisdictions, is pragmatic: methods which seem to be successful have been continued.

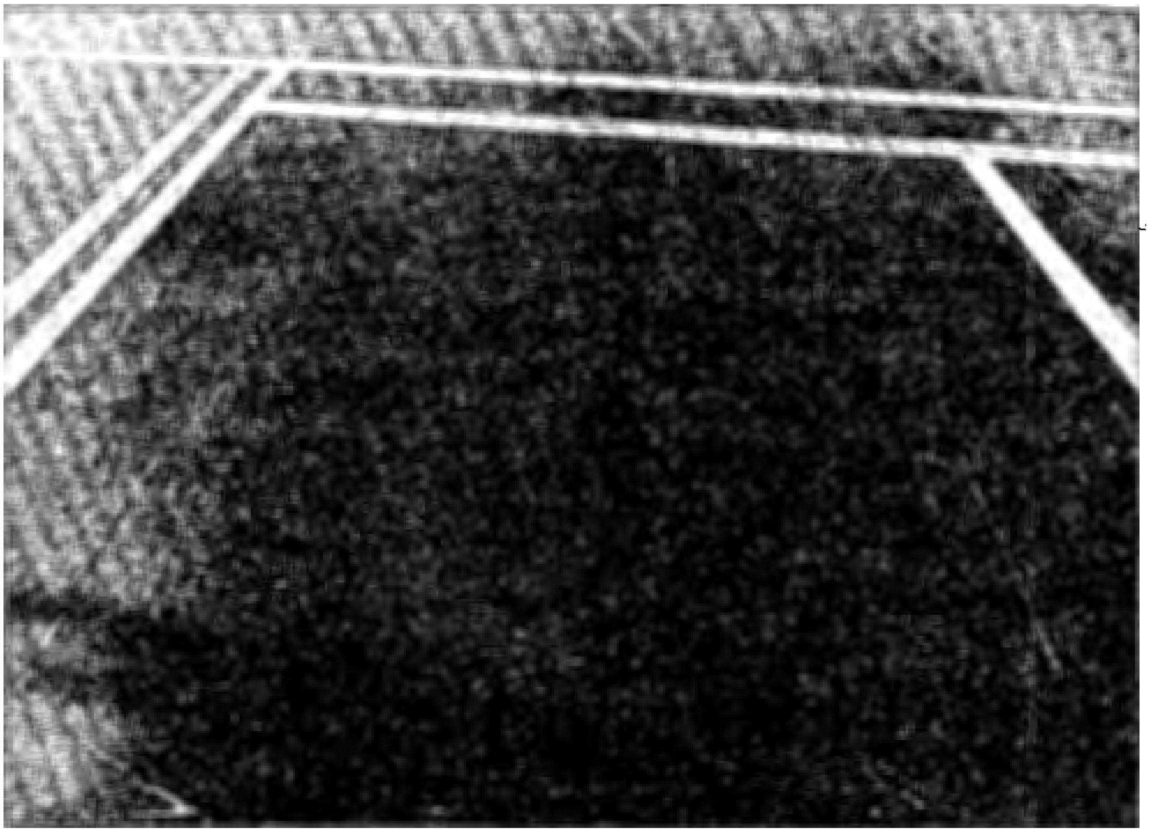

Figure 1. Octagon shaped loop used in Los Angeles

LOOP SYSTEM THEORY

A prime part of the detector system is the inductor formed by the multi-turn loop winding buried in the roadway surface. It forms the sensing part of a resonant circuit composed of the loop, a two-wire transmission line and the input capacitor in the detector unit. The conditions surrounding the loop or large inductor are of the most interest in this discussion of the loop functions and limitations.

The theory of the inductive loop system as currently in use is a direct derivation from the theory of resonant circuitry which has been treated at some length by writers such as Terman.[1] These authors have not extended their work to the limited conditions of the traffic detector; however, the three-turn loop can be described theoretically as a short solenoid and seems to be a special case of the theory.

A model of the resonant circuitry may be considered as a transformer primary, tuned by the input capacitor and having some value of parallel or shunting resistance across the circuit. The secondary of this air core transformer is formed by the metallic electrically conductive surface of a vehicle. When a conductive surface or object is partially over the area enclosed by the loop, the induced current in the secondary (vehicle surface) absorbs energy from the primary circuit (eddy current loss) and this appears as a reduction of the reactance and inductance of the primary winding. The detector unit provides the excitation frequency and energy to the transformer primary and, by appropriate circuits, can sense the shift of the circuit resonant frequency caused by the reduced inductance.

A second effect (known as the ferromagnetic effect), is also present when the vehicle is a ferrous metal object. Insertion of an iron core in the field of an inductor acts to reduce the reluctance of the flux path and increase the net inductance. In the case of detector loops, there are opposing effects operating and the eddy current loss effect decreases the inductance more than the increase from the ferrous material. It is possible to continue to add conducting surfaces, or the equal in the form of a shorted or closed turn of wire, until the change caused by a vehicle over the loop area is less than required to actuate a detector. A key point in maintaining a sensitive loop area is to preclude any shorted turns or conductive surfaces in or near the loop area to allow the desired object to have maximum effect.

The amount of change in inductance of the primary is determined solely by the coefficient of coupling and not by the number of primary turns.[1] *(Page 151, para. 4)* The effect of the secondary or vehicle decreases rapidly as the coefficient of coupling is reduced; the coefficient is inversely proportional to the square of distance from the loop plane to the vehicle surface. A particular vehicle will cause the same percentage change of inductance independent of the number of turns, but the percentage change varies dependent on the distance of the vehicle from and the size of the loop.

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[1] Numbers refer to references listed at the end of this report.

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LOOP CHARACTERISTICS

The inductance of a loop or combination of loops must be within a specified range to match the design limits of each type of detector unit. Many different equations have been proposed for calculating the inductance of different sizes or shapes of inductors. However, most are oriented toward circular coils whose length to diameter ratios are one (1) or greater (length/diameter ≥ 1). For the flat single layer rectangular or polygonal shape coil used as an inductive loop in the street surface, the ratio of length to diameter approaches 0.01 exceeding charted values. The length is defined as the vertical distance in the pavement slot occupied by the wire turns, and the diameter is the distance across the loop.

The equation from Terman[1] *(page 56)* for a single-layer rectangular coil accounts for variation in perimeter, the number of turns, and uses a chart value for length to diameter ratio, wire size, and spacing. The approximate inductance (L) of an inductive loop installation is:

$$L = pn^2 (G + H)$$

where $p = $ perimeter, $2(S_1 + S_2)$

$S_1 = $ length of short side, inches

$S_2 = $ length of long side, inches

$n = $ number of turns

G and H are factors related to coil geometry and wire size

The chart value for our purposes, $(G + H) = .028$

Then for a 6-foot x 6-foot rectangular loop of 3 turns, constructed from #12 wire and having a length of $\approx$ 0.75 inch, the inductance is, in microhenries,

$$L_{6x6} = pn^2 (0.028) = 288 \times 9 \times (.028) = 73\,\mu h$$

Using the same conditions and the perimeter for a 6-foot (across flats) octagonal-shaped loop, the inductance is

$$L_6 = pn^2 (0.028) = 238 \times 9 \times (.028) = 60\,\mu h$$

which agrees closely with measured values.

An even simpler equation based on the same variables of perimeter and number of turns as adapted from a detector vendor's pamphlet[8] is:

$$L = (L + W)\,\frac{(N^2 + N)}{2}$$

where L and W are the sides of the rectangle in feet and N = number of turns.

For a 6 x 6 rectangular loop of 3 turns,

$$L_{6x6} = (6 + 6)\,\frac{(9 + 3)}{2} = 72\,\mu h$$

Using the perimeter of a polygon relationship where P = perimeter in feet,

$$L = \frac{P}{2}\,\frac{(N^2 + N)}{2} = P\,\frac{(N^2 + N)}{4}$$

$$L_{6x6} = (24)\,\frac{(9 + 3)}{4} = 72\,\mu h$$

and for an octagonal 3 turn loop

$$L_6 = (19.8)\,\frac{(9 + 3)}{4} = 59.5\,\mu h$$

Circuit Q and Significance

The quality factor or Q of a resonant circuit is an indication of the dissipated or lost energy taken from the oscillating circuit. Q is defined as the inductive reactance divided by the series and reflected (or equivalent) resistance of the circuit. For a series connection,

$$Q = \frac{\omega L}{R_e}$$

where Q is dimensionless and is an index

ω = $2\pi f$

f = the operating frequency

L = the inductance of the loop and lead-in

R_e = equivalent series resistance

For a parallel circuit and a resistor (R_p) shunted across the terminals, the expression becomes

$$Q = \frac{R_p}{\omega L}$$

The above relationships are used for expressing the Q of circuits with low losses or having relatively high Q and where the inductance, resistance, and frequency can be readily measured with available test equipment. In the case of inductive loops, the inductance is distributed through the loop and lead-in and is not easily measured because of the masking effect of the associated lead-in capacitance. The resistance of the loop and lead-in is larger than the$_e$ series value measured with an ohmmeter and becomes an equivalent resistance (R^e) . The larger R^e is the result of the extra losses associated with the circuit configuration and varies with location.

Significantly, the quality of a loop circuit in terms of response, level of voltage across the circuit and action with a detector unit directly affects the sensitivity and reliability of the system as a vehicle detector. The quality factor, (Q), is a means of attaching a numerical value to these circuit conditions and provides a definition and criteria for acceptance or rejection of any installation.

A practical means of obtaining the circuit Q_e which does not require the values for inductance (L) and equivalent resistance (R^e) consists of measuring the resonant frequency and bandwidth of the loop circuit and calculating a value for Q as follows:

$$Q = \frac{\text{frequency of resonance}}{\text{bandwidth}} \text{ ; or } \frac{f_{\text{res.}}}{Q} = \text{B.W.}$$

This relationship follows from Terman[1] *(page 145)* where the bandwidth is defined as the difference between the two frequencies on either side of resonance at which the voltage across the parallel circuit is reduced to 70.7 percent of the voltage of resonance. When the frequency of the applied voltage deviates from the resonant frequency of the circuit by an amount that is 1/2Q of the resonant frequency, the current that flows is reduced to 70.7 percent of the resonant current and the current is 45° out of phase with the applied voltage.

From the above relationships, let Δf = the frequency shift necessary to reduce the circuit voltage to 70.7 percent and Bandwidth (B.W.) = $2\Delta f$.

By definition,

$$\Delta f = 1/2Q \times f_{\text{resonance}}$$

$$\text{then } 2\Delta f = 2(1/2Q) \times f_{\text{resonance}} = \frac{f_{\text{res.}}}{Q} = \text{B.W.}$$

$$\text{and } Q = \frac{f_{\text{res.}}}{\text{B.W.}}$$

Equivalent Loop System Inductance

The inductance of a loop system is associated with other distributed parameters in the loop, lead-in and input circuit of the detector. The distributed capacitance of the lead-in and street surface is present with the inductance and equivalent resistance in a combined form where it is difficult to separate one parameter for measurement. The inductance cannot be measured accurately with the typical inductance meter because of the cancellation effects of the circuit capacitance and extra losses of the series equivalent resistance.

It is necessary to determine the nominal inductance of a loop system to insure that the combination to be connected matches the designed input range of the detector. A substantial change in the inductance from the as-built value would indicate specific loop problems and obtaining a nominal value measurement would facilitate maintenance procedures.

Sensitivity of Detector System

Detector sensitivity is defined as the smallest percentage change of the inductance at the terminals which will cause the detector to actuate. The percent change presented to the detector depends upon the several parts of the loop and lead-in system plus the type of vehicle. The original inductance of the loop is decreased by a vehicle moving over the loop and the various sizes and heights of vehicles will cause a different percentage change.

The inductance of the lead-in connecting the loop to the detector terminals is also part of the total loop circuit value and the change caused by a vehicle at the loop must be compared to the total inductance when calculating the percentage change at the terminals. From this consideration, it is apparent that a longer lead-in and larger inductance will decrease the sensitivity or percentage change of inductance at the terminals. The detector sensitivity must be a smaller value than the minimum percentage change expected from the loop configuration (loop system sensitivity). Connection of multiple loops in series and parallel combinations causes a decrease in the percentage change of the loop combination and when combined with the added inductance of a long lead-in may be near or below the detector threshold. For this reason, the sensitivity of the loop system and the detector unit must be measured and restrictions observed to obtain a safety margin and assurance of operation.

Sensitivity of Loop and Lead-In

The sensitivity of the loop system, including the lead-in to the detector terminals, can be measured by use of a modified detector and a frequency counter or meter capable of indicating a frequency change of 0.2 percent or better.

Assuming that the circuit of the loop combinations, lead-in and detector input capacitor form a resonant circuit, and at resonance

$$\omega = 2\pi f \qquad f = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad \omega^2 = \frac{1}{LC}$$

If, L_o = equivalent inductance, no vehicle

L_v = equivalent inductance with vehicle standard (*)

f_o and f_v are the resonant frequencies related to L_o and L_v

$\omega_o = 2\pi f_o$

$\omega_v = 2\pi f_v$

$$\omega_o^2 = \frac{1}{CL_o} \quad \text{and} \quad \omega_v^2 = \frac{1}{CL_v}$$

Let,

$$\Delta L = (L_o - L_v) = \frac{1}{C}\left[\frac{1}{\omega_o^2} - \frac{1}{\omega_v^2}\right] = \frac{1}{C}\left[\frac{\omega_v^2 - \omega_o^2}{\omega_o^2 \quad \omega_v^2}\right]$$

The Sensitivity,

$$S = \frac{\Delta L}{L_o} = \frac{1}{C}\left[\frac{\omega_v^2 - \omega_o^2}{\omega_o^2 \quad \omega_v^2}\right] \times \frac{\omega_o^2 C}{1} = \frac{\omega_v^2 - \omega_o^2}{\omega_v^2}$$

$$S = \frac{\omega_v^2 - \omega_o^2}{\omega_v^2} = \frac{f_v^2 - f_o^2}{f_v^2} \quad \text{(fractional)}$$

and in % form; S x 100 = % change in inductance.

The sensitivity of the loop system is a characteristic of the loop size, connection configuration, lead-in length, and amounts of shunting resistances to ground. In order to maintain a large enough change at the detector terminals, there must be limiting values for these characteristics. Similarly, if the sensitivity can be measured against a standard unit, the operating margin can be shown. It follows that a loop system with less sensitivity than required to actuate the detector in use must be replaced.

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* A particular vehicle or simulator used as a reference for all sensitivity tests, to maintain comparison.

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STUDY PROCEDURES

The investigation of inductive loop detector functions was conducted at the General Shop "test loops installation" and at selected intersections within the City of Los Angeles. Various measurements were made on the "shop test loops," with simulated fault characteristics imposed, to determine and isolate those conditions occurring in the field that are critical to the operation of a detector system. Single loops and combinations of various loops and lead-in lengths were used to simulate field installations for the initial measurements and proving of the test instrumentation. The shop measurements were compared with field results to indicate their usefulness in analyzing detector system problems.

An initial visit was made to 41 intersections having reported loop detector problems and the main categories or failure modes were recorded. The 41 reports available covered a period of eight months and these were considered to be reasonably representative of the overall condition except where there may have been intermittent failures not discovered and reported. There were intersections noted where the detector system was apparently operating well but was observed to miss detection occasionally and can be considered marginal in operation. These marginal, borderline, or weak systems are probably the larger part of the detection problem as discussed herein, and are the reasons for the recommendation of a routine sensitivity inspection test for loop detector systems. The main categories of the 41 detector system failures and approximate percentages including multiple causes, which results in the greater than 100% total, were:

70%	Loop or lead-in wires cut by street surface operations.
20%	Erosion of street surface, missing slot filler allowing wire exposure.
17%	Inoperative from unknown causes as reported from the field.
7%	Low resistance, shorted, open from unknown cause and disconnected to allow single loop to function.

The foregoing discussion is included to point out the nature of the information obtainable by the signal repairmen using only an ohmmeter for resistance measurements and visible indications of mechanical causes of failure. Test procedures, test equipment, and a routine sensitivity test are necessary to provide the additional electrical characteristics.

Specifications for detectors, performance data, and recommended installation procedures furnished by vendors were studied, along with the experiences of signal repairmen and the measurements made in the field to indicate which system characteristics appear to have the most effect on the quality of detector systems operation. These include

- Shunt resistance to ground through the loop wire insulation.
- Sensitivity of the loop system, related to configuration and number of loops.
- Q of the loop and lead-in circuit.
- Inductance of the loop system.
- Sensitivity of the detector in operation.

The following parameters and characteristics were measured at the "shop test loops" and at selected intersections to gain insight on the values of the characteristics that would be found in the field. (Refer to Data Sheets in Appendix 6.)

- Resistance of loop and lead-in conductors to conduit ground.
- Equivalent inductance of the loop system at detector terminal end.
- Q of the loop system under operating conditions, of the lead-ins, and various combinations.
- Voltage levels on the loop circuits.
- Sensitivity of loop systems determined by the frequency shift technique, with various vehicles over a loop.

PRACTICAL APPLICATIONS

A small percentage of the over three-thousand inductive loops and associated detectors installed at intersections within the City of Los Angeles had been failing to detect the presence of vehicles. Some of these failures were not readily apparent by observation of the signal operation unless the timing was known. In these cases, an inspection of the controller and detectors was required to identify the type of malfunction.

A failure of the detection system to provide an input to the controller may be caused by an inoperative detector, intermittent operation, or detection followed by dropping of the presence indication.

Detector System Failure

An inoperative detector system is indicated by the loss of response to a vehicle over any of the system loops. Several indications appear external to the controller in the signal sequence of operation to indicate the type of malfunction.

- Signal Stuck - Lack of change of signal light indication can be caused by either non-detection or an initial detection in presence mode not being retained by the detector until the controller is ready to accept a call.
- Extends to Maximum - The actuated phase extending to a maximum time when no vehicle is present over the loops can be caused by a continuous call from the detector unit. For failsafe reasons and by design, the detector provides a continuous call output if power is lost, loops or lead-in circuit opened, or other internal failure occurs.
- Works OK Sometimes - Malfunctions of this type can be the result of a low sensitivity detector unit or loop system or a combination of both. The operation is dependent on vehicle characteristics and the number of vehicles over the loops in the particular system. A detector system that has a short presence holding time, because of low sensitivity, will operate in this manner.

Detector System Deficiencies

The analysis of an inoperative or partially malfunctioning detector system is difficult with the test equipment presently in use in the field. Substitution of other detector units and rearrangement of the loop connections has been used as a means of trouble-shooting, but this becomes a trial and error approach which requires excessive maintenance time. A means of quickly testing for operation and accurately indicating the condition of the detector system would improve the maintenance procedure and system reliability.

The characteristics of similar loop configurations at different locations were observed to have changed to the point where a single type of detector would not operate all of the installations. The causes of the changes in loop parameters need to be isolated to provide information on material and installation requirements for future construction. Availability of a single type of detector capable of use under all the conditions encountered would be desirable. Certain conditions at an intersection may preclude use of a universal detector and tests or checks should be made to assure satisfactory performance from the particular type in use.

There are loop installations presently in service where movement of the street surface, cracks across the loop slots, and loss of the slot sealing material have caused excessive insulation wear and stretching of the loop wires. The presently used types of insulation may contain small pinholes, may be easily worn away or may deteriorate rapidly in the environment of the street surface. Exposure of the loop conductor allows moisture to form a low resistance path from the conductor to the ground system. There are causes for non-operation that are obvious and clearly indicated by physical conditions such as a broken loop wire or lead-in. Some 70 percent of the loop failures noted with the Department's loops are mechanical and result from construction and repair work on or through the street surface. A second cause of wire failure is the wear on the insulation when the wire becomes exposed by surface erosion, insulation deteriorates from motor drippings, and the loop turns become shorted together.

Replacement of the loop or loop pairs has been the most expedient means of correcting an installation where the operation is not satisfactory as determined by operational checks with a standard sedan or maintenance truck. Loop replacement is an expensive substitute for an accurate test analysis. There are certain loop failures, such as a very low resistance to the ground system, and broken or cut loop wires, that can only be corrected by replacement.

