INSTALLATION AND MAINTENANCE OF INDUCTIVE DETECTOR LOOPS

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DISCLAIMER

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CONTENTS

ABSTRACT

Inductive Loop Detectors (ILDs) are the most common form of vehicle detection for vehicle activated traffic signals in use today. They consist of a number of loops of wire buried in the roadway pavement and connected to a detector unit or amplifier.

Accurate and reliable detection of vehicles is required to minimise delays, stops and fuel use of vehicles passing through an intersection. For example a recent study in Sydney estimated savings from improved detector performance of A$23 million were possible for that metropolitan area.

This report provides a practical guide to the installation of the loop in the roadway to increase the reliability of that component of the ILD. Different commonly used methods are explained and their advantages and disadvantages discussed in relation to simple theoretical and practical considerations. This is to enable practitioners to use some judgement in applying the techniques to their particular conditions. Important aspects are the type of wire used and the type of sealant used to seal the sawcut slot in the pavement after the wires have been laid in it. The recommended sealant is a flexible epoxy material. A more detailed description of some theoretical aspects of ILD's is contained in an Appendix.

An Instruction Leaflet for Installing Standard Detector Loops is included in which the recommended method for installing loops in standard situations is set out in the form of simple instructions for field staff.

1. INTRODUCTION

Inductive Loop Detectors (ILDs) are the most common form of vehicle detection in use today. With ever more sophisticated microprocessor traffic control systems being developed and installed, more reliance is being placed on accurately and reliably detecting vehicles. Unfortunately the ILDs in use have not always been as accurate or reliable as they should have been.

A recent study in Australia (RTA 1989) estimated that in the Sydney metropolitan area, alone, over A$23 million per year in delays, stops, and fuel usage costs could be saved by improving detector performance from 16% with faults, down to an achievable 6% with faults at any one time.

An ILD consists of a number of turns of wire buried in the pavement and connected to a detector unit or amplifier. Current is passed through the wire loops to create a magnetic field. As vehicles pass over this loop and influence the field, the overall inductance of the loop circuit changes. The detector unit senses this change and sends a message to the signal controller, the traffic counter or other device.

The aim of this report is to provide a practical guide to the installation of the loop in the roadway to increase the reliability of that component of the ILD. Different commonly used methods are explained and their advantages and disadvantages discussed in relation to simple theoretical and practical considerations. This will enable practitioners to use some judgement in applying the techniques to their particular conditions. A more detailed description of some theoretical aspects of ILD's is contained in the Appendix.

An Instruction Leaflet for Installing Standard Detector Loops is included at the end of this report. It sets out, in summary form for field staff, the recommended method for installing sound loops in standard situations.

It is important to note that the loop is only one component of the detector system. There have been major advances in detector unit technology in recent years, and these new units can often compensate for poor loops. However, they will not work with a 'failed' loop, so sound and permanent installation of the loop in the road is still essential to provide the accurate and reliable detection required for today's traffic control.

2. LOOP TYPE, SHAPE and SIZE

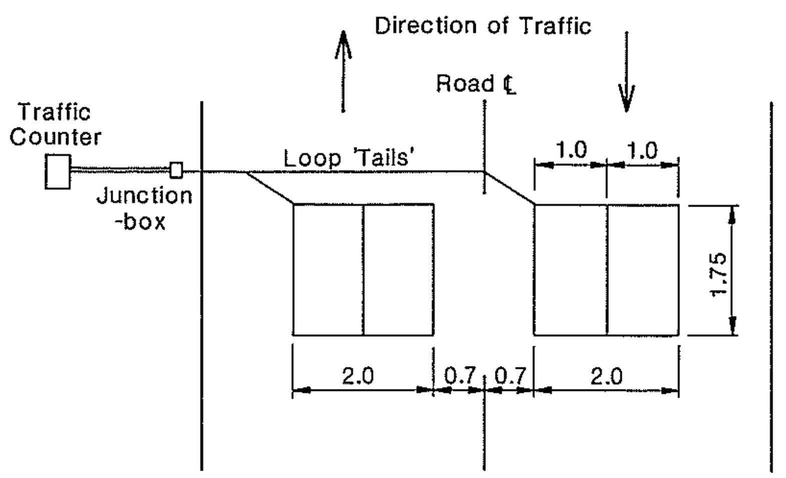
The two basic types of detectors are passage (or dynamic) and presence detectors (see 'Glossary' for definitions). The shape and size of loop to use depends on the function the detector is designed to perform. A general outline of types, shapes, and sizes is given in Section 7 of 'A Guide to the Design of Traffic Signal Installations' (NAASRA 1987), most of which has been adopted as a standard by Transit New Zealand.

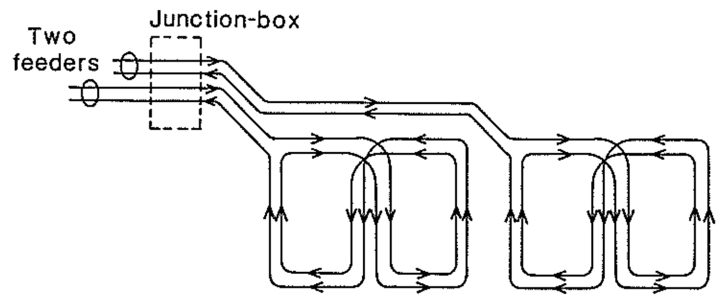
Loops for traffic counting, and for "gap seeking" well in advance of the stop line at a vehicle-actuated signal-controlled intersection, are operated either as passage or presence detectors. They are often rectangular in shape, spanning a number of lanes and with a short dimension (of the order of 1.5 m) in the direction of travel. A quadrupole configuration, as in Figure 1, has however been shown to be more effective and is now recommended.

The most common loop being installed in New Zealand at present is the 'double quadrupole' (or 'symmetripole') shape for use as a presence detector near the stop line at an intersection (Figure 2). Research has shown this to be a most effective type and shape for vehicle presence detection. It is also the standard specified by the Roads and Traffic Authority, New South Wales, Australia, for use with the area wide Sydney Co-ordinated Adaptive Traffic System (SCATS). A number of cities in New Zealand have already installed SCATS but even those not planning to in the near future should still consider using this loop configuration as an effective standard for a presence detector loop. The wiring direction shown in Figure 2 should be followed for maximum effectiveness.

Special loop shapes and sizes are sometimes employed for special situations. For example, the 'chevron' or 'slanted' configuration shown in Figure 3 (also NAASRA 1987, p. 36) has proved effective for detecting bicycles while still detecting other vehicles when operated as a passage approach loop. A small quadrupole loop, also shown in Figure 3, has been found effective in detecting bicycles in cycle lanes. Alternatively bicycles can be directed over the most sensitive part of a standard symmetripole loop by the use of pavement markings. Sometimes a push button can be installed for cyclists on busy routes where automatic detection is not possible.

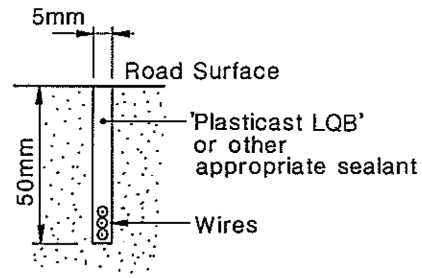
Although the proposed positions of loops at an intersection to be signalised will be shown on a plan, some latitude to deviate from these positions should be allowed in the field. This is to ensure the loop does not encompass or pass through heavy iron manhole lids or cesspit grates or does not unnecessarily cross pavement joints or poorly backfilled service trenches. An accurate site survey could avoid these problems.



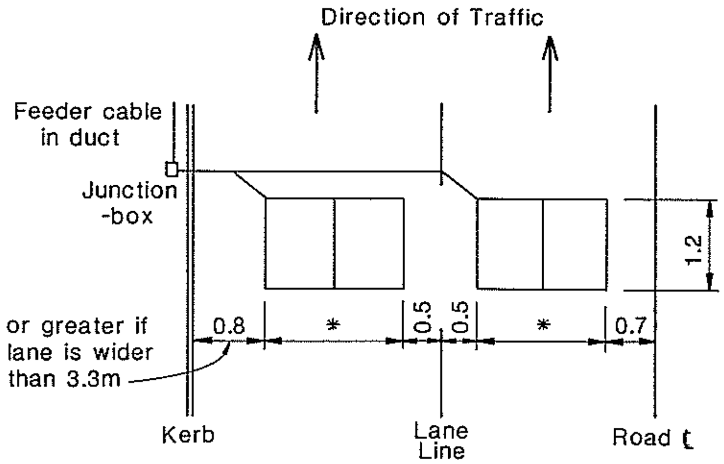


Wiring Direction and Connections
(Arrows indicate direction)

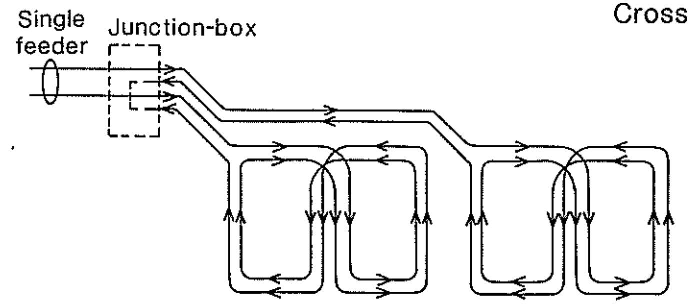
(a) LOOPS for TWO-WAY TRAFFIC COUNTING



Cross Section for All Loops



* varies depending on lane width, but maximum 2m

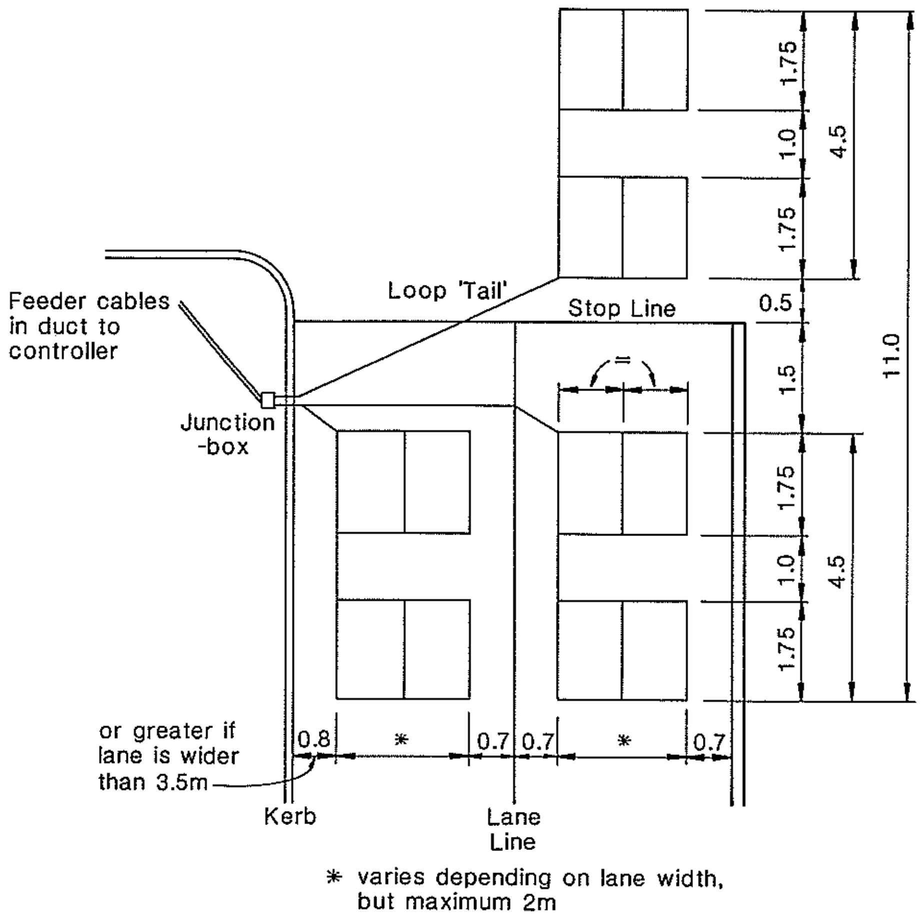


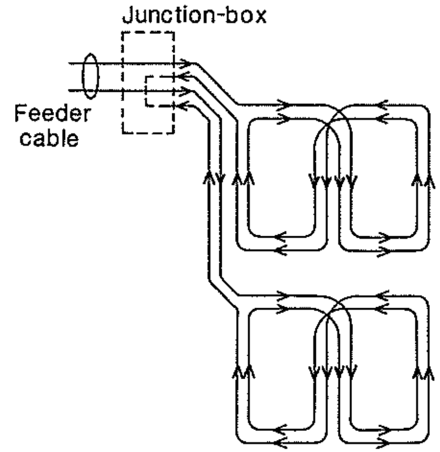
Wiring Direction and Connections
(Arrows indicate direction)

(b) ADVANCE PASSAGE (Dynamic) DETECTOR LOOPS

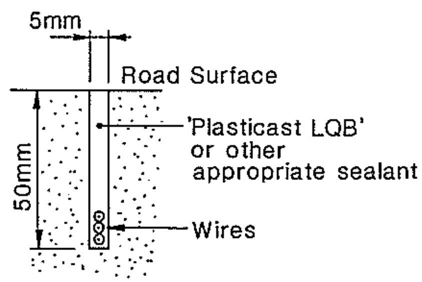
NOTE: See the Instruction leaflet for standard installation method, techniques and materials.