Loop configurations presently in use are derivations from information supplied by vendors and measurements made on the proposed shapes by Department personnel. A specification is needed for the size, position, and number of loops to provide optimum detection coverage and maximum sensitivity of the system. The specifications for a detector unit sensitivity should indicate the worst expected values of the loop system under which the detector will be expected to operate. Loop installations with measured characteristics less than specified would require replacement. *(Note: The current Los Angeles specification prepared as a result of this study is in Appendix 7.)*

Minimum Vehicle Standard

There is no standardized test for the required sensitivity of a detector and loop system to assure detection of a vehicle having the least capability of being detected. A definition for a "minimum vehicle" to be detected is required to specify a minimum sensitivity.

Sensitivity of the loop system is dependent on the number of loops and connection configuration, length and type of lead-in, and the insulation resistance when it is very low. A test for minimum sensitivity of a loop system requires an actual minimum vehicle or a simulator that presents the same inductance change at one loop as the vehicle. A simulator that is low in cost, easily transported for use by maintenance personnel, and standardized as a reference is proposed for use at loop system installations as a routine inspection test. *(See Appendix 2.)*

Interchangeability of Detectors

All detectors presently in the Department inventory will not operate successfully at all loop installations, but must be selectively fitted to the position in order to obtain detection. There is some question as to the sufficiency of a selected unit in providing the sensitivity necessary to detect all licensed vehicles expected to use the street. Presently used tests consist of observing the operation of the detector when a vehicle passes or using a maintenance truck as a test vehicle and measuring the presence holding time. There are some brands of detectors that appear, by the above test, to have more sensitivity than others based on the increased presence holding time that can be obtained with a particular loop combination. Certain brands and/or types will not operate with adverse conditions such as very low circuit Q or a low value of shunt resistance to the conduit ground.

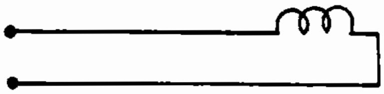
A means is required for checking detector sensitivity under typical operating conditions to assure that all new and repaired units meet the minimum specifications. Without a quantitative indication of detector sensitivity, the operation of the overall detector system cannot be assured.

Connection of Multiple Loops

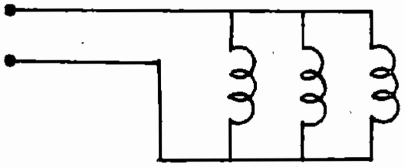
The loop configurations presently in use are based on satisfactory operation with the detectors on hand. Combinations of series and parallel connections of loops to be used with a detector have been established by theoretical considerations and trial connections and testing for acceptable operation. Acceptable operation has been indicated by a conventional sedan being detected and holding a "presence indication" for more than one signal timing cycle.

Numerous series and parallel combinations, shown in Figure 2, can be connected that will maintain an equivalent inductance within the input range of the detector. The detector circuit will tune to a reasonant frequency but may not receive a sufficient inductance change from a vehicle over one loop to actuate the output. Quantitative measurements are necessary in order to specify the loop system sensitivity or to indicate if the value for a particular system has dropped below the value required by the detector.

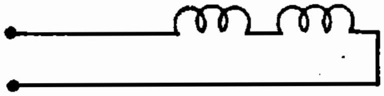
The limiting condition on a multiple loop configuration is the number of loops that can be connected while retaining more than a minimum sensitivity of the loop system. Each added loop increases the total detection area but decreases the



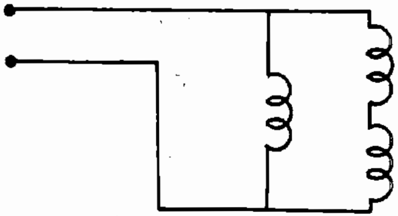
Single loop



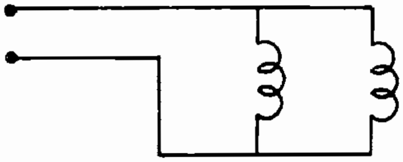
Three loops, parallel



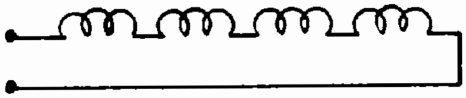
Two loops, series



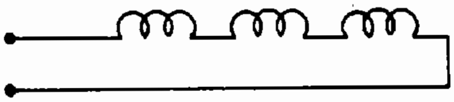
2 series, 1 parallel



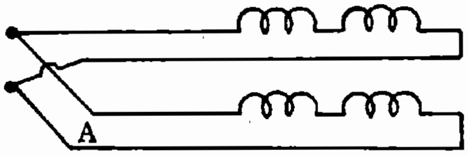
Two loops, parallel



Four loops, series



Three loops, series



2 series + Lead-in
in parallel with
2 series + Lead-in (A)

Figure 2. Loop circuit connections

system sensitivity which is dependent on the change in inductance caused at one loop area as a percent of the total loop area inductance. Where a proposed installation requires a larger number of loops or longer lead-in lengths that will reduce the sensitivity below a specified detector value, a more sensitive detector will be required.

Q of a Loop System

Investigation of the electrical parameters of a loop and detector system indicated that the quality of the resonant circuit, consisting of the loops, lead-in and input capacitor, has a direct bearing on the sensitivity, presence holding time, and reliability of the system. The quality, (Q), of the resonant circuit is measured and defined by the amount of energy loss from the circuit. The less the resistive loss, the higher the Q. The principle of operation of many of the automatic or self-tuning detectors depends directly on the slope of a frequency response curve to provide the change in signal level that indicates a vehicle detection. The effect of a low Q circuit is to flatten the response curve and make the system less sensitive.

Deterioration of Loop Wire Insulation

The investigation of inductive loop wires at several intersections where an inoperative detector was reported revealed that the insulation material on the loop wires had deteriorated or been worn away exposing bare wire. Drainage water or trapped moisture and salt accumulations in the asphalt or concrete paving had provided conductive paths to the conduit ground system. These paths effectively place shunt resistance across the loop circuit and lower the quality factor, (Q), of the parallel resonant circuit formed by the loop, lead-in, and capacitor at the detector input terminals. Operating voltage across the loop circuit is reduced to the point where the amount of change in voltage level at the detector terminals is insufficient to actuate the detector, or if actuated will not hold for the required 10-minute presence time.

Characteristics of Loop Wire Insulation

The insulation of the wire used for inductive loop construction must withstand severe environmental conditions to continue to provide the quality of inductor element necessary in a resonant detector system. A high insulation resistance must be maintained after being subjected to wear and abrasion from a shifting street surface, saturation by moisture in or standing on the surface and attack by petroleum solvents and oils.

An insulation of latex rubber with a thin jacket of neoprene has been used extensively in past years for the loop wire and this combination was noted at many of the installations investigated. There were locations where the erosion of the surface and loss of slot filling material had allowed the rubber-covered loop wires to be exposed. The neoprene jacket has been penetrated by solvents where the covering was thin from wear or had pinholes when installed. Resulting breakdown of the rubber and exposure of the conductor allowed shorting of the loop turns or when subjected to moisture would form a low resistance path to the conduit ground.

The following are some of the insulation materials that have been considered or used on loop wires installed in asphaltic and concrete street surfaces:

- Polyvinyl chloride thermoplastic (TW) usable in wet locations.
- Rubber, heat resistant, (RH); moisture and heat resistant, (RHW).
- Latex rubber with neoprene jacket.
- Polyethylene, high density or cross-linked, (XHHW or XLPE).

The cross-linked or high density polyethylene material has the desirable characteristics of being resistant to abrasion, petroleum solvents, and liquid absorption. The extruded material is dense but pliable enough to resist abrasion and has a tendency to flow together when heated, thereby avoiding pinholes. This insulation material is readily available on a stranded #12 AWG wire, rated for underground feeder uses and operation at 600 volts in wet locations, and is recommended for use. (See Specification in Appendix 8.)

Correction of a Loop System Having Low Q for Unknown Reasons

Loop replacement by pairs has been the only corrective action available if the trial of various loop connection combinations failed to provide satisfactory detection. The Q of the loops in some installations is consistently lower than can be tuned and operated by a majority of the detector units on hand and there are no obvious reasons for the low Q conditions. Consequently, there is no indication that loop replacement would improve the circuit Q and a detector capable of operating with a very low Q loop circuit is required.

A self-adjusting, fixed low frequency (35KHz), non-resonant type detector is available that will operate a low Q and low shunt resistance loop set. In this unit, the internal oscillator output is adjusted to the total inductance of the loops and lead-in and does not depend on the voltage response across a resonant circuit. Detection occurs by comparing the voltage across the inductance of the loops with no vehicle present to the smaller value resulting from vehicle presence. Use of this type detector is recommended for those loop systems where the physical condition of the slots and wire appears to be satisfactory but the Q and/or shunt resistance is less than the values required for the resonant type units. Use of the non-resonant type unit appears to be the least expensive means of obtaining detection at those locations where the Q is low for unknown reasons. (Refer to Data for N/B LT at Washington and Grande Vista, Appendix 6.) The disadvantages of the non-resonant unit appears to be the limited inductance range and price in small quantities.

Measurement of Loop Inductance

The limits of loop system inductance to which a detector unit will tune and operate are specified by the vendor for each type of unit. The inductance of a loop system must be known from design table values or actual measurements made on the installed system to assure a value within the required range of the detectors. Measurement of the inductance of the parts of a loop system combination installed at an intersection will be necessary for an analysis of reported trouble with a detector system.

The inductance of a loop and lead-in combination cannot be measured easily with readily available commercial measuring instruments. The distributed parameters of inductance, capacitance and resistance form a combination where one characteristic cannot be separated for measurement and an alternate means of equivalents and conversion charts is required.

A prototype unit shown in Figure 3, called a "Loop Test Meter" used for indicating the frequency of resonance of a loop system was designed by a detector vendor and submitted for use. The unit contains a specified size capacitor used to tune with the loop system inductance to provide the resonant frequency. The equivalent inductance is then determined from a frequency-to-frequency conversion chart or by a rough meter scale indication. Subsequently, a commercial field test unit has become available and is now used. Shown in Figure 4, it permits direct readings of loop system inductance, detector frequency, and change in inductance with passage of a vehicle. This last quantity is a measure of loop system sensitivity.

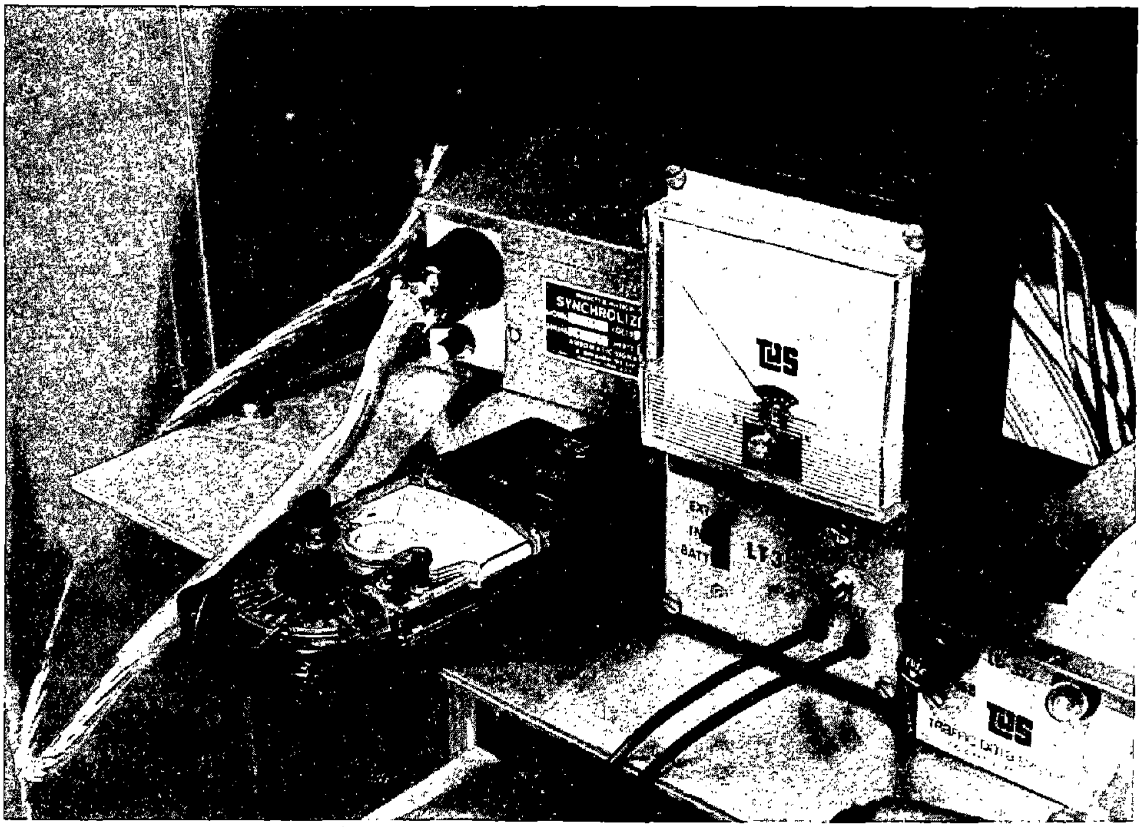


Figure 3. Equipment used for field testing loop systems

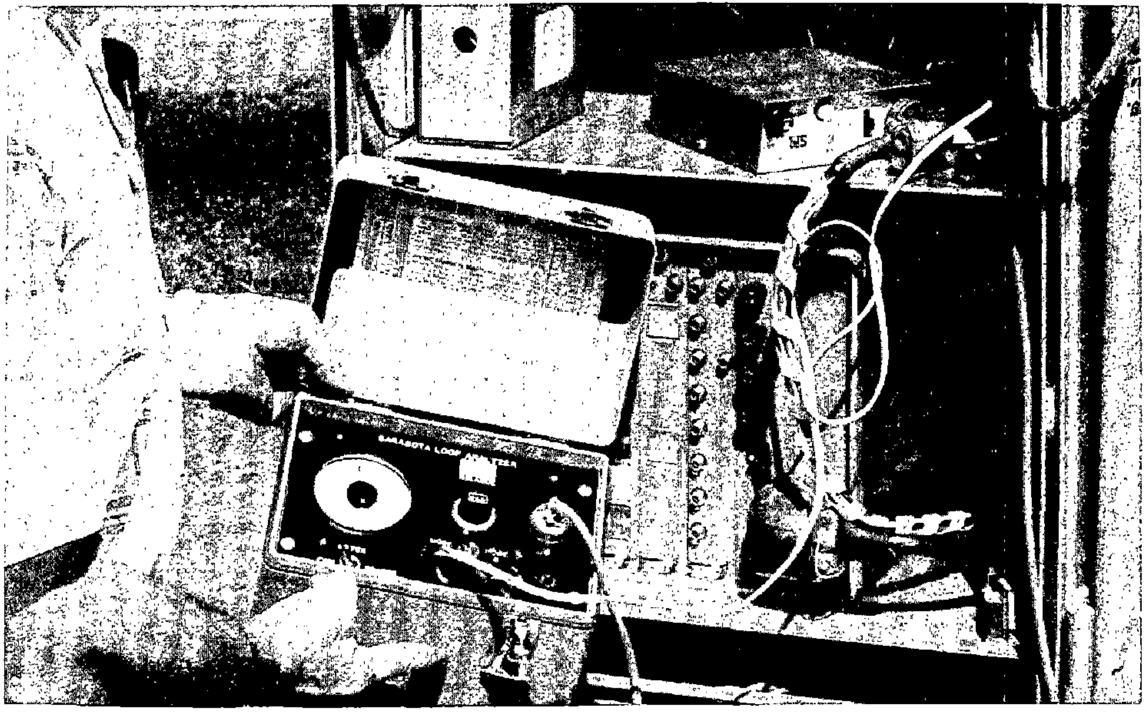


Figure 4. Commercial field test unit

Loop Size and Shape

Los Angeles - An octagonal-shaped loop, as shown in Figure 1, has been adopted by the City of Los Angeles for several reasons. The length of slot to be sawed is reduced from approximately 24 feet for a 6-foot x 6-foot square to a nominal 20 feet for an octagon (6 feet across the flats). For a 3-turn loop the required wire length is reduced from 72 to 60 feet. The smaller loop size does have less inductance, but the field distribution is more uniform across the area than compared with the square where the field reduces at the corners.

A minimum of four feet for one dimension of a loop has been indicated by several vendor test reports. The four-foot limit represents a practical minimum that will detect a majority of vehicles since the height of the zone of detection is reduced as the loop size is decreased. Other factors such as detector sensitivity have a direct effect on the class of vehicle that would be detected with the small loop.

Larger sizes of loops such as 6-foot by 30-foot along a lane have been used for greater areas of detection but the percent change of inductance (i.e., sensitivity), caused by a vehicle is reduced compared to a 6-foot by 6-foot size. A similar inductance can be provided by selection of the number of turns in either size loop but the percent change is dependent on the under surface area of the vehicle in relation to the loop area. A conventional sedan will provide a larger percent change on a 6-foot by 15-foot than two 6-foot loops with typical spacing but has a smaller effective detection area for vehicles only partially over the loop area.

Other Configurations - Considerable creativity has been demonstrated in the layout of detector loops so as to enhance their sensitivity and thus respond to a wide range of vehicles, particularly motorcycles. The traditional 6-foot x 6-foot square loop with angled corners has given way to diamond, octagon, skewed, and multitudinous other configurations. Some of these are illustrated to show the range of experimentation.

The diamond shaped loop shown in Figure 5 is actually two loops connected in series. It reportedly has greater sensitivity at its corners than does a square loop in a conventional orientation. Shifting the orientation of a conventional square or rectangular loop has produced improved results. By positioning loop corners along the lane centerline, a 30-45 degree skew alignment produces a sharply defined inductance change. With computer controlled systems, this sharp definition of presence is important to the accuracy of speed computations. When placed in adjacent lanes, this configuration produces a chevron pattern as shown in Figure 6.

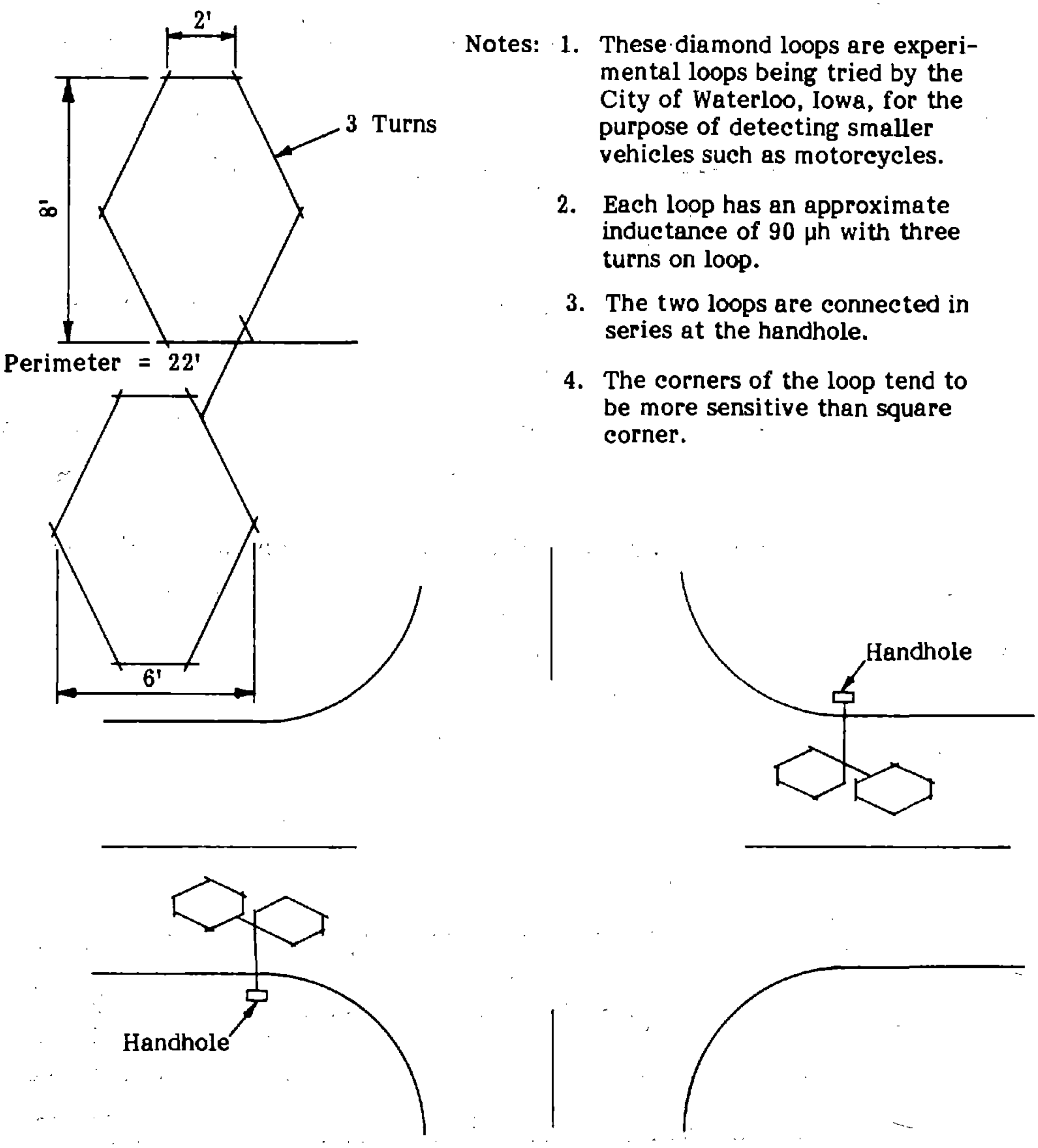
Long loops operating in a presence mode have been used to implement "loop-occupancy control" concepts. They too have progressed into configurations beyond the conventional long rectangular shape. The simple rectangular shape generally proved inadequate in producing an inductance shift sufficient to register the call of small motorcycles. One satisfactory solution is the addition of a small-loop "powerhead" at the stopline as shown in Figure 7. Others have integrated the skew concept, as shown in Figure 8, for further improvements in performance. Another variation is the use of a second powerhead at the upstream end of a long loop.