FIGURE 1 QUADRUPOLE VEHICLE DETECTOR LOOPS for TRAFFIC COUNTING and ADVANCE GAP SEEKING





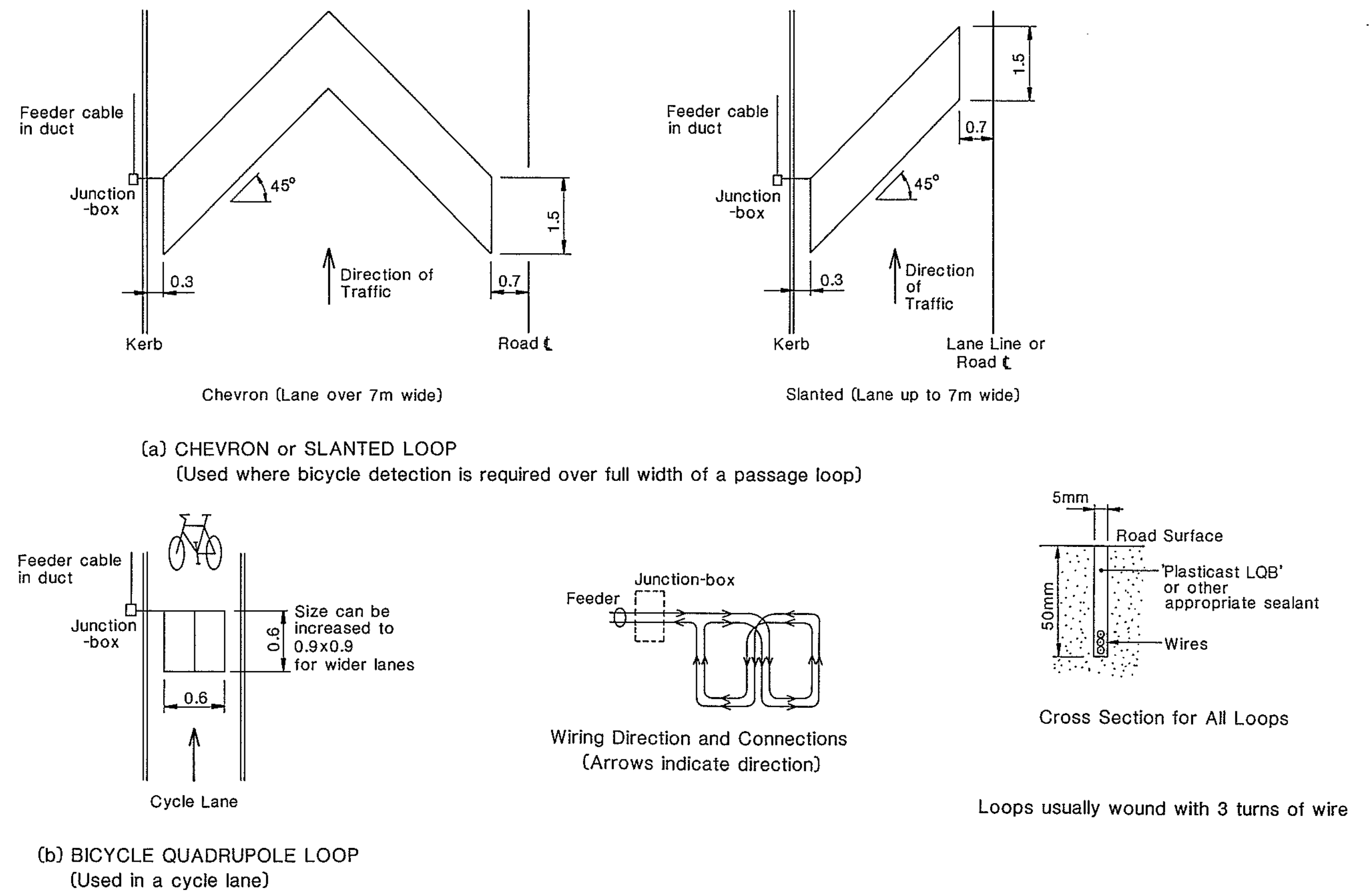
Wiring Direction and Connections
(Arrows indicate direction)



Cross Section for All Loops

NOTE: See the Instruction leaflet for standard installation method, techniques and materials.

FIGURE 2 SYMMETRIPOLE (Double Quadrupole) VEHICLE DETECTOR LOOPS for STOPLINE (Presence) DETECTION



NOTE: See the Instruction leaflet for standard installation method, techniques and materials.

FIGURE 3 BICYCLE DETECTION LOOPS

3. LOOP INSTALLATION METHODS

3.1 General

The three basic installation methods are:

(a) single insulated wires laid in a narrow sawcut slot,
(b) multi-core cable laid in a wider slot,
(c) wire (either single or multi-core) laid in some sort of protective conduit.

Which method to use in any particular situation depends on the road surface type and condition. Method (a), being the cheapest and most cost-effective, should be used wherever there is a reasonable depth of sound pavement. If problems can be foreseen or repeated failures have occurred at a particular location, then the other two methods can be considered.

It is not worth the extra trouble and cost involved to use methods (b) or (c) just to increase the life of the loop. Many loops do not reach the end of their economic life but 'fail' because they have been damaged when trenches are excavated for other services, or when the road surface fails or is milled for resurfacing. This is particularly so in inner city areas, where much building reconstruction is taking place, and extensive reconstruction of underground services is required.

Whichever method is used the integrity of the road surface must be maintained. Loops often fail because the road fails; but localised road failures are sometimes caused by the installation of the loop. A sawcut slot for a loop which goes through the surfacing to the basecourse and is not properly sealed, can allow water to penetrate and soften the subgrade, causing pavement failure.

3.2 Single Wires in a Narrow Sawcut Slot

In general, if sufficient depth of sound pavement (such as hot laid asphalt, concrete or accumulated layers of chip seal) exists, separate wires laid in a narrow sawcut slot is the cheapest and most cost-effective method of installing a loop.

The proposed position of the loop should be accurately and completely marked on the pavement with chalk or crayon prior to cutting. The slot is then cut with a self-propelled concrete cutting saw with a water-cooled, diamond-tipped blade. This usually gives a width of slot of 3 - 5 mm, depending on the newness of the blade. In hot weather, installation must proceed rapidly as a narrow cut will tend to close up. Some authorities insist on a wider sawcut slot (5 - 6 mm) if they are using larger diameter wire. This width of slot is achieved with two blades bolted together but that does slow down the cutting and increases the cost.

The depth of cut will vary depending on the number of wires to be installed. For a normal double-quadrupole SCAT loop with four wires in the centre slot, an average cover of 20 mm is recommended with an absolute minimum of 13 mm. This requires a slot depth of 40 - 50 mm. Wires should not be installed so deep that, with subsequent pavement overlays, the loop loses its sensitivity. Where the sawcut slot back to the roadside kerb is used for wires from a number of loops, the slot should contain no more than eight wires.

All sawcuts must extend beyond the loop's corners to ensure the cuts reach their full depth at the corners. With a chisel remove the sharp corners in the slot where two cuts meet at right angles to prevent the corners damaging the wire's insulation. Rounded corners are essential if thicker wire is used which cannot be bent in a sharp right angle.

Cleaning out the sawcut slot to remove debris and any sharp stones is important. Ways to do this range from scraping out, hosing out and / or using compressed air which also dries out the sawcut slot after cleaning.

From this point on, practices differ considerably not only in the installation methods used but also in the wire used (see Section 4), and the sealants used (see Section 5).