An alternative to the use of long loops to obtain vehicle presence detection over a length of roadway is the use of multiple interconnected small loops. A typical layout as shown in Figure 9 has produced detection with greater reliability, improved small vehicle detection,and more flexibility in sensitivity control.

Installation Procedures - Dealing With Pavement Joints

Many failures of the wire loop itself can be attributed to improper installation techniques. One project which has experienced an extremely low loop failure rate is the Washington, D.C., Urban Traffic Control System (UTCS). This favorable situation is attributed to the care and effort expended in developing a comprehensive installation procedure, and then employing it throughout the installation. This installation procedure is presented in its entirety in Appendix 9.

One loop installation problem perhaps warrants further discussion - installation across pavement joints. Most recommend that loops be shifted during installation to avoid pavement joints. However, there are cases where such shifts in detector locations are not possible. In these cases, the primary concern is to provide some allowance for pavement shifts at the joint due to expansion/contraction. Figures 10, 11, and 12 illustrate typical solutions to the installation of loops across pavement joints.



Notes:
1. These diamond loops are experimental loops being tried by the City of Waterloo, Iowa, for the purpose of detecting smaller vehicles such as motorcycles.
2. Each loop has an approximate inductance of 90 μh with three turns on loop.
3. The two loops are connected in series at the handhole.
4. The corners of the loop tend to be more sensitive than square corner.

Figure 5. Example of a diamond loop, (Ref. 9)

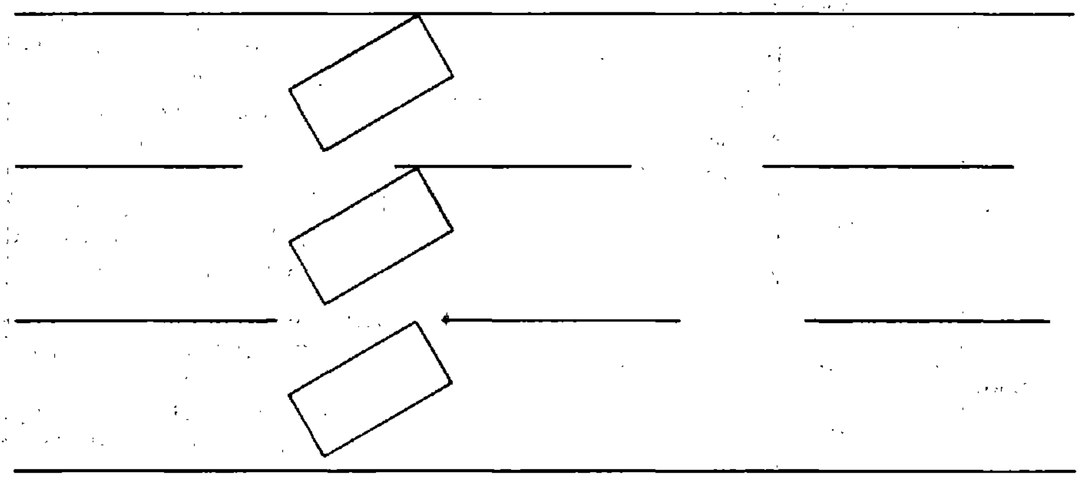


Figure 6. Diagonally oriented loops in adjacent lanes, (Ref. 10)

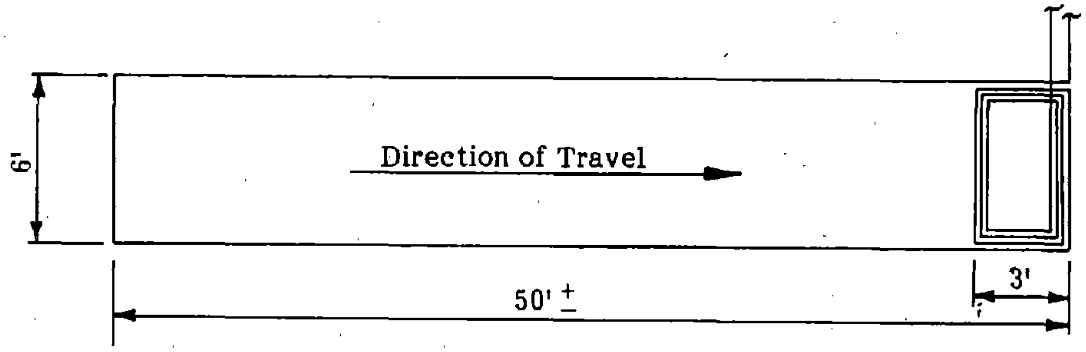
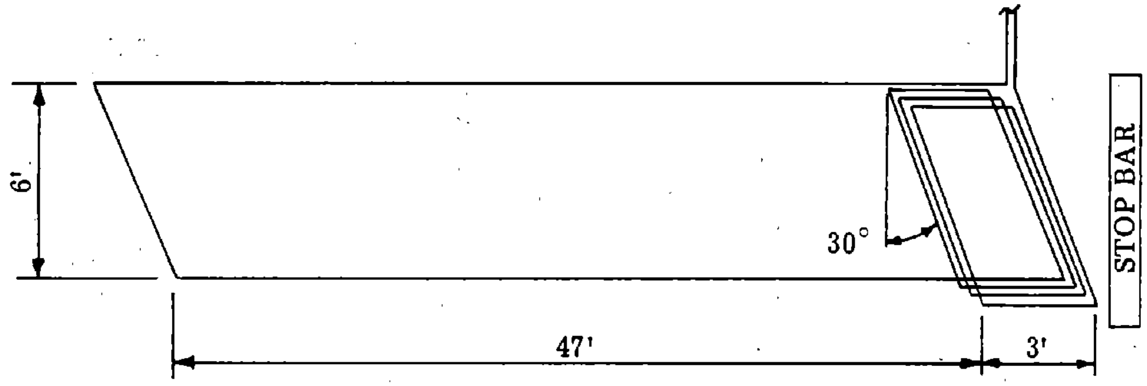
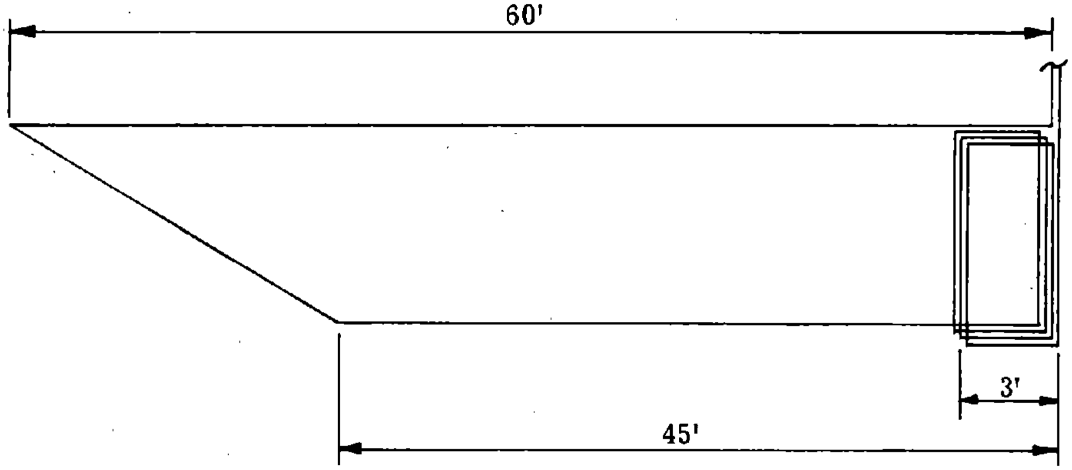


Figure 7. Long loop with powerhead

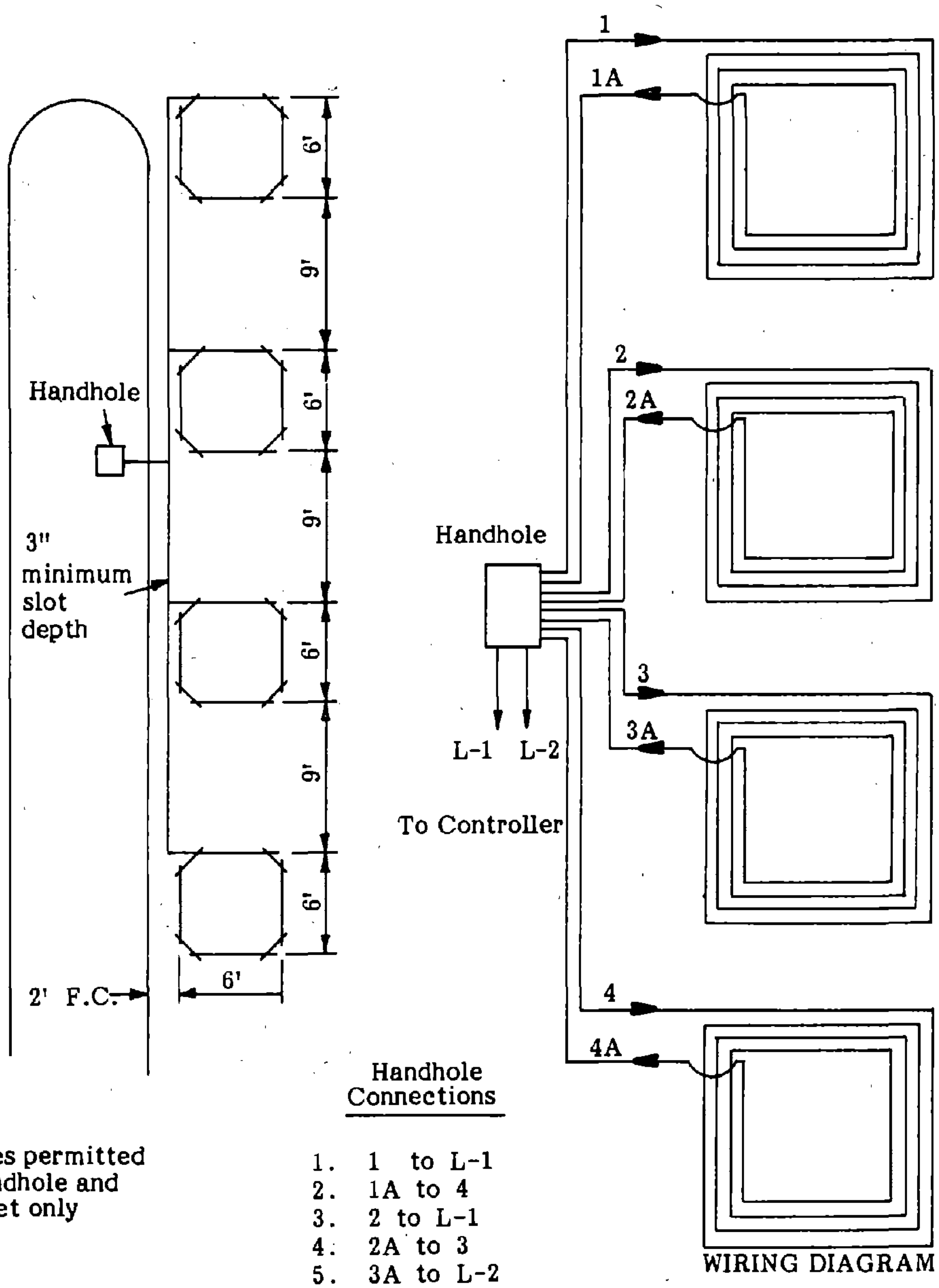


a. Angled powerhead, (Ref. 11 and 12)



b. Skewed loop, City of Arlington, Tx.

Figure 8. Skewed long loops with powerhead

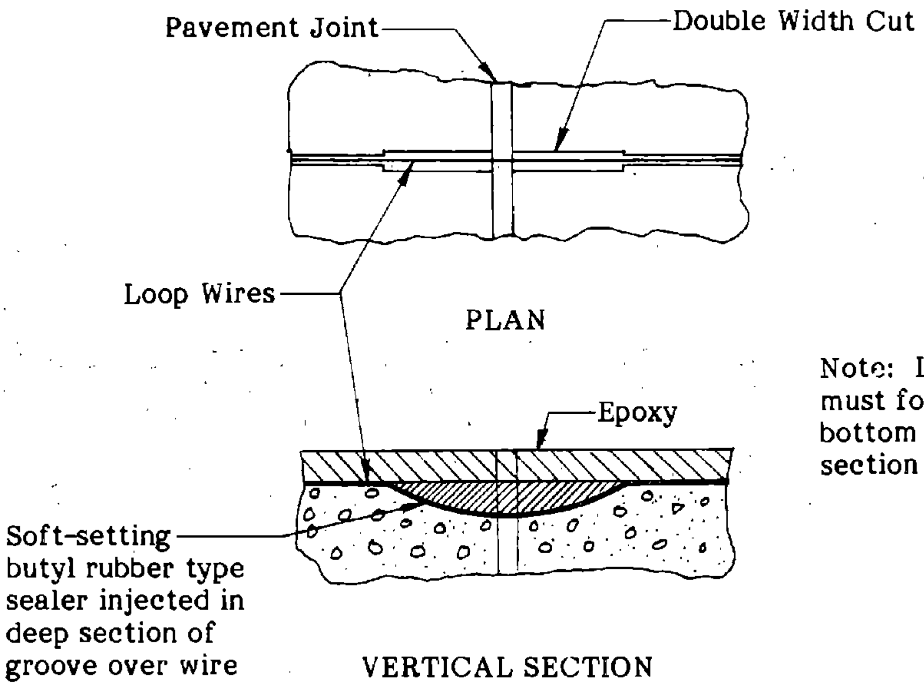


Note:
Splices permitted
in handhole and
cabinet only

Handhole Connections

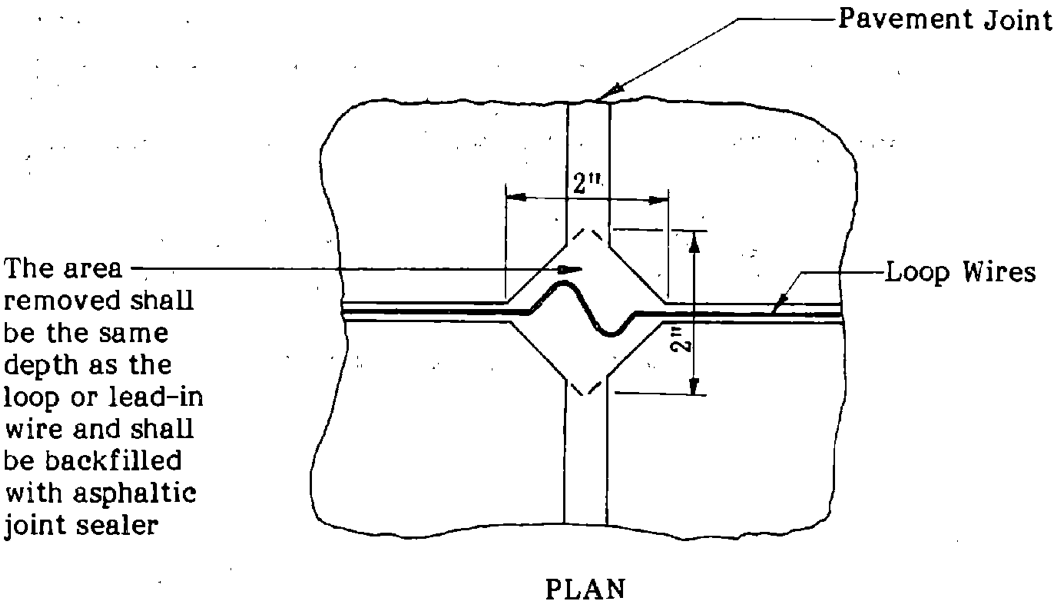
1. 1 to L-1
2. 1A to 4
3. 2 to L-1
4. 2A to 3
5. 3A to L-2
6. 4A to L-2
7. L-1 to 1 & 2
8. L-2 to 3A & 4A

Figure 9. Typical layout of multiple loops for presence detection, (Ref. 9)



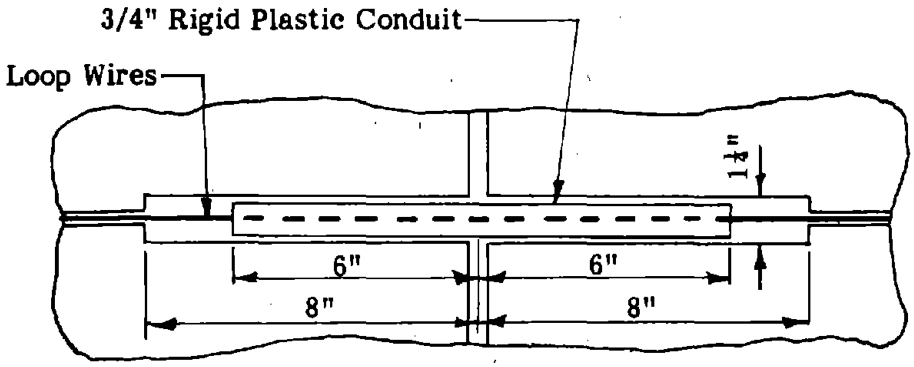
Note: Loop conductors must follow saw cut to bottom forming slack section at joint

Figure 10. Pavement joint details for loop detectors used by the State of Iowa Traffic Engineering Department

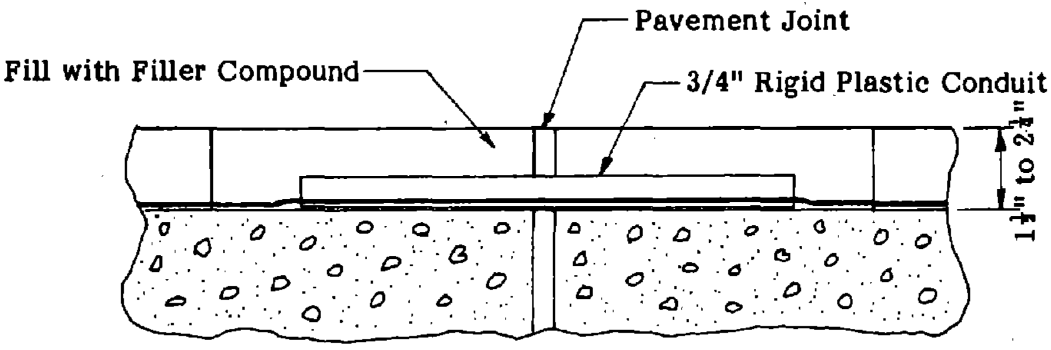


The area removed shall be the same depth as the loop or lead-in wire and shall be backfilled with asphaltic joint sealer

Figure 11. Pavement joint details for loop detectors used by the State of Oklahoma Traffic Engineering Department



PLAN



VERTICAL SECTION

Figure 12. Pavement joint detail for loop detectors used by the City of Worchester, Mass. and State of Minnesota Traffic Engineering Departments.