Some authorities, especially those overseas, insist that the wire is installed on top of a layer of sealant placed in the bottom of the sawcut slot. This is not just for mechanical protection of the wire but also to prevent moisture coming into the sawcut slot from below. Encasing the wire like this may be technically sound but is difficult to achieve in practice and is not considered cost-effective.

To seat each wire down in the sawcut slot without damaging the insulation is important and can be achieved by using a disc to roll along in the slot (for example, use an old concrete-cutting blade fitted with a handle, and able to turn). To keep the wires down while the sealant is applied, some authorities specify the use of plastic retaining wedges at 300 to 400 mm spacing. This is only necessary with certain combinations of wire and sealant where the wire has a tendency to float to the top of the sealant. Usually wires are jammed together in the bottom of the slot which avoids this problem.

The loop wires from the corner of the loop to the roadside junction-box should be as close to each other as possible and some authorities consider that the wires should be twisted together to neutralise the effects of inductance and capacitance between them. However this is not necessary provided the distance to the junction-box is less than about 5 m. To avoid 'cross-talk' (see Glossary), lead-in wires from each loop may need to be installed in a separate sawcut slot. This is not necessary with newer multi-channel digital detectors that activate and search only one loop at a time.

The practice of taking the loop lead-in wires via sawcuts all the way back to the signal controller should be avoided. The best and most common practice is to install a small junction-box behind the kerb, near the loop. There the loop lead-in wires are connected to a properly twisted and shielded feeder cable. This is taken back to the controller in ducts which are also used to carry signal-head cables under the road and footpath or berm.

As well as avoiding the loss of sensitivity which would result if long lengths of unshielded lead-in wire were used, the availability of a kerb-side junction-box connection also assists in isolating loop faults and avoids having to replace both the feeder cable and loop when a fault occurs in one or the other.

The best method of taking the loop wires or tails through the kerb and channel is by a simple sawcut slot. The sawblade must be large enough, and have a blade guard which moves far enough out of the way to enable the blade to penetrate to a depth of 50 mm right in the inside corner between kerb and channel.

If the loop wire has to pass through a grass berm or gravel shoulder to the junction-box, it must be contained within a rigid polyvinyl chloride (PVC) conduit which is concreted in at both ends. The junction-box must also be set in either concrete or asphalt and preferably as close behind the kerb or road edge as possible. Junction-boxes set in grass berms or gravel without some concrete to hold them in place usually end up being dislodged, with the wire connections exposed.

3.3 Multi-Core Cable Laid in a Wider Slot

This is an alternative installation method if there are problems with the standard method. The main advantages are the extra protection afforded by the double layer of insulation and the reduced depth of slot that is sometimes possible.

The main disadvantage is the extra width of slot required. The width of slot is usually specified as 10 mm minimum which is achieved by using two sawblades bolted together with a spacer between them. This makes the sawcutting much slower, requires extra sealant for backfilling, and weakens the pavement more than does a narrower slot. All this adds considerably to the cost.

The method should only be used in situations where the extra protection is worthwhile, such as where failure of single-wire loops has been caused by excessive flexing of the pavement or where the road surfacing is so thin that a 40 - 50 mm-deep sawcut penetrates through to a loose or sharp basecourse. Even then, putting an extra thickness of asphaltic concrete (AC) overlay on the areas where the loops are to be located is often a better solution. If the loop has failed because the pavement has failed the only remedy is to repair the pavement first with a minimum thickness of 60 mm of surfacing.

The other practical aspects of installing loops covered in Section 3.2 should still be followed when using multi-core cable. These include the care required to clean out the slot and to seat the wire down properly in the bottom of the slot, the care required crossing the kerb and channel, and the need for a properly installed junction-box close behind the kerb.

3.4 Loop Wire Laid in a Protective Conduit

This is an alternative method sometimes used for installing a loop under a new chip seal, or an AC surface less than 40 mm thick. A conduit, either rigid or flexible, provides maximum protection while allowing the cables or wires inside freedom to move without breaking, even if some differential pavement movement occurs.

Usually a 20 mm-diameter high impact PVC conduit is used. This requires a minimum 25 mm-wide slot to be cut in the road, unless it is laid in the basecourse of a new pavement prior to sealing. The conduit should be installed with proper elbows and T-joints glued to ensure a water-tight housing for the loop wire.

An alternative is to encase the wires or cable in flexible vinyl plastic tubing. This provides extra protection and allows for movement of the wires or cable within the tube, if there is some differential pavement movement or faulting. Being flexible, the tubing is possibly less likely to break in these conditions than the rigid PVC conduit and does not require such a large pavement slot. It is, however, more difficult to thread the wire or cable through the flexible tubing than through the larger diameter, rigid PVC conduit.

The disadvantages of any conduit method are first, the extra time and cost involved. Second, they still often fill with water, and third, the road pavement has a greater tendency to fail with such wide slots filled with material of a different flexibility to the rest of the pavement. Even with new pavements, thickening the surface where loops are to be installed and then using the standard method is often a better option.

For these reasons, loops in conduits are not recommended in most situations except in new chip seal pavements, or where an unstable pavement cannot easily be replaced, or where a loop must cross joints in a more rigid pavement. Although not used as often as rigid PVC conduit, flexible vinyl tubing would generally appear to be a better material to use, considering the flexibility of most pavements in New Zealand.

The other practical aspects covered in Section 3.2 should also be followed when installing loops in conduits or flexible tubes.

4. LOOP WIRE and FEEDER CABLES

Many types of wire seem to have been found satisfactory by different authorities, although they must have some general properties which, most will agree, are essential. The basic type of wire used will, of course, depend on the loop installation method adopted, as outlined in Chapter 3.

4.1 Single Core Loop Wire

This wire is suitable for use in a narrow sawcut slot and must be multi-stranded, with a total cross-sectional area of copper wire of at least 1 mm^2. Thinner conductors have a higher resistance which can reduce the sensitivity of the loop. In fact, many authorities here and overseas recommend a minimum cross-sectional area of 2 mm^2 (14 American Wire Gauge) although this is considered unnecessary in most situations. Some use tin-coated copper to prevent oxidation at connections or where the insulation may be damaged.

The most commonly used wire in New Zealand is heat-resistant appliance wire which has a PVC insulation. Most overseas authorities recommend against the use of PVC because the capacitance and inductance of a loop with PVC-insulated wire varies considerably with temperature. They usually recommend cross-linked polypropylene or polyethylene insulation. Since the introduction of polypropylene loop wire as a standard in Australia (SAA-AS 2276.3, 1986), a number of New Zealand authorities are also specifying it.

Modern digital detector units with their larger 'environmental tracking' range (see Glossary) can usually cope with the changes in properties of PVC-covered wire, but earlier detectors sometimes prove troublesome. PVC-covered wire is also more prone to corrosion.

Standard appliance wire (or equipment flex) is available in both 2 mm^2 and 1.1 mm^2 cross-sectional area. It is heat-resistant to 85°C and has an 0.8 mm PVC-insulation thickness. The standard requires that the heat resistant nature and temperature be printed or embossed on the side of the wire. Wire without this identification is unlikely to be heat resistant.