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TEST AND TROUBLE-SHOOTING PROCEDURE

An analysis procedure was developed for step-by-step testing of the detector system, containing specific data forms for recording the system characteristics. The information obtained from the data and analysis provide an indication of the available operating margins of the characteristics, or indicate the requirement for a particular maintenance action. The final decision on the actual maintenance to be performed is subject to Department procedures and policies. Test results provide specific information on which to base a decision.

The analysis procedure progresses from an initial visual inspection to catch broken leads or loose wires to more comprehensive tests requiring added equipment and test time. This procedure performs the shorter, less involved tests first and can be terminated when the problem is isolated to the desired extent. Portions of the procedure can be performed as required for specific information only. After making a test and analyzing the results, the data may be retained for future comparisons of the detector system operation or to show recurring causes of malfunctions.

The test and trouble-shooting procedure and data sheets for recording and calculating the characteristic values are included in Appendix 5 in a format suitable for local reproduction and distribution to technicians for field use if desired.

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STUDY RESULTS

Summary of Field Measurements

The measurements made in the field indicate that a wide range of parameter values can exist at an intersection. Refer to Table 1, Summary of Loop System Characteristics, and Sample Loop Data Sheets in Appendix 6.

The resistances from loop conductors to conduit ground ranged from greater than 10 megohms for new and some older installations, to a low of 1.5 kilohms at an inoperative detector system. The loops with measured shunt resistances less than 10KΩ appeared to be unreliable in operation, or inoperative with the type of detector requiring a resonant circuit. The circuit Q measured was typically low where the resistance was low but several low Q locations had resistances greater than 10KΩ .

The inductance values measured with the Loop Test Meter (LT-350) were within the ranges required by the detectors used since the loop circuits had been connected previously with the use of the Test Meter. Any large change in the inductance of the loop system would have indicated open or shorted loops within the system and the inductance test was included to check for such a condition.

Measurements were made for calculating the circuit Q of the detector systems where the operation was intermittent, marginal or inoperative with one type of detector. The Q values ranged from 12.0 down to 1.5, as measured with the Q Test Unit (See Appendix 3) and calculated by the bandwidth method. The higher value was obtained on two series-connected loops with a lead-in length less than 10 feet. A similar loop configuration on the opposite approach but with a lead-in length of 180 feet had a Q of 4.7, and both had shunt resistances of greater than 1.5 megohms. The Q for the above pair connected in parallel at the detector terminals was 5.5, and the presence holding time was about 3-1/2 minutes for a conventional American sedan.

The low Q of 1.5 was obtained on a long lead-in (200 feet) with a loop configuration composed of 2 octagonal 6-foot loops in series, paralleled with a second similar pair and connected to the lead-in. Insulation resistance of the combination was a low (4.7KΩ) at the detector terminals, and the loop system would only operate with a resonant type detector having a transformer coupling to the loop system. Here, the transformer serves to isolate the detector circuits from the ground system and reduces the effects of the low shunt resistance on this type of detector. Although the Q of the circuit was indicated at 1.5, the particular resonant type of detector received enough amplitude change to cause detection. This example is an exception, compared with several other similar low Q loop systems which would not tune with any of the resonant type detectors.

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TABLE I

SUMMARY OF LOOP SYSTEM CHARACTERISTICS

Location	Shunt Resistance	Equivalent Inductance	Loop Voltage	Q	Lead-in Length	Presence* Holding Time
Riverside Drive & Ethel Avenue						
S/B	> 10 MΩ	110 µh	.390	4.7	180 ft.	-
N/B	> 1.5 MΩ	150 µh	1.45	12.0	10 ft.	> 10 min.
S/B, N/B connected in parallel at detector	-	80 µh	.370	5.5	-	3'40"
Washington Blvd. & Grande Vista Ave.						
N/B LT	170 KΩ	115 µh	.240	2.3	165 ft	No operation with LD-352
N/B Thru	> 10 MΩ	385 µh	1.32	8.0	160 ft.	> 3 min.
E/B Thru	4.7 KΩ	110 µh	.20	1.5	190	No operation with LD-352 Short with AT-101
W/B LT	100 KΩ	490 µh	.43 untuned	4.5	65 ft.	Same as above
4th Street & Anderson Street						
N/B & RT	1.5 KΩ	6.7 µh	2.75	3.0	30 ft.	Same as above
S/B & RT	10 KΩ	685 µh	2.70	2.6	140 ft.	Same as above

* Checked with Conventional American sedan.

Detectors: TDS LD-352
LINK AT-101, AT-100A

Loop System Sensitivities - Calculated

Table 2 indicates the calculated change of the equivalent inductance in percent at the detector unit input terminals that can be obtained with a conventional sedan over various loop connection combinations. A nominal value of 70 microhenries (μh) inductance was used for each 6-foot, 3-turn octagonal loop, which corresponds to the Department's typical installation. The lead-in line equivalent inductance used was 22 μh per 100 feet, which is a nominal value for #8720 Belden cable installed with the shield foil connected to the system ground at the controller bus.

The sensitivities of the various loop combinations were calculated by assuming a base value inductance change of 8 percent for a conventional sedan over a single loop and calculating the percentage change reflected to the detector terminals. This change of the equivalent inductance at the detector terminals, taken as a percent of the value with no vehicle, was tabulated as the sensitivity based on the above conditions. The algorithm used accounted for variable lead-in lengths and the series-parallel loop combinations listed. The final column titled "loops only" indicates the percent change presented to the detector terminals with zero lead-in length and is included to provide a comparison of the basic loop sets. Additional sets of calculations were made for minimum type vehicles causing[1] 0.25 percent and 0.5 percent changes at a loop and are shown as part of Tables 3, 4, and 5.

Table 3 shows the maximum lead-in lengths that will be usable for the circuit configurations described, using a detector having a 0.1 percent sensitivity. For example, a vehicle that provides a change of 0.25 percent to the inductance of one loop of a series-connected pair, would be detected adequately only where the lead-in length was less than 50 feet. Where values are shown in parentheses, the changes are in percent provided at the detector terminals with no lead-in and represent a non-detection condition. To obtain detection with these conditions, a more sensitive detector would be required.

Table 4 indicates the percent change available at the detector terminals, with no lead-in length, for the indicated vehicle effect at one loop of the system.

Table 5 displays at the least percent change required from a vehicle to be detected at a loop of the system. For example, a system with two loops in series at the end of a 500-foot lead-in will require a 1.79 percent change of the inductance of one of the loops to actuate a detector with 0.5 percent sensitivity.

Bandwidth - Response Curves of Example Loop Circuits

The amplitude of the voltage responses across various loop circuits operated from the same detector unit are plotted in Figure 13 to show the relationship of the voltage levels with calculated Q values. The lower Q circuits typically have a lower voltage across the resonant circuit, as would be expected where the circuit is driven from a moderately high source resistance. A higher voltage may be obtained

TABLE 2

LOOP SYSTEM SENSITIVITIES

Loop Configurations	Lead-in (A) Length (feet)							
	50	100	150	200	300	500	750	Loops only
(1) Loop	6.91	6.10	5.43	4.90	4.11	3.10	2.38	8.00
(2) Series	3.70	3.45	3.23	3.04	2.71	2.24	1.83	4.00
(3) Series	2.53	2.41	2.30	2.20	2.03	1.75	1.49	2.67
(4) Series	1.92	1.85	1.78	1.72	1.61	1.43	1.25	2.00
(5) Series	1.55	1.50	1.46	1.42	1.35	1.21	1.09	1.60
(2) Parallel	*3.17	*2.56	2.14	1.85	1.44	1.00	.73	4.17
(3) Parallel	*1.91	*1.45	*1.17	.98	.74	.49	.35	2.82
(2) In series in parallel with (2) in series, Single lead-in	1.85	1.63	1.48	1.32	1.10	.83	.64	2.04
(2) In series + lead-in A in parallel with (2) in series + lead-in A	1.89	1.76	1.65	1.55	1.38	1.13	.93	2.04
(2) In Series with variable lead-in A in parallel with (2) in series with 50-foot lead-in	1.88	1.69	1.53	1.39	1.16	.86	.62	2.12
(2) In series with variable lead-in A in parallel with (2) in series with 200-foot lead-in	2.07	1.87	1.69	1.55	1.30	.96	.70	2.31

Octagonal loop, 6-foot across flats, 3 turn, nominal 70 μh at pullbox; expressed in (%) at detector terminals.
Conventional sedan
* Inductance less than detector requires

TABLE 3

MAXIMUM LEAD-IN LENGTHS (FEET) USABLE WITH A DETECTOR SENSITIVITY = 0.10%

Circuit Title			Vehicle Effect [1]	
			0.5%	0.25%
Single loop			1,000	400
Two	loops			
	series		750	200
	parallel		250	50
Three	loops			
	series		600	(0.08)[2]
	parallel		75	(0.08)
	2 series, one parallel		(0.08)	(0.04)
Four	loops			
	series		250	(0.06)
	2 series in parallel with 2 series distance to set A			
		50 ft.	100	(0.06)
		100 ft.	150	(0.07)
		150 ft.	150	(0.08)

---

[1] Effect of vehicle in percent of a 70 microhenry loop

[2] Loop sytem sensitivity (%) with no lead-in where the value is less than required to actuate the 0.1% detector.

TABLE 4

PERCENT CHANGE AVAILABLE AT DETECTOR TERMINALS

Circuit Title			Vehicle Effect[1]	
			0.5%	0.25%
Single loop			(.50)[2]	(.25)
Two	loops			
	series		(.25)	(.13)
	parallel		(.10)	(.06)
Three	loops			
	series		(.17)	(.08)
	parallel		(.17)	(.08)
	2 series, one parallel		(.08)	(.04)
Four	loops			
	series		(.13)	(.06)
	2 series in parallel with 2 series distance to set A			
		50 ft.	(.13)	(.06)
		100 ft.	(.13)	(.07)

[1] Effect of vehicle in percent of a 70 microhenry loop.
[2] Loop system sensitivity (%) with no lead-in.

TABLE 5

MINIMUM CHANGE REQUIRED[1] TO ACTUATE A DETECTOR WITH SENSITIVITY = 0.5%

Circuit Description			Change (%) Required at a 70 μh Loop		
		Lead-in:	100 ft.	250 ft.	500 ft.
Single	loop		.66	.89	1.28
Two	loops				
	series		1.16	1.39	1.79
	parallel		1.61	2.53	4.1
Three	loops				
	series		1.67	1.89	2.28
	parallel		2.86	4.88	8.16
	(2) in series with	Δ on series loop	4.35	6.35	9.75
	(1) in parallel	Δ on parallel	1.11	1.61	2.47
Four	loops				
	series		2.17	2.38	2.78
	2 series-parallel	50 ft.	2.38	3.18	4.76
	Distance to set A	100 ft.	2.30	3.03	4.55
		200 ft.	2.15	2.86	4.16

---

[1] For reference consider a conventional sedan providing 8% and a sports motorcycle approximately 0.25% change.

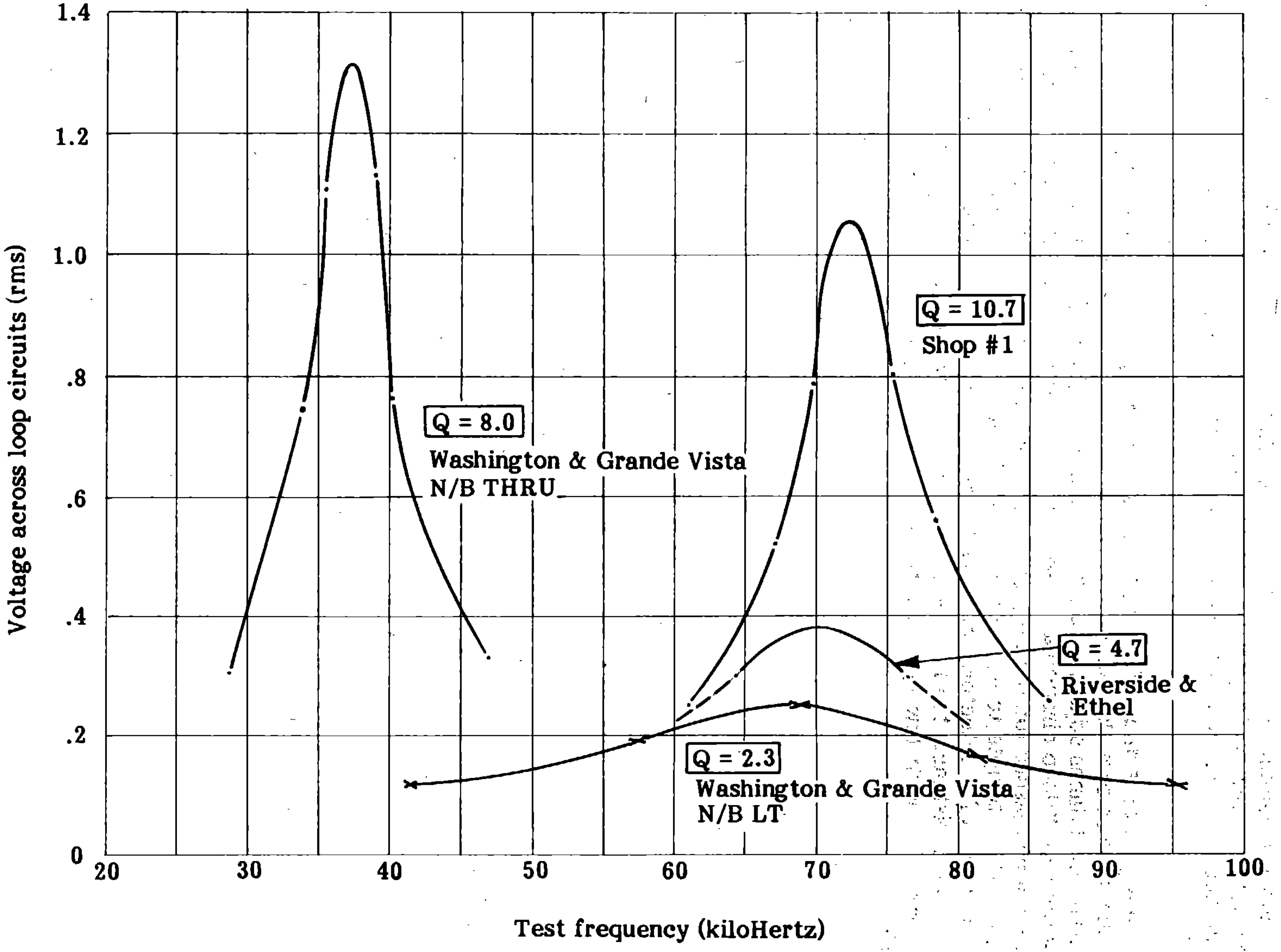

Figure 13. Voltage responses of selected loop systems

across a larger inductance loop system but the voltage is not a reliable indicator of the operating condition of the system. The Q relationship remains proportional to the inductance and resistance parameters and is normally the best circuit quality indicator.

The response curve at the low frequency end of the graph was obtained from a circuit connected to provide a large inductance value. This combination of 4 loops was located in the lanes adjacent to the circuit with a Q of 2.3. The street surface that contained both loop circuits appeared to be the same material and there were no other obvious reasons for the large difference in the calculated Q values. There have been many attempts to correct the low Q condition and the most effective appears to be use of a detector unit capable of operating with a very low Q circuit and low shunt resistance to the conduit ground. A non-resonant type detector provides operation with low Q circuits and is recommended for the above circuit conditions.

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CONCLUSIONS

The investigations of existing loop installations, shop test loop simulations, evaluations of presently used equipment, and information obtained from technical publications have resulted in the following conclusions:

1. The major cause of failure of inductive loop systems was found to be physical damage to the loop wires and lead-in lines as evidenced by 29 cases out of a sample of 41 reported failures. The damage was incurred by wires being cut during street surface repair and the wearing away of wire insulation when exposed by street surface shifting and erosion.

2. High density or cross-linked polyethylene material is recommended for use as insulation on the wire used to construct inductive loops. This material has the mechanical characteristics of being tough, resistant to abrasion and is moisture and heat-resistant. It is readily available in a 1/16-inch wall thickness, which is desirable for longer wear, and will provide the best quality insulation in comparison with other materials of similar thickness and cost.

3. The condition of the loops and lead-in in a detector system can be described by measurement of the Q of the resonant circuit under actual operating conditions. Use of a modified detector unit and the bandwidth method of measuring Q can provide a numerical index of the system condition helpful in arriving at a maintenance decision.

4. The parameters of an inductive loop detector system which must be maintained to assure consistent operation are:

    a. The insulation resistance must remain greater than 10KΩ from the loop conductors to conduit ground.

    b. The Q of the loop and detector system must be greater than 5.0, measured under operating conditions by the bandwidth method.

    c. Inductance of the loop combinations and lead-ins must remain within the specified range of the detector system.

    d. Detector unit sensitivity must remain equal to or better than a specified value.

    e. Loop system sensitivity measured at the point of connection to the detector terminals must exceed the value required to actuate the detector.

5. A malfunctioning detector system can be analyzed by use of a sequential test that progresses from a visual inspection to a comprehensive measurement of detector system characteristics. The parameter values obtained will indicate the system condition, provide information for the determination of the operating margin or a requirement for necessary corrective actions.

6. The sensitivity of the detector units must be tested before field installation using a calibrated shop test unit that provides simulated worst-case operating conditions. All units processed through the shop for repair or inspection should require the sensitivity test for final inspection and acceptance.

7. A test of an installed detector system for the sensitivity required to detect a specified minimum vehicle can be provided by a test unit that causes a known percentage change of inductance at one loop of the system. A flat sheet of aluminum of a specified size will provide the required change for use as a standardized minimum sensitivity test.

8. A detector system found to have a presence holding time less than the specification requirement of 10-minutes probably has a low sensitivity. Possible causes include a degraded detector unit, low insulation resistance shunting the loop turns or lead-in, and loop configuration which does not provide sufficient sensitivity as required by the type detector in use. Corrective actions include:

   a. Substitution of a detector with known sensitivity.

   b. Insulation resistance measurements.

   c. Analysis for Q and sensitivity of loop system.

   d. Loops and detector replacement if indicated by results of the above tests.

9. Corrective actions for loop systems that will not operate with a resonant type detector and having a shunt resistance less than 10KΩ or a Q of less than 5.0 are:

   a. Replace loops as required with polyethylene insulated wire where physical condition of the wire and slots has deteriorated.

   b. Replace the detector with a non-resonant, fixed frequency, self-adjusting detector that will operate the system at the minimum repair cost.

RECOMMENDATIONS

Based on the information obtained from observations, measurements, and technical articles, the following are recommended:

1. Use polyethylene type insulation for all loop wire repair and new installations. Adopt the proposed specifications for use in purchasing materials. (See Appendix 8.)

2. When installing loops, round off all sharp corners on saw cuts to reduce the possibility of separation of insulation due to pressure caused by environmental changes and street surface movement.

3. Standardize a sensitivity test unit representing a Minimum Vehicle to be detected and establish a test as part of the routine inspection procedures.

4. Obtain and use a shop test unit (Appendix 4) to indicate detector sensitivity for incoming inspections, repair testing, and checkout.

5. Adopt the Q Test Unit (Appendix 3) as a means of measuring the detector system Q and sensitivity which provides numerical indexes of the system conditions.

6. Use the proposed analysis procedure in the field to assess the condition of a reported maulfunctioning detector system.

7. As a last resort maintenance function, use a non-resonant type, fixed low frequency, self adjusting detector unit with loop systems having a low Q caused by unknown reasons.

8. Change purchase specifications to include a required value for detector sensitivity applicable to all types of detectors and require meeting of all operation specifications when used with a loop circuit having a Q of 5.0 or greater. (See Appendix 7 for Los Angeles specifications.)

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APPENDICES

APPENDIX 1

Test Equipment List

The following equipment was used during the investigation, as available, and does not constitute a recommended list:

1. Oscillator, Audio, Model 241, Hewlett-Packard
2. L-C Meter, Model LC 130, Tektronix
3. Oscilloscope, Model 564, Tektronix
4. Voltmeter, AC Millivolts, Model S 1053C, Motorola
5. Multimeter, Volt-ohm, Model 260, Simpson
6. Resistance decade, variable, Heath
7. Detector, Modified for Q Measurements, Model LD-352, Traffic Data Systems
8. Loop Test Meter, LT-350, Traffic Data Systems
9. Counter, Digital Frequency, Model 521C, Hewlett-Packard
10. Aluminum Sheet, Octagonal, 30 inches flat to flat, 18-inch diameter center hole
11. Megohmmeter

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APPENDIX 2

Minimum Vehicle Simulator

A simulator unit intended for use in making field sensitivity tests was constructed from a 30-inch flat to flat octagonal piece of 3/32-inch thick aluminum and represented a "minimum vehicle standard." An 18-inch diameter hole was cut through the center to form, effectively, a shorted single turn which could be positioned in the center of an inductive loop to provide a known percent change of the loop inductance. The unit described was not calibrated for a standard but caused an inductance decrease of approximately 0.3 percent or roughly 1/20 of the change provided by a conventional American sedan over 6-foot square and octagonal loops. Various other sizes of sheets could be calibrated to operate with the usual 6-foot loops in common use and a simulator for the least detectable vehicle could be standardized as a "go" or "no-go" test for routine sensitivity inspections.

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APPENDIX 3

A Test Unit for Measurement of Loop Circuit Q

An analyzer and means of measuring the circuit Q appeared to be necessary to adequately describe the condition of a loop and lead-in system at intersections having reported erratic or poor operation. The most readily available unit that could be adapted as an analyzer and yet maintain the same operating conditions in the loop system was one of the detector units.

A detector unit was converted to a variable frequency oscillator by substituting a manually-controlled voltage for the automatic tuning voltage. The driver circuit remains intact and presents the same conditions on the loop circuit as when in the self-tune mode. By adjusting the control voltage and monitoring the resultant frequency, the resonant frequency is indicated when the voltage across the loop terminals is at maximum. The driver unit can be adjusted above and below the resonant frequency, to where the voltage across the loop circuit is reduced to 70.7 percent of the resonant value and the bandwidth is the difference between these upper and lower frequency points. Used in conjunction with a digital counter to determine frequency and an AC voltmeter, the modified detector provides a portable test unit for Quality Factor (Q). The Q of a loop circuit can be easily determined by measuring the resonant frequency, determining the bandwidth and calculating from:

$$Q = \frac{\text{Frequency of resonance}}{\text{Bandwidth}} = \frac{f_{\text{res.}}}{\text{B.W.}}$$

A form entitled "Inductive Loop Characteristics, Quality (Q)" is proposed for recording the values obtained at loop systems around an intersection. (See Figure 16.) The results of the measurements and analysis can be retained for reference purposes or later performance comparisons for an installation with unusual conditions.

A block diagram of the Q test unit is presented on the following page.

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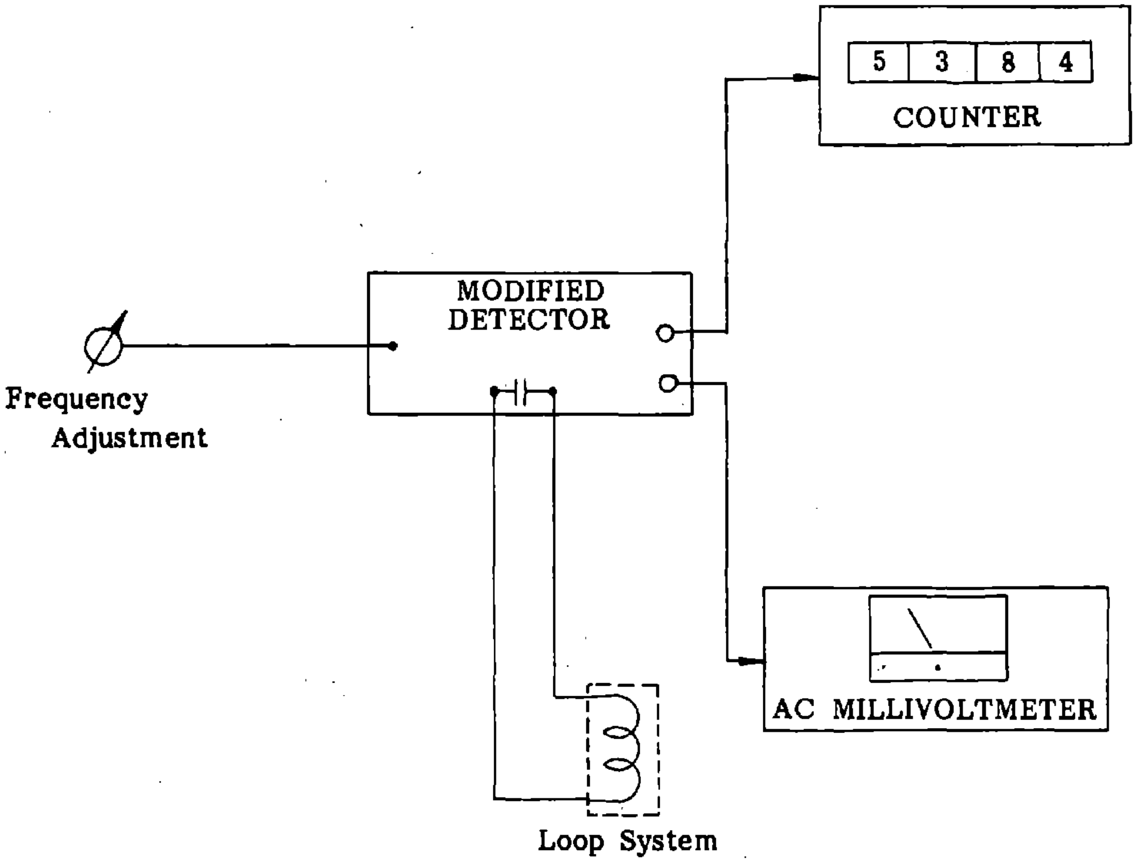
Q TEST UNIT



Detector: TDS LD-352-R
Operating Modes:

Internal	-	Normal detector, monitors loop voltage and frequency.
Q Test	-	Provides a variable frequency for resonance and bandwidth measurements.

Frequency Range:	30 KHz to 100 KHz
Input and Output:	Operates in place of the usual detector or may be adapted.

APPENDIX 4

Bench Test Loop

A commercial unit is available that will provide switch selected inductors in the range from 22 μh to 700 μh. The Q of the inductors has been artificially degraded to simulate the poor Q of a loop installed in a roadway. An aluminum plate, mounted at calibrated distances from the inductor winding plane as shown in Figures 14 and 15, provides reproducible changes from 0.02 percent to 2 percent of the inductance when moved into a position parallel to the plane of the inductor. In operation, the metal plate is rotated over the inductor to simulate a loop with a vehicle present; swinging the plate 180 away simulates no vehicle. The percent change can be reduced until a detector unit will no longer actuate to obtain the minimum sensitivity of the unit under test.

The availability and cost of the test loop unit is reasonable enough to make it desirable for use as a shop test unit for maintenance and acceptance testing.

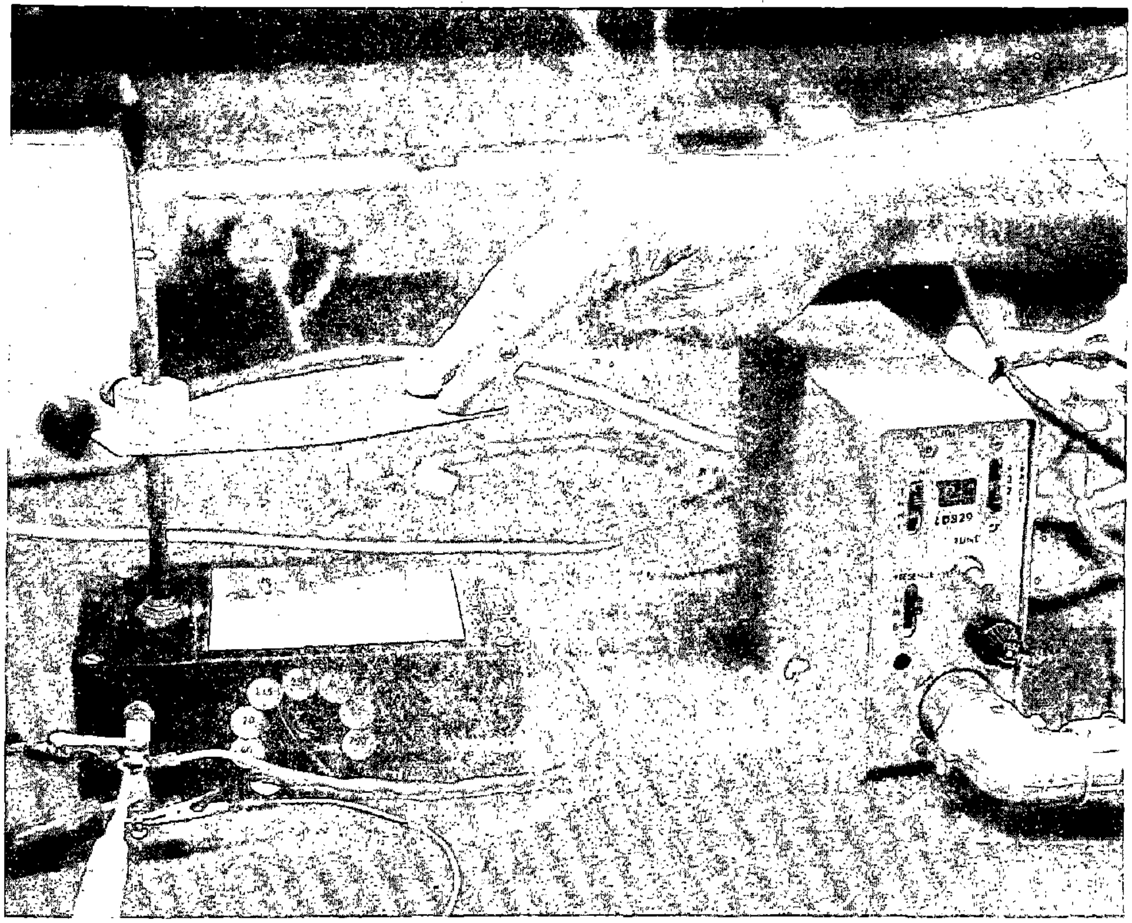


Figure 14. Shop test unit with simulated vehicle.

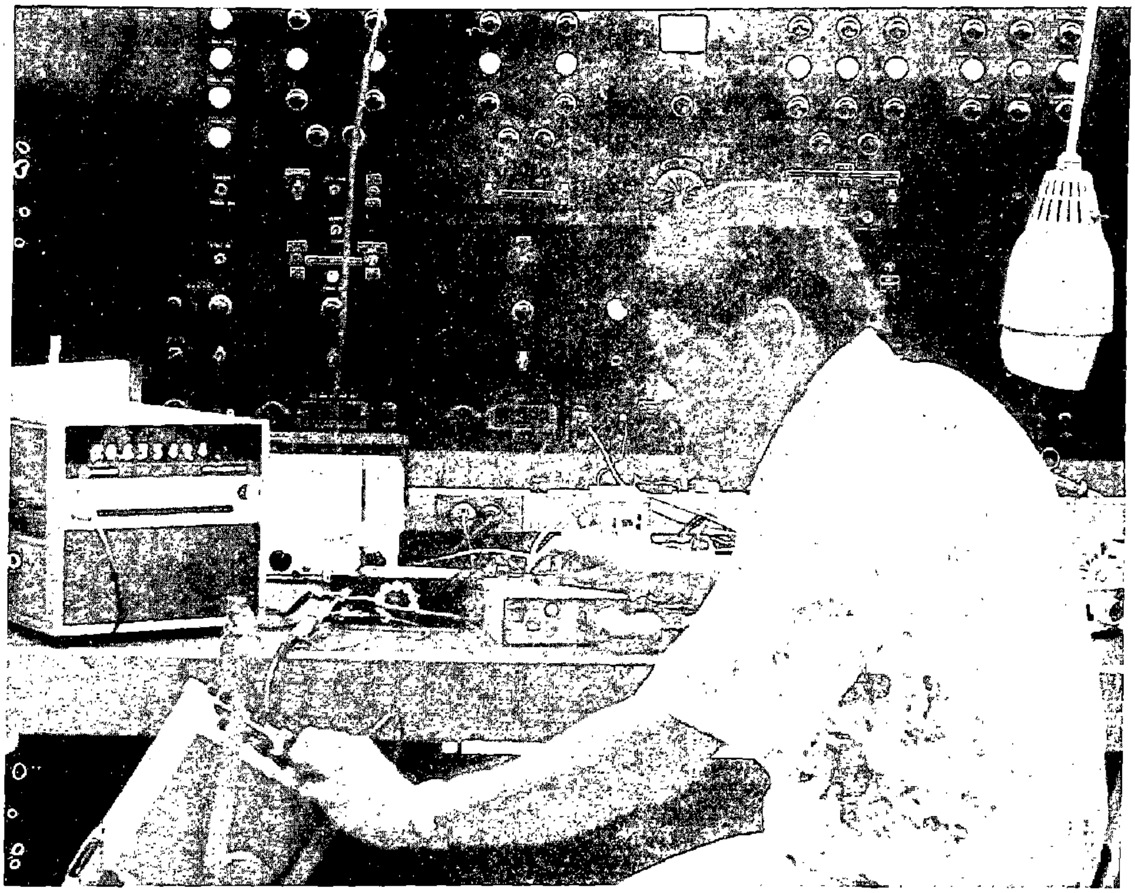


Figure 15. Shop testing a detector unit for sensitivity

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APPENDIX 5

INDUCTIVE LOOP DETECTOR SYSTEM TEST AND TROUBLE-SHOOTING PROCEDURE

A test and trouble-shooting guide for use by Signal Maintenance Personnel

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INDUCTIVE LOOP DETECTOR
SYSTEM TEST AND TROUBLE-SHOOTING PROCEDURE

EQUIPMENT REQUIRED

1. Ohmmeter, battery operated.
2. Voltmeter, AC millivolts, high impedance input to 100 KHz.
3. Counter, digital frequency, input impedance > 50 KΩ to 200 KHz.
4. Q Test Unit.
5. Loop Test Meter, LT-350.
6. Data recording forms for Q and Sensitivity.
7. Vehicle simulator (Sensitivity Standard).

PROCEDURES

The following tests performed sequentially should isolate the causes of a detector system being inoperative or having erratic operation.

1. Visual Inspection

   Check for indications of broken or cut loop or lead-in wires. Check for open leads within the controllers and for availability of power to the detector.

2. Substitution

   Replace the existing detector unit with one having a known sensitivity to rule out the existing unit as a cause. If the system operation is not considerably improved, remove the detector unit and continue step (3).

3. Measure and record the following on the QUALITY (Q) Data Form (Figure 16).

   a. With the detector disconnected and power removed from the loop, measure the resistance from either loop terminal to the bus or conduit ground. Record as (R_p). Check for series continuity between the terminals.

   b. Measure the inductance of the loop system with the Loop Test Meter, LT-350, attached to the controller tie points with the detector disconnected. Record the frequency (f_{LT}) and the inductance L (μh).

4. Q Determination

   a. Attach the Q Test Unit to the existing cable and plug or adaptor cable as required.

   b. Connect the AC voltmeter and digital frequency counter to the Q Test Unit to read loop voltage and frequency in KHz.

   c. Adjust the frequency for maximum voltage across the loops; record the frequency as (f_r) and the voltage across the loops as (E_{loops}).

   d. Adjust the frequency higher and lower to obtain the frequency points having 70 percent of the resonant voltage value. Record these as higher (f_h) and lower (f_l).

   e. Calculate and record the bandwidth and compute Q =

   $$B.W. = (f_h - f_l); \quad Q = \frac{fr}{B.W.}$$

5. Sensitivity measurement of loop system

   Record the frequencies obtained from either of the following methods on the SENSITIVITY DATA Form (Figure 17).

   Method I:

   a. Set the function switch to "Q MEAS." on the Q Test Unit.

   b. Adjust the frequency to obtain resonance and record as ($f_{res.}$).

   c. Record the reference number of the Sensitivity Standard to be used and place this simulator or vehicle on the desired loop.

   d. Retune the frequency to the new resonant point and record as (f_2).

   e. Calculate the sensitivity as indicated on the data form.

   Method II:

   a. Set the function switch to "INTERNAL," and the mode switch to "S" on the Q Test Unit. Allow the detector to tune downward in frequency to the "lock-on" point. Note the frequency and record as ($f_{res.}$).

   b. Place the Sensitivity Standard on the desired loop and note the new lock-on point frequency. Record as (f_2).

   c. Calculate the sensitivity as indicated on the data form.

6. Complete the analysis by comparing the values obtained for each of the system characteristics with the acceptable limits listed on the Loop Trouble-Shooting Chart, Table 6 Determine the required maintenance from the suggested corrective actions.

QUALITY (Q)

LOCATION: ____________________ DATE: ____________

DESCRIPTION: ____________________ BY: ____________

Position	Connection	E_{loops}	f_{LT}	L(μh)	f_r	f_h	f_1	B.W.	Q calc.	R_p	Remarks

Analysis:

f_{LT} = frequency of Loop Test Unit LT-350; f_r, f_h, f_1 for resonance, high, low.

Bandwidth (B.W.) = $(f_h - f_1)$; Q calculated = $(f_r/\text{B.W.})$; R_p = resistance to conduit ground.

Figure 16. Data form - Quality (Q)

SENSITIVITY (S)

LOCATION:____________________ DATE:__________

DESCRIPTION:____________________ BY:__________

Loop Position	Sensitivity Standard	Frequency (KHz)			Sensitivity S (%)	Presence Minutes	Remarks
		$f_{res.}$	f_2	$f_2^2 - f_r^2$			

Analysis:

$f_{res.}$ = resonant or tuning frequency; f_2 = loop frequency with test standard or vehicle.

$S(\%) = [(f_2^2 - f_r^2)/f_2^2] \times 100 \simeq$ the change in inductance in per cent.

Figure 17. Data form - Sensitivity (S)

TABLE 6

LOOP TROUBLE-SHOOTING CHART

Characteristic	Indicated Condition	Suggested Corrective Action
Loop wire	Broken, cut Insulation worn away	Install new loops at a position shifted by 6" and assure that each previous loop is cut at least twice.
Loop slots	Filler missing Wire exposed Surface eroded	Clean slot of loose material and refill or replace entire loop and lead-in as required above. Street surface patch if loop wire is not exposed.
Resistance to ground	10KΩ or more Less than 10KΩ Shorted	Acceptable if Q is greater than 5.0. Replace resonant detector with non-resonant type. Replace affected parts of required.
Series loop resistance	Open circuit Greater than 3Ω	Locate and correct open circuit. Isolate cause of high value and delete.
Q	Greater than 5.0, R_p>10K Greater than 5.0, R_p<10K Less than 5.0, Any R_p	Acceptable with resonant detector units. Replace detector with non-resonant type. Same as above.
Sensitivity of loop system	Measures lower than design chart value for the configuration	Consider Q, shunt R_p , and series R as possible causes and correct as indicated. Determine loop interconnection and rework to accepted design values as required.
Sensitivity of detector	Remains actuated Does not actuate Insufficient sensitivity	Substitute known serviceable detector Substitute known serviceable detector. Substitute and return unit removed to shop.