It is recommended that either 1.1 mm^2 standard heat-resistant appliance wire or a similar diameter polypropylene-insulated wire is used as the standard wire for most loops. The 2 mm^2 appliance wire tends to be a rather tight fit in a standard sawcut slot, although some polypropylene-insulated wire also has this problem and is difficult to bend around right-angled corners.

4.2 Multi-Core Loop Cable

If multi-core cable laid in a wider slot is used for the loop, the individual wires should still be multi-stranded cores, each with a minimum cross-sectional area of 1 mm^2.

Usually 3-core cable is used because it is commonly available. With a SCAT double quadrupole configuration, laying it once around the figure of eight provides a spare wire for use if one of the other wires fails. Two-core cable is sometimes used.

Some authorities use standard, flat 3-core, housing cable which has a PVC-based insulation. Others use round cross-section, 3-core by 1 mm^2 thermoplastic-rubber (TPR) cable. This is also PVC-based and not oil-resistant.

The best cable to use has a polyethylene insulation, such as chloro-sulphonated polyethylene (CSP), used for both the inner insulation and outer sheath or for the outer sheath only, in conjunction with an ethylene-propylene rubber (EPR) inner insulation. Such a cable is probably only warranted with older type detectors where an environmental tracking problem persists.

4.3 Feeder Cable

The feeder cable connects the ends of the loop at the kerbside junction-box back to the controller. The cable should always be electrically shielded to enable it to be placed in ducts together with power cables and other loop feeder cables.

Usually a 2-core shielded cable is used for each loop. It is recommended that the cross-sectional area of each wire core should be 2 mm^2 or greater, especially where the loop is some distance from the controller. However, sometimes 2-core screened triaxial audio cable is used which only has 0.75 mm^2 wires. With thinner wires either more turns in the loop or higher frequencies are needed (see Appendix).

Sometimes a single 5-core shielded cable is used for four loops, with one core acting as a common return. The use of this cable is only possible with modern 4-channel detector units, where only one channel and loop are activated or searched at a time. Research has shown that there are problems with using this cable. It also makes tracing loop faults much more difficult. Multi-pair shielded instrument cable is a better solution as it has twisted pairs of wires, each pair individually shielded from the others. It is available with up to 24 pairs.

Polyethylene or polythene are recommended as the most desirable kinds of insulation for feeder cables. However PVC-insulated cables are often used, even though their capacitance varies with temperature, because capacitance effects are not large in a twisted shielded cable, and temperature variations are not large in a duct underground.

The feeder cable shielding is usually made from copper-braided or aluminium-braided sheath, or a layer of galvanised steel wire armouring. The shielding is covered with another layer of insulation giving the feeder cable considerable mechanical as well as electrical protection.

5. LOOP SLOT SEALING METHODS

5.1 General

The main aims of sealing the loop slot are to preserve the pavement, provide protection for the loop wires, and keep out water. Moisture around a loop wire can have a considerable effect on the inductance of a loop even if there is no damage to the wire's insulation. This effect occurs if the medium immediately surrounding the loop absorbs water and, as a result, its electrical conductivity changes. However, it appears that most modern detector units have a large enough environmental tracking range to be able to cope with most changes in loop inductance. Older detectors were known to cause problems with sand-filled loop slots when the sand absorbed moisture or dried out.

The two basic products in common use in New Zealand for sealing the loop slot in the pavement surface are bitumen emulsion and epoxy resin. These are frequently used in conjunction with sand, either as a filler mixed with the sealant or as the main backfill material, with the sealant being applied on top of the sand in the slot. Overseas hot-poured bitumen is frequently used, but because of the extra equipment required on site this method has not been favoured here.

A number of authorities overseas do not specify the exact type of sealant to be used but instead specify in some detail the characteristics the sealant should possess. Most of these characteristics are based on completely encapsulating the loop wire with the sealant. They usually require the sealant to have an initial viscosity that enables it to be easily poured into the slot and encapsulate the wire, yet not run out on sloped pavements, and to set rapidly even in the presence of water. The set sealant is required to be hard enough to resist the penetration of debris, yet flexible enough to accommodate pavement flexing and temperature movements, without becoming too soft in hot weather. In addition, it should adhere strongly to the existing pavement and be resistant to all weather, abrasion, oil and petrol, and not react with the loop-wire insulation.

Many New Zealand authorities feel that a sealant of reasonable cost which is easy to use and meets most of the above requirements has yet to be developed. They simply use the cheapest and easiest method available that appears to have worked over the years. This usually means using dry sand as the main backfill material.

5.2 Use of Sand

Many authorities and detector manufacturers specifically warn against using sand as a backfill material, yet many practitioners experience no problems with its use.

The main argument against using sand is that, when it absorbs moisture or dries out, the inductance of the loop changes. Another is that sand does not provide stable support for the wires. It can be washed out of the slot, or settle down when very dry, leaving the wires loose under a thin surface sealant layer. The use of sand means that the wire does not receive the same mechanical or electrical protection as when encapsulated in a sealant. This places more reliance on the loop wire insulation.

Practitioners who use sand as the main backfiller maintain that they have not experienced these problems. This could be because they use modern detector units. Also the low viscosity of the surface sealant they apply probably allows it to penetrate the sand so that most of the slot is actually filled with a sand/sealant mixture with very little loose sand in the bottom. If the sealant sinks down slowly through the sand and the slot has to be topped up repeatedly, this can slow down the slot filling operation.

Note that with the use of a water-cooled sawcutting blade, the slot and road are often still damp when sand is poured into the slot. If sand is used separately from the sealant it is very important to use fine dry silica sand to ensure it flows in easily and completely fills the slot.

Sand is probably best used as a filler pre-mixed with a good sealant, and then used separately dry as a blinding material, on top of the sealant before opening the lane to traffic.

5.3 Use of Bitumen Emulsion Products

The most common product of this type used in New Zealand is 'Mulseal', a bitumen-latex emulsion. It is usually used with sand.

Common practice is to fill the slot to within 5 - 10 mm of the surface with dry sand (on top of the loop wire which has been laid directly in the sawcut slot) and then fill to the surface with Mulseal. This can be quite difficult as Mulseal is a sticky substance to handle. After the initial 'set' has taken place the surface of the Mulseal is blinded with dry sand before traffic is allowed to pass. The time taken for the initial set depends on the weather.

Sometimes Mulseal is mixed with bitumen emulsion (55% anionic) to assist with adhesion to existing bitumen roads, while some authorities use straight bitumen emulsion instead of Mulseal.

Using Mulseal (or bitumen emulsion) as a slot sealant for the full depth with no sand has not proved successful because it is usually too thin initially, running out on slopes and soaking into the pavement. It often takes too long to set (as it depends on the evaporation of water), is washed out if it rains, and shrinks and settles too much when it does set.

This method has other disadvantages, such as that the material is messy to handle and the residual bitumen is quite soft, allowing sharp objects to be imbedded in the slot and sometimes working down and cutting the wire. These problems still exist, although to a lesser extent, if the Mulseal or bitumen emulsion is poured in on top of sand.