The limits placed on the characteristics are nominals determined from this investigation and may require modification with additional experience.

APPENDIX 6

SAMPLE LOOP DATA SHEETS

INDUCTIVE LOOP DATA

LOCATION: Riverside Dr. & Ethel Ave.

DATE: 6-22-71

DESCRIPTION: (2) 6 ft. Octagonal each side S/B & N/B Ethel
Semi-actuated, presence mode

BY: Allen - Bailey - Smith

No.	Loop Tester		Resistance		Q Measurement					Loop E	Remarks
	Freq. KHz	Induct	Series	Shunt	f_r	f_h	f_1	B.W.	Q	(rms)	Loop Connections
1,2	70	110µh	1.3 Ω	>10 MΩ	70.0	77.5	62.6	14.9	4.7	.390	(2) parallel; 180' #8720 Lead-in
3,4	58	152	.4 Ω	>1.5 MΩ	59.0	61.5	56.6	4.9	12.0	1.45 v	(2) series; <10' #8720 Lead-in
1,2 // 3,4	84	75	–	–	85.0	92.7	77.3	15.4	5.5	.370	(2) series S/S; (2) parallel N/S; in parallel at detector
3,4 S/S					(2) Series only w/ lead-in						Holds presence 1 min.-10 sec, w/30" sign on loops
1,2 // 3,4					(2) Series + 10 ft. lead-in // (2) parallel + 180 ft lead-in						Holds presence 3 min.- 40 sec, w/ Sedan (Valiant) N/S

INDUCTIVE LOOP DATA

LOCATION: General Shop DATE: 6-25-71

DESCRIPTION: 6' Octagonal, #4 loop, Center Lane BY: Allen

No.	Loop Tester		Resistance		Q Measurement					Loop E	Remarks
	Freq. KHz	Induct	Series	Shunt	f_r	f_h	f_1	B.W.	Q	(rms)	Loop Connections
1	68	115	.4Ω	200 K	68.0	71.2	63.9	7.3	9.3	.95v	Series (R_s) added None
2				-	68.0	73.1	62.3	10.8	6.3	.66	R_s = 2Ω
3				-	68.0	75.0	60.8	14.2	4.8	.52	R_s = 4Ω
-											
4	68	115	.4Ω	200K	68.0	71.7	64.5	7.2	9.4	.97v	Added Shunt (R_p) None
5				-	68.0	72.0	64.3	7.7	8.8	.90	R_p = 5KΩ
6				-	68.0	73.2	63.2	10.0	6.8	.70	R_p = 1KΩ
7				-	68.0	74.7	61.9	12.8	5.3	.56	R_p = .5KΩ
8				-	68.0	79.5	58.6	20.9	3.25	.32	R_p = .2KΩ

INDUCTIVE LOOP DATA

LOCATION: Riverside Dr. & Woodman Ave.

DATE: 7-8-71

DESCRIPTION: (2) □ in LT Pocket; (2) in 2 Thru Lanes, Similar all approaches

BY: Allen - Bleibaum

No.	Loop Tester		Resistance		Q Measurement					Loop E	Remarks
	Freq. KHz	Induct	Series	Shunt	f_r	f_h	f_1	B.W.	Q	(rms)	Loop Connections
EB LT #1	58	160	.3 Ω	4 KΩ	58.0	69.0	46.2	22.8	2.5	240	(1) loop only w/lead-in Inop w/6 Pack AT-100
#2	64	130	.3Ω	20 KΩ	64.3	69.6	57.3	12.3	5.2	.320	(1) loop only w/lead-in Oper. w/ 6 Pack
EB LT #1	–	138	–	–	62.5	70.7	55.2	15.5	4.0	.290	At pull box, no lead-in
#2	–	115	–	–	68.3	73.5	63.3	10.2	6.7	.590	At pull box, no lead-in

INDUCTIVE LOOP DATA

LOCATION: Washington & Grand Vista Ave. DATE: 7-28-71

DESCRIPTION: (4) Octagonal ea. LT Pkt; (4) Octag. ea. 2 Thru Lane BY: Allen - Bailey
Fully actuated, Quad

No.	Loop Tester		Resistance		Q Measurement					Loop E	Remarks
	Freq. KHz	Induct	Series	Shunt	f_r	f_h	f_1	B.W.	Q	(rms)	Loop Connections
N/B LT	68	115	-	170 KΩ	68.0	82.2	52.6	29.6	2.3	240 v	2s//2s ; TDS will not tune AT-101 used, Marginal
					-	95.9 180.0	42.3 19.3	- -	- -	.5 E_L .25 E_L	No obvious reason for low Q
N/B Thru	38	385	-	>10 MΩ	37.5	39.5	34.8	4.7	8.0	1.32 v	(4) Series TDS tunes OK
					-	41.2	33.1	- -	- -	.5 E_L .25 E_L	-
E/B Thru	70	110	-	4.7 KΩ	69.5	88.7	41.3	47.4	1.5	.20 v	(2) Series // (2) Series TDS No Tune; AT-101 used
					-	110.0 ×	28.0 ×	- -	- -	.5 E_L -	Exceeds freq. range
W/B LT	33	490	-	100 KΩ	33.0	37.1	29.7	7.4	4.5	.430	(4) Series No tune on TDS LD-352

INDUCTIVE LOOP DATA

LOCATION: Shop Loops #1 & 2

DATE: 7-28-71

DESCRIPTION: 6' Octagonal, Polyethylene Insul.; Jetcoat West of 50' Loop

BY: Allen - Bailey

No.	Loop Tester		Resistance		Q Measurement					Loop E	Remarks
	Freq. KHz	Induct	Series	Shunt	f_r	f_h	f_1	B.W.	Q	(rms)	Loop Connections
1	73	86	-	>10 MΩ	72.6	76.3	69.5	6.8	10.7	1.07 v	(1) Loop w/20' lead-in to shop #8720 - New inst'l. 7-23-71
-						78.8	67.3			.5 E_L	
-						86.1	61.3			.25 E_L	
2	74	85	-	>10 MΩ	74.3	77.8	71.0	6.8	10.9	1.12 v	As above, slightly less lead-in
-						80.2	69.0			.5 E_L	
-						87.5	63.0			.25 E_L	
	Excellent example of a new installation and parameters.										

SENSITIVITY (S)

LOCATION: Riverside Dr. & Ethel Ave. DATE: 6-22-71

DESCRIPTION: (2) 6 ft. Octagonal, N/B Ethel BY: Allen - Bailey

Loop Position	Sensitivity Standard	Frequency (KHz)			Sensitivity S (%)	Presence Minutes	Remarks
		$f_{res.}$	f_2	$f_2^2-f_r^2$			
S/S 3,4	30" Alum.	59.00	59.08	9.45	0.27	1m - 10sec.	Min. Veh. Std. (Proposed)
1,2 N/S 3,4 S/S	Amer. Sedan	85.0	85.70	119.4	1.63	3m-40sec.	Valiant, City Veh. on N/S loop

Analysis:

$f_{res.}$ = resonant or tuning frequency; f_2 = loop frequency with test standard or vehicle.

S (%) = $[(f_2^2-f_r^2)/f_2^2]$ x 100 ≃ the change in inductance in per cent.

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APPENDIX 7

CITY OF LOS ANGELES
DEPARTMENT OF TRAFFIC

Specification No. 92-038-07 September 25, 1972

For: Detector, Vehicle, Inductive Loop, Automatic Tuning or Tracking

I. GENERAL

The purpose of this specification is to describe minimum acceptable design and operating requirements for a vehicle detector which will be connected to a wire loop buried in the roadway so that the presence of vehicles moving or standing over the loop may be detected.

II. OPERATION

A. Pulse Mode

With the mode selection switch in the PULSE position, the detector shall provide one output pulse (switch closure), having a pulse width of 50 to 500 milliseconds, for each vehicle passing or stopping over the loop.

When a vehicle is stopped over, or near the loop, so as to be within the area of detection, the detector shall be able to detect other vehicles passing through, or stopping over, the area of detection within one-and-one-half seconds after the detection of the first vehicle.

B. Presence Mode

With the mode selection switch in the PRESENCE position, the detector shall provide one output pulse (switch closure), for each vehicle passing over the loop, or when a vehicle is stopped over the loop, for a minimum of three minutes. When a vehicle remains over the loop long enough to cause the presence feature to time out, the detector shall again respond to both moving and stopped vehicles within one-and-one-half seconds.

III. DESIGN REQUIREMENTS

A. Operation

1. General

The detectors shall be designed to operate with loop and lead-in wire combinations having a wide variation in electrical characteristics.

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The electrical characteristics are a function of the length and width of the loop, the length and type of lead-in wires, and other factors. The detector shall operate with the usual configurations of loops and lead-in wires, standard with the Department, which have a 70 to 300 microhenry total inductance.

The detector shall provide reliable detection and maintain an output indication for a period of not less than three (3) minutes for a vehicle that causes a 0.02% change in the total inductance of the loop and lead-in system as measured at the detector loop input terminals. The detector shall provide operation as above with a loop system having any or all of the following characteristics:

(1) A shunting resistance of 10,000 ohms or greater to a common or circuit ground bus.

(2) A loop system quality factor (Q) of not less than 5.0, when connected to the detector being tested. Q is defined as the ratio of the resonant operating frequency over the half-power bandwidth.

(3) A total or equivalent inductance within the range of 70 to 300 microhenries at the detector loop input terminals.

A sensitivity adjustment or selector shall be provided to allow selection of a high, medium, or low sensitivity adjustment. Increments shall include: High - .02%, Medium - .06 ± .01 Low - .125 ± .025%.

2. Loop Energizing and Detector Sensing Circuits

The detector shall provide reliable detection of licensed motor vehicles. The detector shall provide an output (switch closure) only when vehicles are passing or stopped over the loop and shall detect all vehicles passing over the loop at speeds up to 80 miles per hour.

When first turned on, while tuning, or being tuned, the detector shall provide a continuous output pulse (switch closure), plus a visual indication, in both the presence and pulse modes of operation. On power failure, or loop failure that would cause the inductance to exceed the tuning range, the detector must place a continuous call.

The detector unit must be tunable with or without traffic passing over the loops and must meet the sensitivity and presence requirements with a warm-up period not to exceed ten minutes.

The detectors shall be suitable for counting, or detecting, vehicles in each of two or more parallel ten-foot traffic lanes, without mutual interference, using six-foot octagonal loops (spaced ten feet between centers), one in each lane, connected to separate detectors.

The operation of the detector shall not be affected by changes in the inductance of the loop caused by environmental changes, such as rain, hail, snow, temperature, humidity, nor shall the sensitivity be markedly affected.

3. Accuracy

The accuracy of the detector shall be ± 2 counts per 100 vehicles when the detector is used to count traffic.

4. Operational Test

The detector unit will be operationally tested on a loop system consisting of:

(1) Two 6-foot, 3-turn octagonal loops 8 feet apart, connected in series, with 150 feet of twisted pair lead-in (Belden #8720).

(2) Two 6-foot, 3-turn octagonal loops 8 feet apart, connected in series, with 100 feet of twisted pair lead-in (Belder #8720).

(3) Each pair of loops and lead-ins to be paralleled at the detector terminals.

B. Detector Output

The detector output (switch closure) to the associated traffic control equipment shall be provided by means of a relay. The relay shall have a mechanical life of at least 1,000,000 operations. The contacts shall have a rating of at least 1.0 ampere at 120 volts ac or dc.

C. Power Supply

The detector shall be designed to operate on a 110-commercial 60-hertz power line over a voltage range of 100-125 volts. The primary of the power supply transformer shall be fused with a 1/4 inch diameter, 1-1/4 inches long, 250 volt fuse of suitable current rating. An extractor-post fuse-holder shall be provided. The fuse rating shall be marked by the fuseholder.

D. Visual Indicator

A light shall be used to provide a visual indication of each vehicle detection. Lamps shall be easily replaceable without the use of tools. The indication must be readily visible in indirect sunlight.

All indicator lights shall have a minimum design life of 20,000 hours at rated voltage unless an ON-OFF switch is provided to control the lights. If an ON-OFF switch is provided, the design life of the lights need be only 10,000 hours at rated voltage.

E. Dielectric Strength

The detector shall withstand a dielectric strength test of 1,250 volts, 60 hertz per second, ac applied between the 120 vac line-supply circuit and the terminals for the external loop for a period of one minute.

F. Interchangeability and Design Life

All modules and components of the same type shall be interchangeable. The design life of all components, under conditions of normal operation, shall not be less than five years.

VI. ENCLOSURE

A. General

A dustproof, metal enclosure shall be provided to enclose all electrical parts of the detector. The enclosure shall be designed for placement on a shelf in a weatherproof field cabinet. The detector shall not be position sensitive.

B. Detector Units

Detector units shall be designed for use with loop combinations (two or four loops in series or parallel or series-parallel). The detector model shall have a visual indication of a call and will not require external equipment for tuning or adjustment.

C. Size

A small size enclosure and the ability to stack the enclosures, one on top of another, is desirable. Single detector units shall not be larger than 6 inches by 3 inches by 8 inches deep.

D. Marking

Each detector shall be marked with the manufacturer's name, model, catalog, or type number, and serial number. The electrical input rating (voltage, frequency, and wattage) shall be included in the marking.

V. INPUT/OUTPUT RECEPTACLE

A. Function Assignment

Input and output connections for the detector shall be made to a type MS-3102-A-18-1P box receptacle with 10 male contacts. A plastic cover shall be provided on the receptacle. The pin positions of the input/output connector shall be assigned as follows:

Pin No.	Function
A	120 vac (-)
B	Output Relay Common
C	120 vac (+)
D	Input from Loop
E	Input from Loop
F	Output Relay
G	Spare
H	Chassis Ground
I	Spare
J	Spare

B. Plug and Cable

A plug, type MS-3108-B with Type 18-1S insert, with 10 female contacts shall be furnished, wired, with leads of #18 AWG stranded, color-coded wire with 300 volt insulation. A type MS-3057-10 cable clamp and boot shall be provided for strain relief. The leads shall be 5'-0" in length, the first 16 inches of leads, from the plug, shall be enclosed in cotton braiding. No terminals are required on the leads.

VI. COMPONENTS

A. Inductors and Transformers

All inductors and transformers shall have their windings insulated and shall be impregnated to exclude moisture. All wire leads shall be color coded.

B. Resistors and Capacitors

All resistors and capacitors shall be insulated and shall be marked with their resistance or capacitance value. Resistance and capacitance values may be indicated by the Radio Electronics Television Manufacturer's Association (RETMA) color codes. All electrolytic capacitors shall be marked to indicate polarity and voltage.

C. Printed-Circuit Boards

All printed-circuit boards shall be at least 1/16 inch thick and shall be made of glass-cloth silicone, National Electric Manufacturer's Association (NEMA) type G-10 glass epoxy or equivalent. The conductor material shall be copper, 0.0027 inch thick, having a weight of 2.0 ounces per square foot, with a protective solder coating. All printed-circuit board connectors (male and female) shall be gold plated over the copper base. The printed-circuit boards shall be securely mounted in such a way as to prevent flexing or bending of the boards, and shall be easily removable for servicing or replacement.

D. Wiring

All interconnecting wire shall be insulated #22 AWG or larger, suitable for 180° F operation.

E. Solid State Circuitry

Transistors, integrated circuits, or semiconductor diodes shall be used for all amplifying, detecting, rectifying, counting logic, and regulator circuits. No vacuum or gas tubes shall be used except for pilot lights. Transistors, integrated circuits, and diodes shall be marked with their type number and shall be types listed by the Radio Electronics Television Manufacturer's Association (RETMA). No electromechanical timers, synchronous motors, or relays shall be employed, except as specified in Section III-B.

All electronic and electrical components must be of standard manufacture and available from a source other than the manufacturer of the loop detector unit.

No modifications to the circuit, parts substitutions or changes in the function or form from the original bid sample item shall be allowed without prior approval of the Engineer.

F. Temperature

The temperature of components shall not cause any appreciable reduction in component life when the detector is operated in an ambient temperature from 20°F to 180°F.

VII. WORKMANSHIP

The enclosure and all modules shall be fabricated, assembled, and wired in a workmanlike manner.

VIII. WIRING DIAGRAMS

Wiring and schematic diagrams, descriptive parts lists, and instruction and maintenance manuals shall be provided for all items furnished under these specifications. Equipment or unit modifications as approved must be accompanied by revised diagrams with the first shipment of the modified units. Tables, charts, or equations for use in designing loops of various sizes and configurations shall be provided. Five complete sets of diagrams, manuals, etc., shall be furnished with each order. In addition, one complete set shall be furnished for each ten pieces of equipment.

IX. GUARANTEE

All units and all component parts shall be guaranteed against all defects in materials and workmanship for a period of not less than two years from date of installation, except as noted below. Following delivery, each unit will be tested for compliance with the specification and then stored by the Department until installed. A record will be kept of the original installation and the subsequent history of each unit. The supplier will be responsible for return and replacement costs of any materials or equipment found to be defective within the guarantee period, including labor, freight, shipping and delivery costs. All electrical equipment, components, and workmanship shall conform to the standards of the National Electrical Manufacturer's Association or to the Radio Television Manufacturer's Association, whichever is applicable. All equipment returned under the guarantee shall be replaced within 30 days of receipt of vendor. The guarantee shall terminate three years after delivery date, or two years after the installation date, whichever occurs first.

X. INSPECTION

Prior to awarding of contract, the vendor may be required to furnish detailed drawings and samples of the bid items for inspection. The detailed drawings and samples, if required, shall be delivered, within 10 working days after the bids are opened. The vendor shall be responsible for the following:

1. The delivery of drawings and sample to the Department's General Shop, 430 Commercial Street, Los Angeles, California 90012.
2. All shipping, freight, and delivery charges incidental to the sample items.
3. The return of such samples and drawings, if required. Samples furnished shall not constitute any part of a delivery under any Purchase Order issued under these specifications.

IV. PACKAGING

All wire shall be provided in minimum single lengths of 2,500 to 3,000 feet spooled on non-returnable reels. Each reel shall be marked with the Purchase Order Number and date, the nominal number of feet on the reel, and the title, "Wire, #12 AWG, Stranded, Polyethylene."

APPENDIX 8

CITY OF LOS ANGELES
DEPARTMENT OF TRAFFIC

Specification No. _____

For: Wire, Single #12 AWG Conductor, Stranded Polyethylene Insulation

I. PURPOSE

The purpose of this specification is to describe an insulated wire for use in constructing inductive loops in a street surface.

II. WIRE CONFIGURATION

The single #12 AWG conductor shall consist of 7 strands of tinned copper wires, covered with a uniform thickness insulation material.

III. INSULATION

A. Material

Insulation material to be type USE, high density or cross-linked polyethylene, free from voids or pinholes.

B. Thickness

Wall thickness of insulation to be a nominal 4/64 inch (.065) and of uniform density around the conductor; overall diameter to be .205 inch ±.020 inches. Minimum spot thickness shall not be less than 70 percent of the nominal thickness.

C. Voltage

Wire shall be rated for 600 volt applications.

D. Leakage Resistance

Insulation leakage resistance shall be 200 Megohm/1,000 feet, minimum or better, when tested at 500 vdc from the conductor to a conducting metallic plate.

E. Temperature

The insulation shall have a usable temperature rating of + 75° C for underground service entrance and wet applications.

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APPENDIX 9

DETECTOR INSTALLATION PROCEDURE

A reproduction of Appendix 2, Field Installation Methodology of Induction Loop Detectors for Traffic Surveillance and Control, from Urban Freeway Surveillance and Control: The State of the Art, by Paul F. Everall, June 1973, pages 165-175.

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APPENDIX 2

FIELD INSTALLATION METHODOLOGY OF INDUCTION LOOP DETECTORS FOR TRAFFIC SURVEILLANCE AND CONTROL

INTRODUCTION

Since the inductive loop is one of the most common types of traffic sensors used in freeway surveillance and control systems, this section was developed to present the procedures for installing the loop detector system. Basically, the inductive loop detector consists of a few turns of wire embedded in the roadway pavement; the wires are connected to an electronic component located in a cabinet at the side of the road. The detector is designed so that the passage of a vehicle over the loop in the pavement modifies the magnetic flux around the resonantly tuned loops of wire, thereby increasing or decreasing the inductance so that a change in resonant frequency, impedance, amplitude, or phase shift is detected by the transistorized roadside unit, and it is transmitted to an amplifying or relay circuit.