5.4 Use of Epoxy Resins

Most overseas literature recommends the use of some formulation of epoxy resin as a good encapsulating sealant for loops.

Two types of epoxy resins have been used successfully in New Zealand, both as total encapsulating sealants and on top of dry sand-filled slots. The standard solvent-free normal-temperature-curing epoxy is a common one used in many boat building applications and goes relatively hard when cured. There are a number of different brands and formulations and most are available in either summer or winter(cold cure) grades because curing times are dependent on the ambient temperature.

The other type of epoxy resin used remains flexible when cured. At present there appears to be only one brand available, namely 'Plasticast LQB' which is manufactured in New Zealand by Fraser Brown & Stratmore Ltd.

Epoxy resins will set no matter what the weather. Many are hydrophobic (i.e. they displace water) so can be poured in a slot even if this is still damp after sawcutting. However water must not be allowed to become entrapped in the resin. Although both types of epoxy resin could be used as a pure mortar, they are often mixed with sand which increases the viscosity while it is being applied and also reduces the cost.

The standard epoxy resins have some disadvantages apart from cost. They do not retain sufficient flexibility, when used full depth in the slot, to be compatible with the fairly flexible pavements used in New Zealand. This has resulted in virtual 'beams' of hard epoxy resin that either crack and shear the wires imbedded in them, or break loose from the pavement. This is more likely in wider slots when using multi-core cables or conduit, as a wider 'beam' is even less flexible.

Another disadvantage of the standard epoxy resins is that, when used on top of sand, some products are too viscous to penetrate far into the sand so that the wires are embedded only in loose sand. This does however overcome the flexibility problem as the thinner layer of resin is more flexible. Because standard resins are hard when set and could be broken by traffic if protruding above the pavement surface the slot should always be underfilled. Also an increased line of pressure occurs on the pavement layers below an overfilled slot which can cause pavement failure.

The flexible epoxy resin, Plasticast LQB overcomes most of the disadvantages of the standard epoxy resins although it is more expensive. A number of different mix proportions and application methods have been tried since its introduction and the most successful appear to be as follows :

- Using a reduced pot-life formulation (cold cure), mixed 1 part compound, 1 part hardener, and 2 parts silica sand; if dry sand is placed in the slot first a 1:1:1 ratio is used. The manufacturer recommended a 1:1:3 ratio but this was found to be too viscous.

- Tests have shown that Plasticast LQB does penetrate dry sand and encapsulate the wire but this sometimes takes time and hence the slot may need topping up later. A 1:1:2 ratio mix poured in the slot directly onto the wires without any dry sand is considered the preferable method. This not only ensures encapsulation but also reduces the time the lane is closed.

- Thorough mixing is essential and using a power drill has been found necessary to achieve this quickly.

Although both types of epoxy resin have been used successfully, it does appear that the flexible formulation is preferable and its advantages over bitumen-based sealants probably outweigh the increased cost of the material.

6. JUNCTION-BOXES, CONNECTIONS and TESTING

As explained in Section 3.2, a kerbside or roadside junction-box (or toby-box, splice-box, connection-box or pavement junction-box) is needed to contain the connections of loop tails to shielded lead-in cables. It is also useful for testing loops and isolating loop faults.

6.1 Junction-Boxes

At locations near stop lines, where the same box is used for feeding power cables to signal heads, larger boxes are usually used and these should be well concreted into the footpath or behind the kerb. If the junction-box is used solely for the loop connection, a smaller box (100 - 150 mm) is used. It too must be properly concreted in place as it affords no protection for the connections and in fact may damage them if the galvanised steel or aluminium box is loose. Non-galvanised steel boxes should not be used.

The duct leading back to the controller should be concreted into the bottom of the box. It is also essential to provide a protected path or duct for the loop tail wires to enter the junction-box. Studies have shown that the loop tail wires from the loop corner to the junction-box are likely to be the cause of later loop faults.

6.2 Connections

As shown in Figures 1 - 3, not all loop tails for quadrupole loops are connected to the feeder cable but instead often two are joined together for the correct configuration. With loops of 2-core or 3-core cable this becomes even more complicated but it is important to achieve the correct connection directions shown in the figures. The usual convention is to tie a knot in the loop wire to mark the start of the winding, and two knots when it has been wound around twice. Preferably, wire marker tabs should be used to clearly mark each wire. For different loop configurations the loops can also be connected in series or in parallel depending on the sensitivity required. The feeder cable shield should never be connected to earth at the junction-box.

The type of wire-to-wire connection varies but usually some form of crimped connection is satisfactory. The most important aspect is to seal the connection. Some use rubber self-fusing tape and others use a heat-shrink protective sheath. Epoxy resin-encased connections have been found to be the most durable. Connectors that have been already insulated are placed in a small plastic pill bottle which is filled with epoxy resin to fully encapsulate the connections. Resin is conveniently available on site if used as the loop slot sealant, and small self-contained kits supplied with resin and bottle are also available.

6.3 Testing

Although often neglected, it is sound practice to test all loop wires once they are seated down in the slot but before the sealant is applied. If a fault is found at this stage due to a wire being damaged during installation, it can be easily replaced then.

The simplest test is to check the resistance to earth of each loop. This should be 1 Megohm or greater when the wire has just been laid in the slot. Any lesser resistance indicates a definite break in the insulation.

The resistance to earth can be measured with a common volt-ohm meter but other parameters such as loop inductance require a different meter.

7. COMMON FAULTS and MAINTENANCE

7.1 Common Faults

The main causes of loop failure are:

(a) Road pavement failures,
(b) Road excavation for services or pavement reconstruction,
(c) Loop insulation damage or break in loop wire,
(d) Connections loose or insulation damaged.

Causes (a) and (b) are the most common so that the extra trouble and expense to prevent causes (c) and (d) are considered not worthwhile when the loop is likely to be dug up during road works or broken if the pavement fails.

With older type detectors locking-on was a common problem, sometimes caused by the loop inductance changing with temperature and moisture changes in the medium surrounding the wire. In these cases no actual loop fault can be discovered and the detector may only need to be manually re-tuned. If locking-on occurs often it may be more economical to change the detector unit for one with a greater environmental tracking range, than to re-cut and replace the loop with a better quality one.

7.2 Maintenance

Most maintenance on ILDs is carried out only when a fault is reported and traced to the loop. Connections can be re-done and feeder cables can be replaced but usually if the fault is in the loop then the only remedy is to install another loop. Sometimes if an extra wire was originally included in the loop, this can be used, or the number of turns used can be reduced, provided the loop tails were all taken back to the junction-box. With a loop in a conduit, new wires can sometimes be drawn through provided a continuous wire still exists inside the conduit.

Where an important loop has been severed by roadworks or trenching, and the construction work is likely to continue for some time, some authorities will place a temporary loop on top of the pavement using adhesives and tape.

Ensuring that roadside junction-boxes are clean and dry inside is usually a rather neglected item of maintenance. Junction-boxes often fill with dirt and debris washed in during rain, especially if their lids do not close properly, and this can cause problems with connections.

A regular visual inspection of the loop on the roadway is also worthwhile. If the slot sealant is stripping or lifting but the loop still operates satisfactorily then it may be worthwhile to scrape out loose material in the slot and apply more sealant. This sort of maintenance is more economical than leaving the loop to fail and then having to urgently install a new loop. Similarly if localised pavement failures or pot-holes are repaired in time, future loop failures can often be avoided.

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GLOSSARY

AC: Asphaltic Concrete (or Hot Mix). Pavement surfacing material consisting of a preheated crushed stone and bitumen mixture laid hot.

BASECOURSE: Unbound granular crushed rock material under the pavement surfacing.

BITUMEN EMULSION: Bitumen-water mixture where the 'setting' of the bitumen depends on the evaporation of the water.

CABLE: A group of separately insulated wires wrapped together, inside more insulation.

CAPACITANCE: That property of a system of conductors and dielectrics which permits the storage of electrically separated charges when potential differences exist between the conductors.

CHEVRON LOOP: A loop configuration where the loop wires cross the traffic direction at 45°.

CONTROLLER: The electrical device, usually mounted in a separate cabinet at an intersection, which controls the operation of the traffic control signals. Vehicle-actuated controllers usually rely on information from inductive detector loops for their operation.

CRIMPED CONNECTION: A wire connection where the wire is held and connected by the compression of the metal connector.

CROSSTALK: Mutual coupling of magnetic fields, producing interaction between two or more detector units in the same cabinet when the units are operating at similar frequencies. Crosstalk results in a detector outputting an actuation in the absence of a vehicle.

DETECTOR: A device for indicating the presence or passage of vehicles.

DETECTOR SYSTEM: The complete sensing system including the detector unit, the transmission line, and sensor (loop).

DETECTOR UNIT: The electronic or electrical component of the detector system which activates the loop with an alternating current and senses changes in loop inductance as vehicles pass.

DRIFT: Change in the electrical properties of portions of the detector system caused by environmental changes, particularly temperature variations and rain water.

DYNAMIC DETECTOR: See Passage Detector.

ENVIRONMENTAL TRACKING: The ability of a detector unit to compensate for, or track, drift without going out of tune.

FEEDER CABLE: The cable which connects the ends of the loop (loop tails) at the kerbside junction-box back to the controller.

HYDROPHOBIC: The property of a substance which displaces water, or is not wettable by water.

ILD: Inductive Loop Detector.

INDUCTANCE: That property of an electrical circuit or of two neighbouring circuits whereby an electromotive force is generated in one circuit by a change of current in itself or in the other.

JUNCTION-BOX: A container that is placed underground with a removable or hinged lid which is flush with the ground surface. Splices or connections between lead-in cable and loop wire tails are located within it. Also called Toby-box, Splice-box, Pull-box, PJ(Pavement Junction)-box, and Connection-box.

KHz: Kilohertz or thousands of Hertz, which is a measure of frequency in cycles per second.

LEAD-IN CABLE: See Feeder Cable.

LEAD-IN WIRE: See Loop Tail.

LOOP TAIL: That portion of the loop wire that is in the sawcut slot connecting the loop to the edge of the roadway.

MEGOHM: One million Ohms, which is the unit of electrical resistance.

MULSEAL: A proprietary brand of bitumen emulsion and latex mixture.

PASSAGE DETECTOR: A detector which detects the passage of a moving vehicle and ignores the presence of a stationary vehicle within the detection zone.

PRESENCE DETECTOR: A detector which is able to detect the presence or absence of a vehicle within its field of detection whether it is moving or stationary.

PULL-BOX: See Junction-box.

QUADRUPOLE: A loop configuration that adds a longitudinal sawcut slot along the centre of the rectangle, so that the wire can be installed in a figure-eight pattern, thereby producing four electromagnetic poles instead of the usual two.

RESONANT FREQUENCY: The natural vibration frequency of a loop and its lead-in wire to which the detector unit must tune.

SCATS: = Sydney Co-ordinated Adaptive Traffic System. An area wide traffic control system developed by the Roads and Traffic Authority, NSW, Australia.

SELF-TRACKING DETECTOR: A detector unit, not necessarily self-tuning, that includes electronics that compensate for environmental drift.

SELF-TUNING DETECTOR: One that is capable of adapting its operation to the resonant frequency of the loop and lead-in wire without any manual adjustment required. The term applies particularly to the start up of the detector's operation, on turn-on.

SENSITIVITY: As it relates to a 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. As it relates to a detector, it is the minimum inductance change (in percent) required at the input terminals to cause the detector to actuate.

SHIELD: A conductive material surrounding the pair of lead-in wires so that outside electrical interference will not induce noise onto them.

SPLICE-BOX: See Junction-box.

SUBGRADE: The top layer of soil under a pavement.

SYMMETRIPOLE: = Double Quadrupole or two quadrupole loops connected together (see Figure 2).

TOBY-BOX: See Junction-box.

APPENDIX — SUMMARY OF THEORETICAL BACKGROUND

(Most of this Appendix was prepared from notes written by Dr Basil Kerdemelidis, University of Canterbury, Christchuch, New Zealand. A paper in preparation by him will contain graphs and formulae for detailed optimum electrical design of loop feeder systems in non-standard situations.)

A1 General

An Inductive Loop Detection system has as its main components:

(a) Loop,
(b) Electronic Detector,
(c) Feeder Line to connect the Loop to the Detector.

The loop consists of one or more turns of insulated wire wound in a shallow, usually rectangular, slot sawed in the roadway. At the roadside the two ends of the wire are connected to the feeder cable that is led to the detector unit in the controller cabinet.

The loop and feeder cable wire actually possess a combination of resistance, inductance, and capacitance (both interwire and wire-to-earth capacitance). The size of the loop and the length of the feeder cable produce a certain frequency of oscillation that is a natural frequency of vibration for this system of wires. The detector unit must energise the loop with an AC current oscillating at the resonant frequency. This will be within the radio band, in a normal range of 20 to 200 KHz. The detector unit and wire make up a tuned circuit, of which the loop is the most prominent inductor.

The inductive element is composed of the inductance of the loop itself plus the inductance of the feeder cable. The capacitive element is dominated by the detector unit input capacitor but secondarily by the capacitance of the feeder cable, especially with long feeder cables.

A2 Loops

The radio frequency current flowing in the loop induces an electromotive force in the metal of a vehicle close to the loop, causing currents (eddy currents) to flow. These currents create their own secondary magnetic fields, which in turn induce electromotive forces back in the loop. A net decrease in the self-inductance of the loop then occurs and this raises the frequency at which the wire naturally resonates.

The greater the relative changes in the loop's inductance the greater is its 'sensitivity' and the easier it is to detect the vehicle. The various parts of a loop respond differently to the presence of metallic objects, the response depending on the object's properties and the relative orientation of the object and the loop.

A horizontal sheet of metal, as a model of the underside of a car, causes greatest changes in the loop when located above the centroid of the loop, i.e. when in the strongest vertical magnetic field.