The loop detector can be used either as a presence or a pulse-actuating sensor. However, when a vehicle stops and remains in the detection zone, the detection of the vehicle's presence is lost after a period of time and other vehicles passing within the detector zone will be sensed. Departure of a stopped vehicle from a loop does not produce another detection count. The holding (detection) time depends on the magnitude of the electronic detection voltage which in turn is related to the loop size, the vehicle type, and its position in the loop. Figure 117 shows diagrams of various loop-detection installations.

PRELIMINARY PREPARATIONS

The preliminary preparations for making loop installations should include the development of a scale drawing of the roadway which will show the location and content of conduit, manholes, power sources, pavement materials, and the electrical equipment that may be involved or may interfere with the loop installation. These plans should show the exact size and the materials involved for each loop to be installed.

It is recommended that an on-site inspection be made of each location both before and after the loop installation drawings are prepared. This on-site inspection is needed in order to determine:

1. Exact location and number of loops.
2. Exact size of each loop.
3. Type of equipment needed for the particular installation.
4. The exact location of power manholes.
5. The nearest source of water for cooling the saw.
6. The required electrical tie-ins.
7. The location of the roadside equipment cabinet.
8. The strategy for burying feeder cables, by sawing, trenching, rodding, tapping.
9. The position and quantity of barricades according to the specifications in the jurisdictions.
10. The methods for routing traffic around the location during installation.
11. The best period of the day or night for making actual installation.

Checks must be made to insure that the proper permits, licenses, insurance, etc. (requirements vary for each jurisdiction) are obtained by the responsible agency before the installation is initiated.

Specific preparations must be made regarding the programing of personnel and equipment required for installing loops. The following equipment determinations and acquisitions must be made:

1. Determine and obtain the required flagmen, barricades, signs, cones, etc., to conform to the specifications of the jurisdictions where the installations will occur.
2. Obtain an adjustable template or straight edge for drawing outline of loops on the pavement. See figure 118.
3. Acquire a self-propelled power saw with diamond blade or abrasive saw blades that will be used for sawing pavements to the length, depth, and width shown in figure 119. The power saw must be equipped with a depth measurement device, water valve, and guide.
4. Supply splice boxes for connecting loop lead-in to feeder cable fig. 120.
5. If needed, acquire a drill for boring 1-in. hole through curb for conduit to hold lead-in wire to splice box (fig. 121).
6. Locate a water supply (whether it be hydrant or water truck) to keep diamond blade cool and to clean slots.
7. Obtain an air compressor for cleaning out the sawed slots.
8. Acquire small trenching machine for burying cable in dirt.
9. Procure equipment for tapping holes in manholes.
10. Obtain equipment for rodding cable in conduit.
11. Acquire sealer for the saw cut (a type is Bondo Corp. Flexible Embedding Sealer Type P-606, fig. 122).
12. Procure concrete for setting splice box in place.

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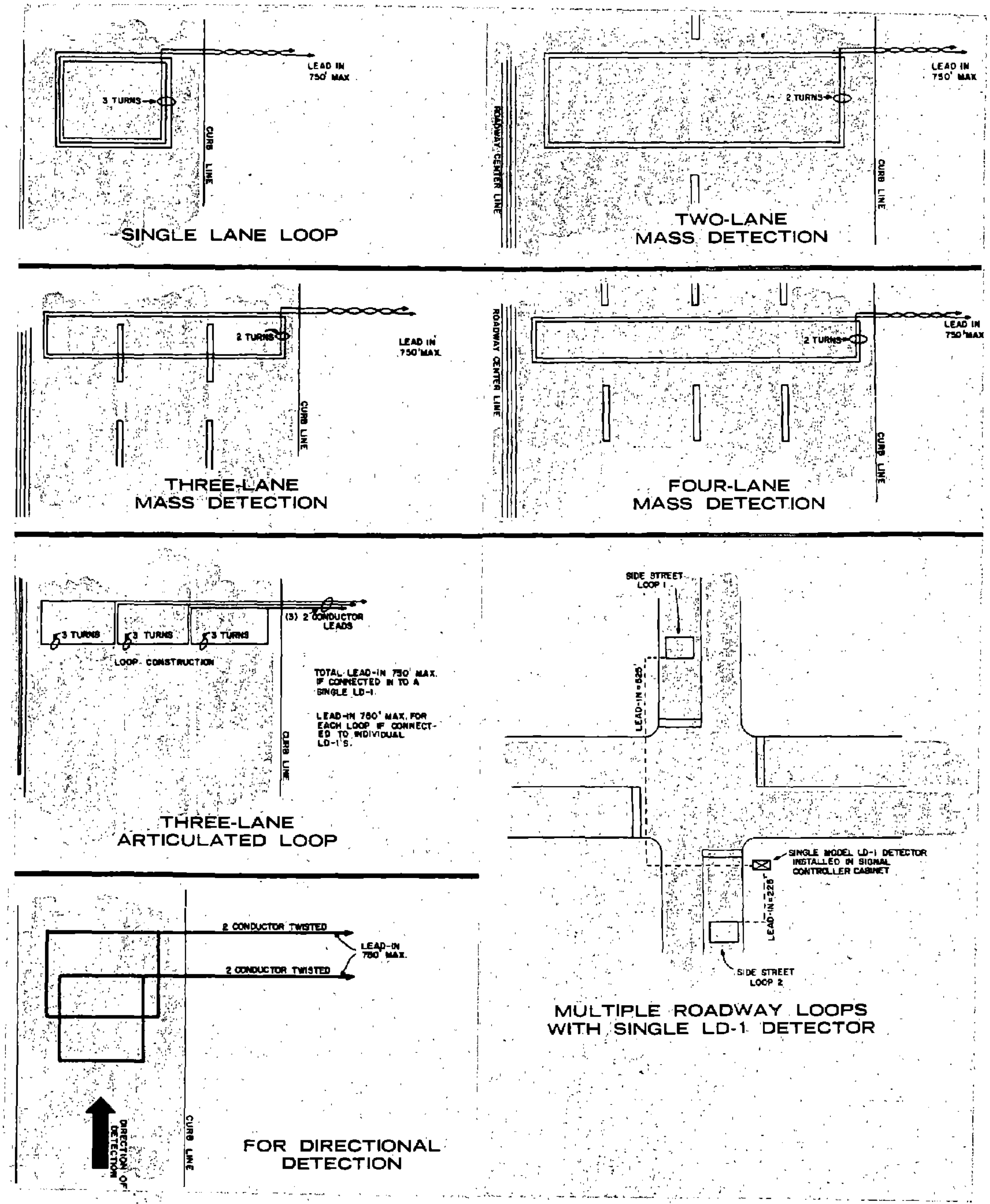


FIGURE 117.—Various loop detector installations.

FIGURE 118.—Template for layout of loop detector.

13. Obtain utility construction equipment for burying cable for long lead distances in the shoulder of the highway (fig. 123).

14. Obtain a 110-V gasoline generator or other power source for making solder connections and for splicing, and furnish auxiliary lighting for nightwork.

15. Acquire all-weather electrical tape and adhesive coating for splicing feeder cable and lead-in wire in splice box (fig. 124).

16. Procure loop wire—XHHW #14 AWG stranded, single conductor (Vulkene or equivalent), feeder cable—suitable coaxial cable.

17. Obtain a Megger meter for checking integrity of loop insulation (fig. 125).

18. Acquire a loop tester for checking continuity and inductance of loop (fig. 126).

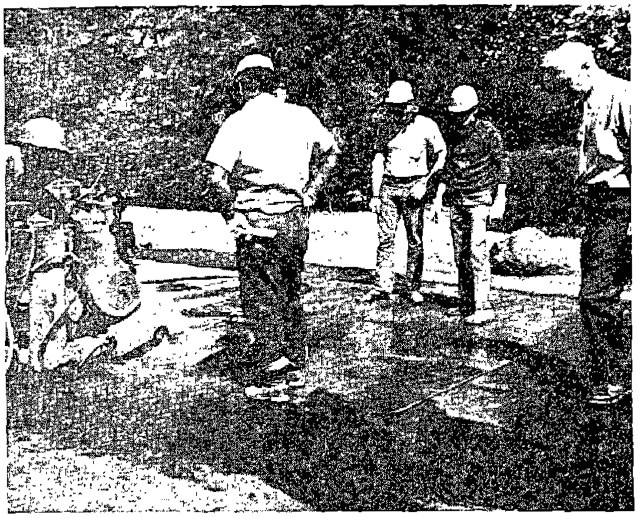


FIGURE 119.—Self-propelled saw for cutting pavement.

The manpower requirements for making loop installations must be met. The following is an itemized listing of the time and labor required for a typical loop installation:

Crew	*Work performed*	*Time*
3 laborers	Set up traffic control	20 min.
3 laborers	Layout road cut for loop	5 min.
3 laborers	Cut slot for 6- by 6-in. loop with 20-ft. lead including setup and tear down time	1 hr. 5 min.
3 laborers	Clean slots	5 min.
3 laborers	Install loop wire in slot and clean up	20 min.
3 laborers	Dig hole for splice box and drill curb for conduit, install splice box, backfill, concrete and finish	2 hr. 30 min.

Many of the tasks mentioned above can be performed simultaneously, thus reducing the amount of manpower and time. Also, this is assuming that only one loop is being installed. If there were more than one in the same area, there would be an overall reduction in manpower and time per loop.

INSTALLING THE LOOP

General

The proper installation of the loop is of the utmost importance. The wires, being underground, are subject to deterioration from chemicals in the soil, water, rodents, and damage from shifting of pavement, frost, and improper installation procedures.

Interruption of the normal flow of traffic should be held to the minimum time necessary for installation of the road loop. To accomplish this, a checklist should be completed and work should not begin until all material, equipment, and personnel are at the site.

Barricades, warning signs, nad flagmen must be deployed to protect the workers and the traveling public.

Planning

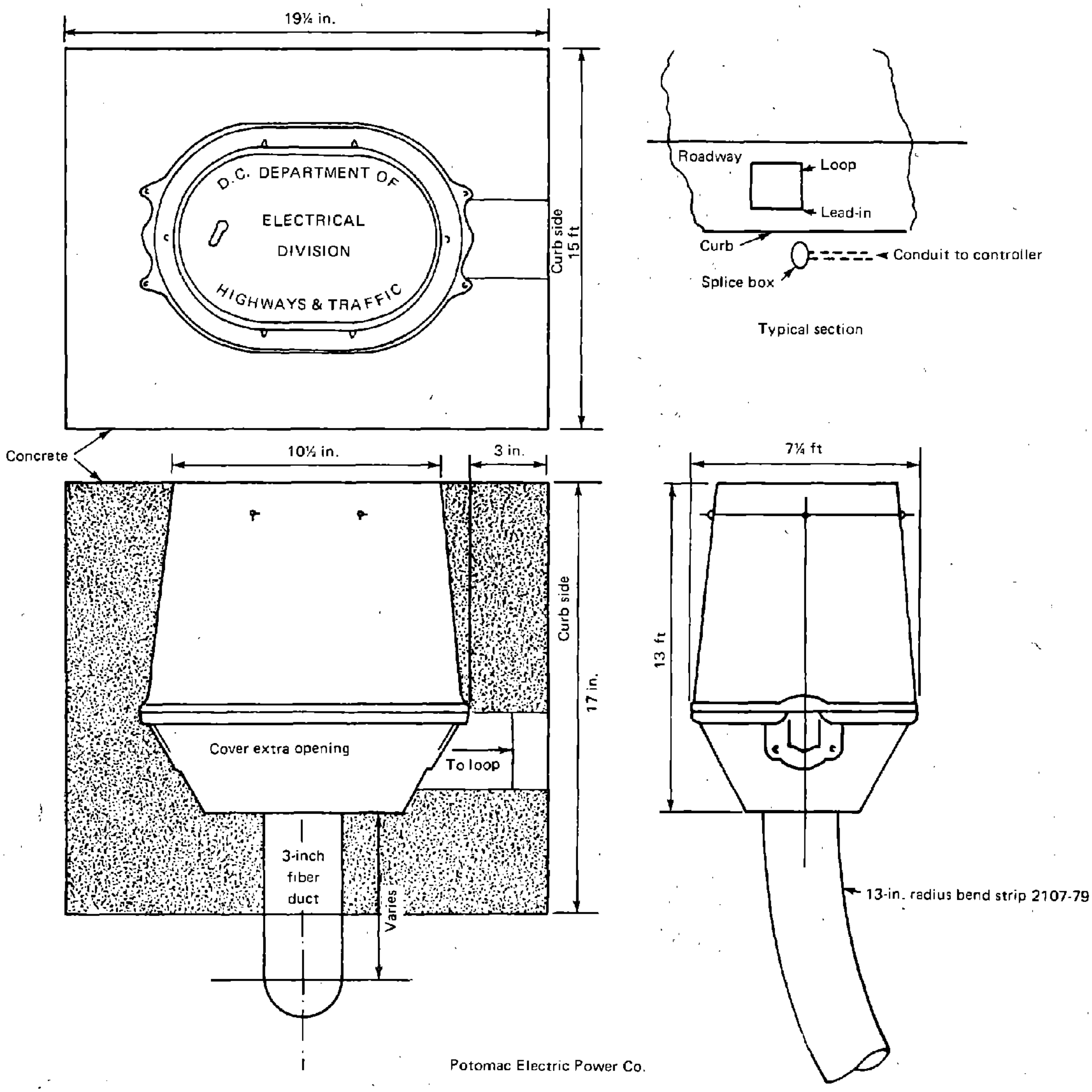
This task involves the review and familiarization of drawings, installation procedures, and materials to be utilized in advance of actual installation. Planning and scheduling of daily operations should be accomplished well in advance of the actual installation for the purpose of material availability, agency notification, and manpower loading.

Any detector installations at the same location should be performed concurrently.

Layout

The installation begins with marking the layout of each loop on the pavement. Care should be exercised to place the loop at the designed location, perpendicular to the roadway lane and to make it the proper size to assure the detection of all vehicles using the lane. The layout can be facilitated by using a template of the proper size and shape and marking the pavement with lumber crayon or spray paint to guide the saw. The loop should conform to the dimension required with overlap cuts as shown in figure 127.

The loop to splice box lead-in dimensions will vary with each site; however, figures 128 and 129 show an example of how they can be run.



Potomac Electric Power Co.

FIGURE 120.—Splice box.

Curb Entry if Required

This task refers to the coupling of the splice box to the lead-in saw cut (fig. 128).

The chase from the saw cut to the splice box should extend no more than 1 ft. from the curb. The chase should be made by means of a punch or drill-type tool rather than by the usual excavating methods.

Conduit should be utilized from the splice box to its intercept with the saw cut. The visible portion of the curbing should not be cut for conduit installation.

Conduit should be installed so that it directly receives the lead-in wire, in-line, and not at an angle. The hole to receive the conduit should be sufficiently below the roadway surface so that there is a minimum of 2 in. of cover on top of the conduit, when installed. The top 2 in. of the cover over the conduit hole should be of the same sealant used to close the saw cut.

The conduit installation should be accomplished at the same time as the splice box installation.

Saw Cut

The sawing of slots in the pavement is accomplished using a self-propelled power saw equipped with a diamond blade or abrasive blade, the diamond blade proving to be much faster and longer lasting. Both types of blades require a

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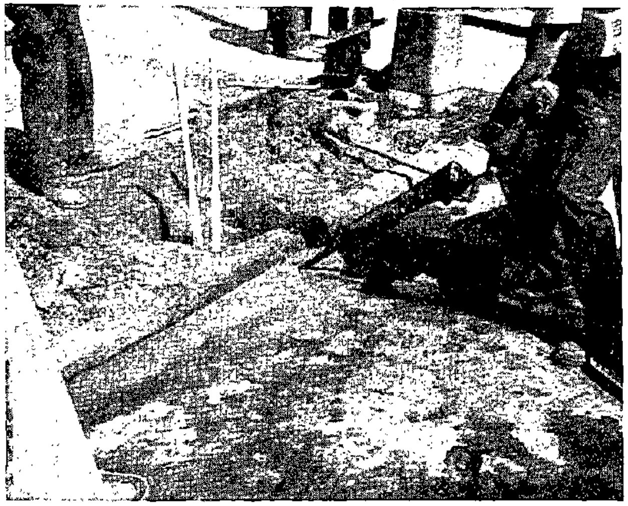


FIGURE 121.—Drill for boring hole through curb.

constant water supply which is used as a lubricant and coolant for the blade. The saw must be equipped with a depth gage and horizontal guide to assure the proper depth and alinement of the slot. Care should be exercised during marking and sawing of slots to avoid alinement deviations that require resawing. The extra slot may weaken the pavement and cause a failure.

The diamond blades to be utilized for the saw cut shall provide a clean, well-defined $\frac{5}{16}$-inch-wide saw cut without damage to adjacent areas. The saw-cut depth shall be at least $1\frac{3}{4}$ in., but must not exceed 2 in. (fig. 129).

FIGURE 122.—Placing of sealer in slot.

The saw cuts shall be overlapped to provide full depth at all corners. All slots requiring a right-angle turn of wire shall be cut at a diagonal (see fig. 127) to prevent sharp wire bends.

Slots may be cut ahead of wiring and wood strips inserted in the slot, or a protective panel placed over the slot, to prevent shrinkage or damage (fig. 130).

Cleaning of Saw Cut

Prior to the installation of wire, the saw cuts should be checked for the presence of jagged edges or protrusions, cleaned, and dried. There should be no cutting dust, grit, oil, moisture, or other contaminations in the saw cut.

The slots should be flushed clean by means of a water stream. The slots should then be cleared of water and dried by means of an air stream. The blown air, from the compressors, should be free of oil or water. The slots should be cleaned immediately after the cutting operation (fig. 131).

Care should be taken during cleaning of the slots, to avoid blowing the debris at passing pedestrians and motorists.

Wire Installation

Before proceeding with the wire installation, it is imperative that the slot be cleaned and free of water.

All wire installation must be made without damage to the wire or its insulation. All damaged wires must be replaced.

The wire should be type XHHW, #14 AWG, stranded, single conductor (Vulkene or equivalent).

The loops shall be installed as per figures 127, 128, and 129, and shall contain three complete turns.

The wire shall be laid in the slot so that there are no kinks or curls and no straining or stretching of the insulation.

The wire shall be installed as far down in the slot as possible. A blunt object, similar to a wooden paint stirrer, should be used to seat the loop wire. In no case shall a screwdriver or other sharp tool be used for this purpose.

The loop lead-in wires should be twisted to provide a minimum of one turn per foot from the loop to the splice box.

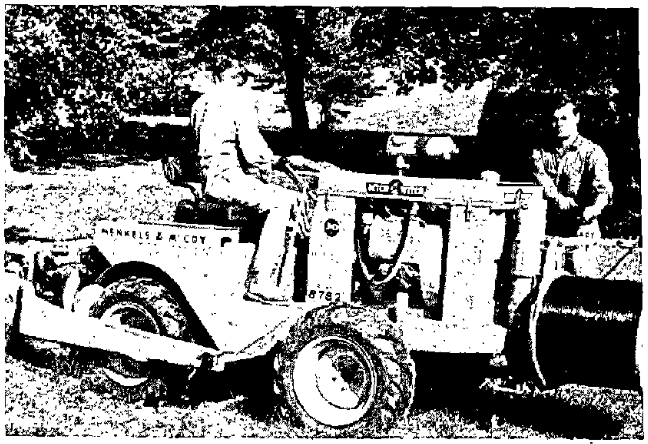
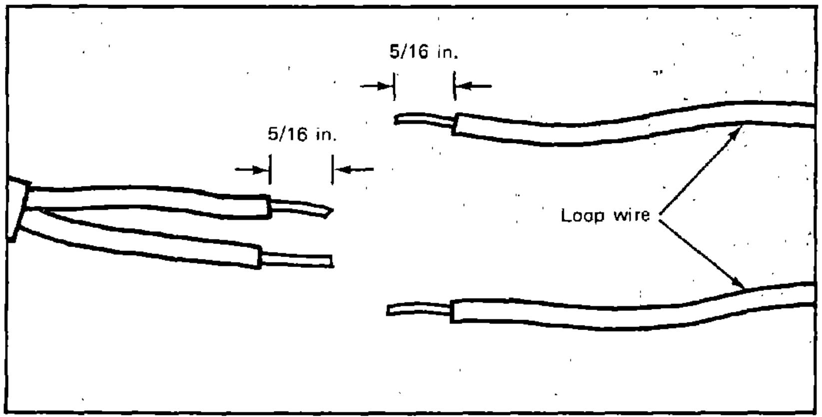
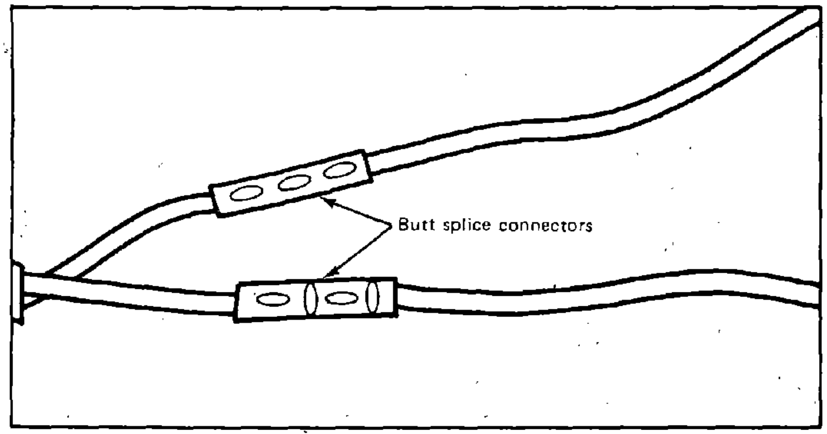


FIGURE 123.—Equipment for burying cable.



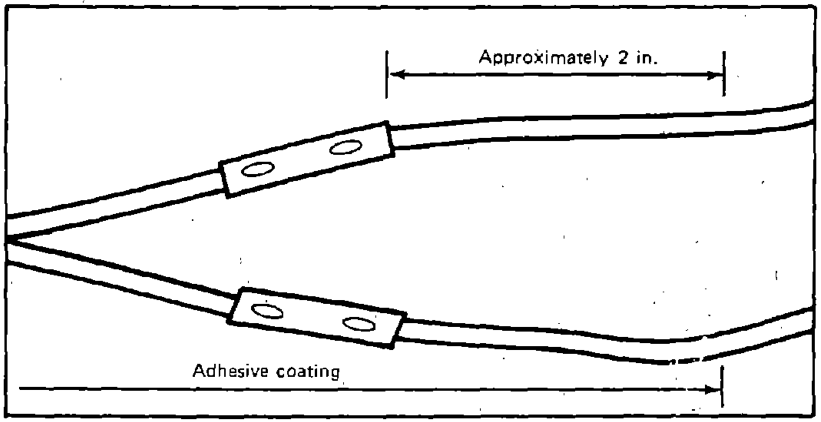
Step 1

Strip wires as shown. Allow bare wire to extend approximately 5/16 in.



Step 2

Make splices using insulated pressure type wire connectors "INSULINK" SN14 or 3M Co. #D42501 connector or equivalent.

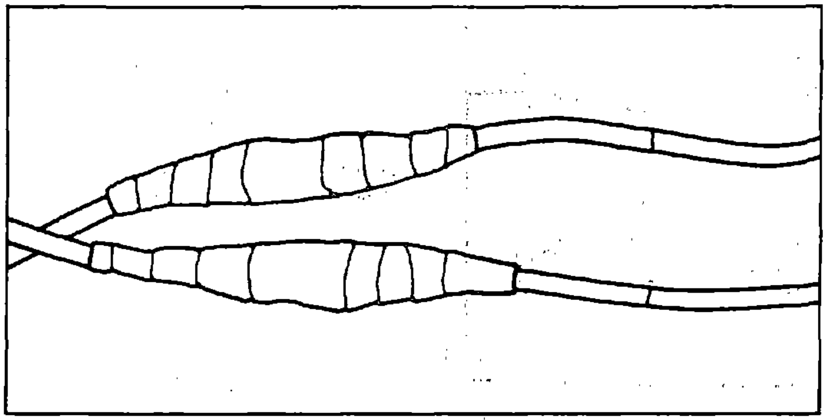


Step 3

Brush on a single coat of Adhesive 55-C (Bishop Manufacturing Corp.) or equivalent. Coat to cover ½ in. of Belden outer jacket, exposed Belden inner jackets, wire connector and 2 in. of loop wire insulation. Allow adhesive coating to dry (at least 5 min).

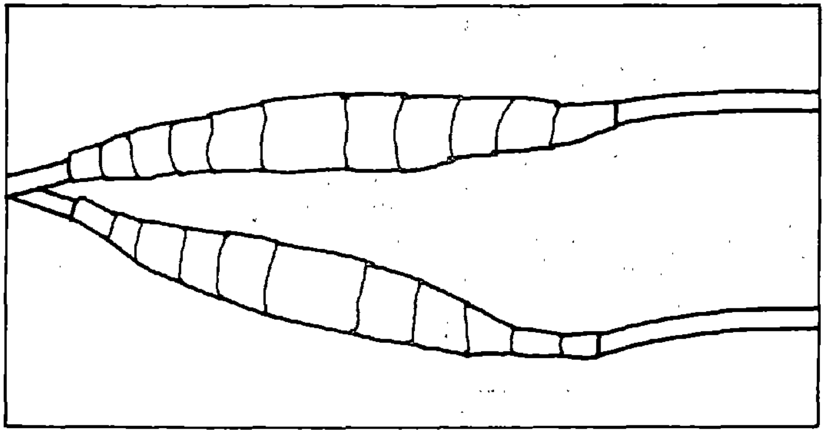
FIGURE 124.—Procedure for splicing feeder cable and lead-in.

FIGURE 124.—Continued.



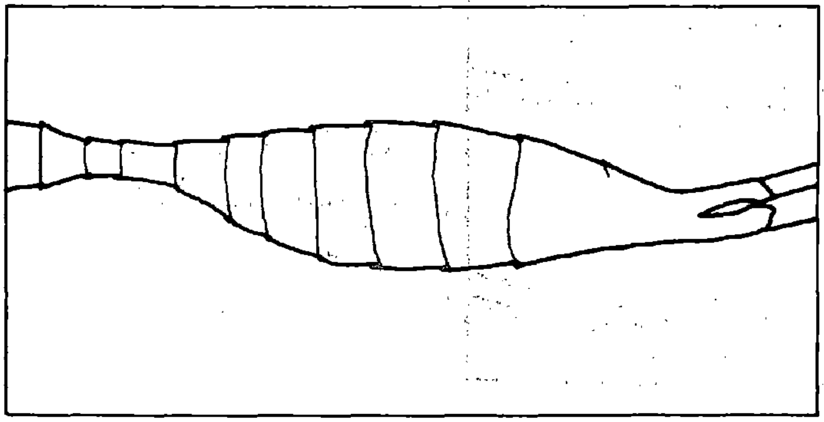
Step 4

Wrap each splice with 3/4-in. "BI-SEAL" Type 3 self-bonding electrical tape or equivalent. Half lap starting at center of splice and proceeding approximately 3/4-in. past connector end, back over connector to 3/4 in. on other end and returning to center.



Step 5

Wrap each splice with 3/4-in. "Scotch" No. 88 All-Weather Electrical Tape or equivalent. Follow same procedure as in Step 4. Cover previous layer of tape.



Step 6

Wrap both splices together with 3/4-in. "Scotch" No. 88 tape. Cover entire splice area including adhesive coating applied by Step 3. Complete splice by inserting a 4-in. piece of No. 88 tape into the "V" formed by the loop wire.

FIGURE 125.—Use of megger meter.

A minimum of 3 ft. of lead-in pair slack should be coiled and left in the splice box.

The wire should be held in place during installation by means of short strips of a polyethylene foam sealant backers similar to Dow Chemical Co. Ethafoam SB. The holddown strips should be approximately 2 in. in length and placed approximately every 2 ft. These strips should be left in the slots during pouring of the sealant. Where the loop wire crosses cracks or joints in the pavement, plastic sleeving should be used to insulate the wire. The sleeve should extend a minimum of 4 in. on each side of the joint.

FIGURE 126.—Use of loop tester.

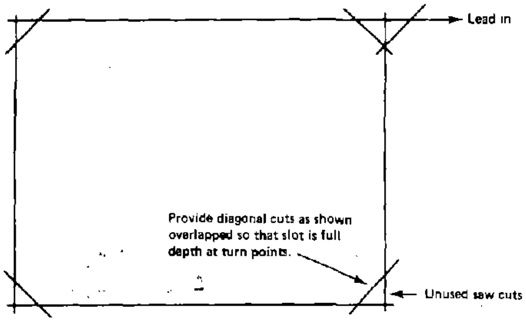


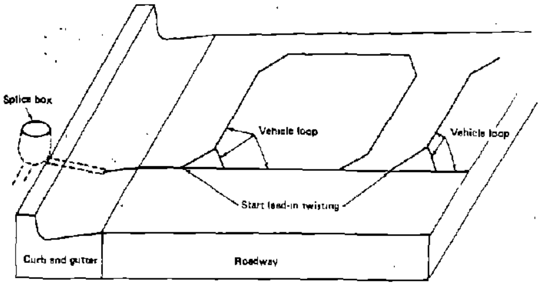
FIGURE 127.—Typical loop layout.

Splice Box Installation

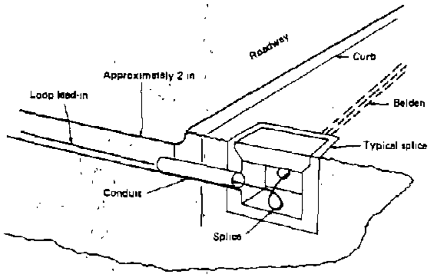
The splice box should be installed at locations shown on the installation drawings.

A type of splice box that can be used is seen in figure 120. The installation should be similar to the following:

- Excavate, at the proper location, to house the splice box.
- Provide support for the splice box (no forms to be used), with its cover flush with the ground (fig. 132).
- Install a short section of conduit from splice box to pass under curbing (if any) and pick up detector lead-in saw cut and chase (fig. 128).



Run loop lead-in wires under curb through conduit



Installation showing conduit through curb

FIGURE 128.—Loop lead-in.

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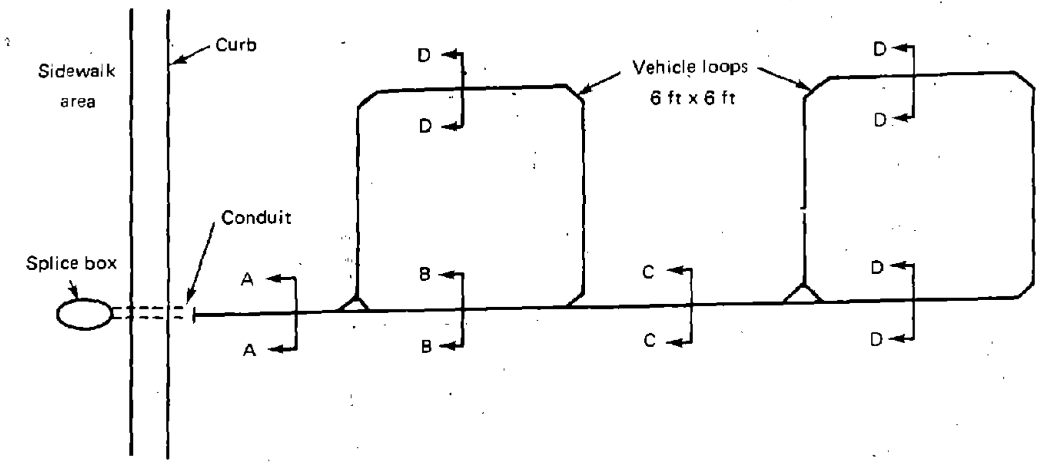
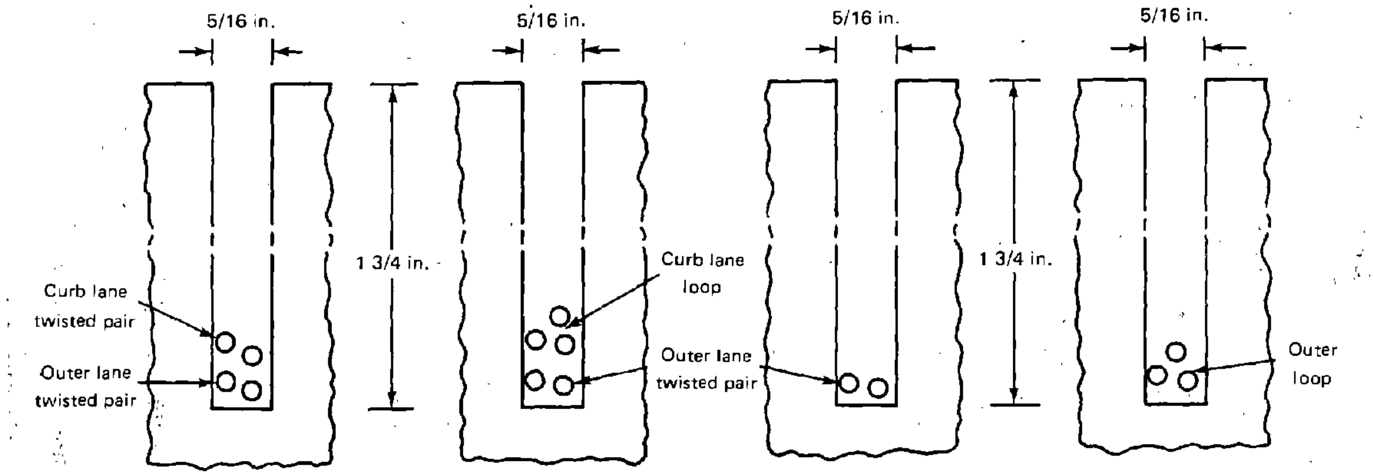


Detector layout—top view



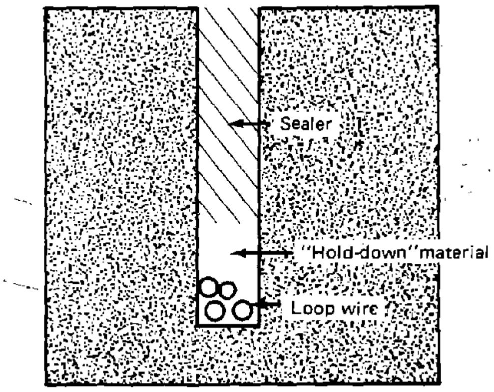
Section A-A

Section B-B

Section C-C

Section D-D

Layout cross sections



Typical completed cross section

FIGURE 129.—Vehicle loop detector.

FIGURE 130.—Protective plates over sawed slots.

- Install a bend from splice box in the direction of manhole, or conduit, as shown on installation drawings (fig. 133).
- Pour concrete around splice box (fig. 134).
- Backfill finish (fig. 135).

Testing

Prior to pouring the sealer, the loop and lead-in shall be checked for continuity and resistance. In addition, the integrity of the insulation shall be checked by applying a megger between each end of the loop lead-in and the nearest reliable electrical ground (e.g., street light, fire hydrant, etc.). In the event that no available ground exists, a suitable ground shall be established for the measurement (e.g., driven metal spike). The megger reading should be in excess of 10 MΩ under any conditions (figs. 125 and 126).

A record shall be made of the location and megger readings, and the indication of satisfactory compliance with the continuity check.

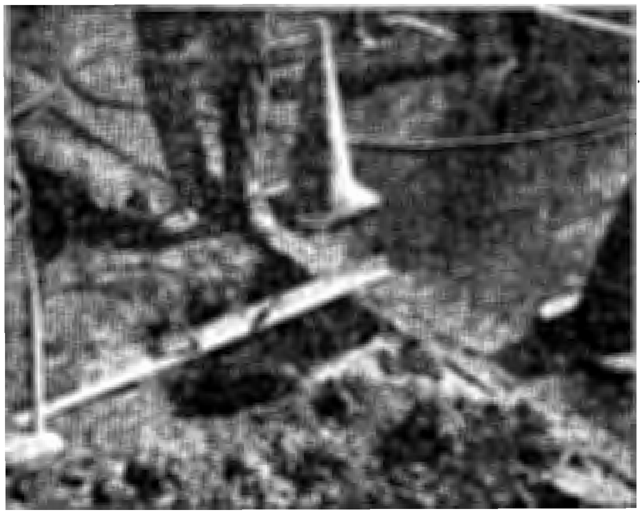


FIGURE 131.—Cleaning out sawed slots.

FIGURE 132.—Support to maintain splice box.

Saw-Cut Seal

The sealer should be flexible embedding sealer.

The sealer should be used strictly in accordance with the manufacturer's instructions.

The sealer should be poured into the slot to half depth. When both the loop and lead-in slots are half filled, check for air bubbles or material pileup, and then proceed to fill the slots to roadway level. Excess sealant should be removed by means of a "squeegee."

In all cases, there shall be neither a trough nor a mound formed (fig. 122).

The sealer, when poured into a saw cut, should completely surround the wires, displace all air therein and completely fill the area of the slot, except for that portion filled with the wire holddown material. Allow sufficient time for the sealer to harden in accordance with manufacturer's instructions (minimum of 1.5 hr.) before allowing traffic to move over the area.

FIGURE 133.—Installation of bend.

Final Test

Repeat the entire test specified in "Testing."

Detector Feeder Cable Installation

1. In areas where there are sidewalks the feeder cable and the loop lead-in wire should be terminated in a handhole and a waterproof splice made at that point with whatever cable is recommended (fig. 124). The cable is then placed in the conduit from the handhole to the control box or to a manhole.

2. In soil, the coaxial cable should be placed a minimum of 18 in. deep by open-trench method. The cable shall be surrounded with sand meeting the requirements for concrete, to a depth allowing for 4 in. on all sides. The trench shall be backfilled in layers not to exceed 6 in. loose and compacted with mechanical tampers to the approximate density of the original ground (density will vary). The loop lead-in wire and feeder cable can be terminated in a splice box as specified above in the paragraphs on planning. The coaxial cable may be placed by direct burial method, using equipment similar to Henkels and McCoy shown in figure 123, provided it can be demonstrated that the method of installation will not damage the cable.

3. In areas where the roadway ends and the shoulder begins, a slot shall be cut at a down angle of approximately 30° to avoid shearing of the lead-in at this point.

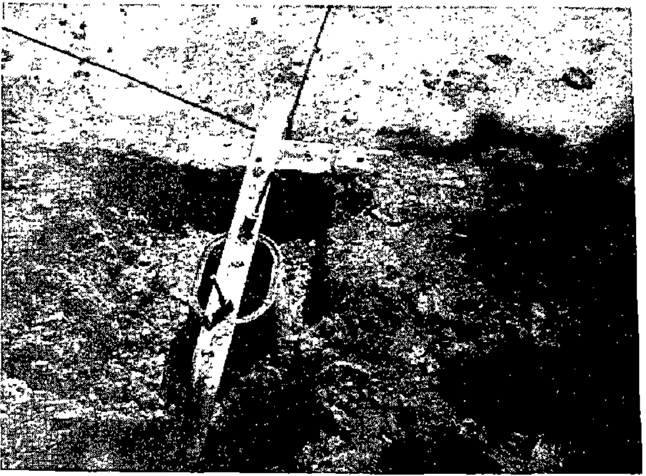


FIGURE 134.—Concrete around splice box.

FIGURE 135.—Finished installation of splice box.

Record-keeping

Before leaving the site, a record of any modification to the original installation drawing should be made.

CONCLUSION

This concludes the description of the procedure for installing loop detectors. Parts of the preceding information were obtained from the installation specification developed by Sperry Systems Management Division under contract to the Federal Highway Administration for the installation of the Urban Traffic Control/Bus Priority Project.

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