A vertical sheet of metal, acting as a model of a bicycle or a motorcycle, causes greater change when placed parallel to a loop wire and directly above it. Because the bicycle or motorcycle is aligned along the traffic lane that it is travelling, the loop wires directed along the lane are of importance.

The size of loop determines its magnetic field and sensitivity. In general a larger area loop has a weaker field (density), and thus a lower sensitivity, near ground level than a small loop (for the same number of turns). However, with larger loops the field drops off at a lower rate with increasing height above the ground. Thus loops larger than the optimal size needed for cars should be used for the detection of higher chassis vehicles, such as trucks.

Motorcycles and bicycles interact with cross-lane magnetic fields. These fields, and therefore the effective loop sensitivity, are largest directly above the longitudinal loop wires. Because the current through the middle branch of a quadrupole loop is twice that through the side wires, the sensitivity of the loop for motorcycles and bicycles is highest over the middle longitudinal wire.

From the theory of loops and the determination of optimal sizes to detect vehicles of various chassis heights, the following findings emerge:

(a) A compromise quadrupole loop to detect cars, vans and motorcycles should not be wider than 2 m and the length along the lane need not be greater than 1.75m.

(b) To detect vehicles like trucks with a chassis at about 0.8 m above the road surface, use either a larger quadrupole (4 m across the lane by 3.5 m long) or a square loop of 2 m x 2 m. The usual alternative is to use a non-optimum loop as in (a) with consequent reduced sensitivity.

(c) If more than one quadrupole is used, i.e. in the symmetripole (or double quadrupole) configuration, consider staggering the quadrupoles across the lane to achieve a more uniform field coverage. This will improve the detection of motorcycles and bicycles.

A3 Feeders

The sensitivity of a loop-feeder combination depends on the magnitude of the loop inductance, the feeder length and 'characteristic' impedance, the frequency of operation, and the velocity of electromagnetic wave propagation in the feeder.

The single, most important, property of a feeder is its 'characteristic' impedance Z_o. Although usually determined experimentally it can be calculated from the known cross-sectional dimensions and properties of the feeder cable.

A4 Detectors

Various designs of detector units process either phase, frequency, amplitude or impedance changes to activate the detector's output relay.

Many older detector units can tolerate only a limited amount of change of capacitance in the loop wire and feeder-cable tuned circuit before failing. Unfortunately the capacitance between the wires and cable conductors varies with environmental conditions, particularly when water gets between and around them. The problem becomes much worse if the insulation is damaged and water comes in contact with the wires.

The latest digital detector units are claimed to have a much larger environmental tracking range and be able to remain in tune even with large changes in circuit capacitance and inductance.

A5 Loop-Feeder Combination

The actual inductance 'seen' by the electronic detector and the changes resulting as a vehicle interacts with the loop's magnetic field depend on the loop-feeder combination. Important factors are:

- Feeder 'characteristic' impedance,
- Frequency of operation,
- Inductance of the loop,
- Feeder length,
- Velocity of wave propagation in feeder,
- Any losses in the feeder.

Many of these factors are interrelated. For example, loop inductance multiplied by the 'angular' frequency of operation is important, not these two factors by themselves. Also the 'electrical' length of a feeder is another derived parameter of importance; it depends on the physical length of the wire, the velocity of wave propagation in the wire, and the frequency of operation.

To compare the effects of the various parameters on the loop-feeder performance, a quantity, 'sensitivity factor' (SF) was defined where:

$SF < 1$ implies a loss of sensitivity relative to loop sensitivity without the feeder.

$SF > 1$ implies an increase in sensitivity, i.e. a given change in self inductance of the loop caused by a vehicle appears enhanced at the end of the feeder.

Analytical trends predicted from a theoretical model have been confirmed experimentally and the enhanced sensitivities in certain loop-feeder combinations have also been observed.

A6 Conclusions

(a) From graphing the relationship between SF and the 'characteristic' impedance Z_o of the feeder it can be shown that the loop reactance should be approximately equal to the 'characteristic' impedance for optimum performance. This implies that if the loop inductance is low then higher frequencies and shorter feeder lines must be used.

(b) If operation at frequencies below 40 kHz is contemplated using 0.75 mm^2 (screened twin stereo) cable, of Z_o = approx. 70 Ohms, then a loop of no fewer than three turns and preferably four turns (assuming a 2 m x 1.75 m quad) must be used. If the feeder is 0.25 mm^2 (screened twin stereo) cable of characteristic impedance $Z_o > 80$ ohms, then more turns or higher frequencies must be used so that the loop reactance at the operating frequency is greater than or equal to the characteristic impedance of the feeder.

(c) Self-tuning detectors tune the loop-feeder combination to resonate at frequencies that tend to produce a sensitivity factor (SF) close to 1.

Instruction Leaflet for

INSTALLING STANDARD DETECTOR LOOPS

(For additional information and background material refer to Transit New Zealand (TNZ) Research Report No. 5, 'Installation and Maintenance of Inductive Detector Loops')

1. Preparation

1.1 Cone off one lane at a time and park a vehicle in the lane for worker protection.

1.2 From plans, and/or Figures 1, 2 and 3 in TNZ Research Report No. 5, accurately mark the position of the loop on the pavement using crayon, chalk or paint. Also mark the line of the loop 'tail' back to the junction-box behind the kerb.

1.3 If the loop passes through a manhole lid or other obstruction, or the pavement is cracked or has failed, the situation should be referred back to the designer who can consider the options outlined in TNZ Research Report No. 5.

2. Cutting the Slot

2.1 Cut the slot using a self-propelled concrete cutter with a water-cooled diamond-tipped blade. This usually gives a width of slot of 3 - 5 mm, depending on how new the blade is.

2.2 The slot should be 50 mm deep and be cut past the corners to ensure full depth of cut at each corner. The loop 'tail' slot should also be 50 mm deep in the channel at the bottom of the kerb face as future problems often occur at this location. No 'tail' slot should contain more than eight wires, i.e. wires from more than two symmetripole loops.

2.3 A chisel should be used to remove the sharp corners in the slot where two cuts meet at right angles to avoid the corner damaging the wire's insulation. This is essential if thicker wire is used which cannot be bent in a sharp right angle.

2.4 The slot should be cleaned out to remove any debris and sharp stones using a screwdriver or similar tool, and preferably blown out using compressed air which also dries out the sawcut.

3. Putting in the Wires

3.1 Use either 1.1 mm^2 standard heat-resistant appliance wire which has PVC insulation or, preferably, polypropylene-insulated wire.

3.2 Seat each of the wires down in the sawcut slot separately, without damaging the insulation, by using a disc to roll along in the slot (for example, an old concrete cutting blade fitted with a handle and able to turn). Follow the wiring directions on the plan or in Figures 1-3 in TNZ Research Report No. 5.

3.3 Bring all the wires, including those to be connected together, back to the junction-box behind the kerb. Tie one knot in a loop wire to mark the start of the winding, and two knots if it is wound around twice or, preferably, use wire marker tabs to clearly mark each wire.

4. Sealing the Slot

4.1 A flexible epoxy resin such as 'Plasticast LQB' mixed with dry silica sand is the recommended sealant. Others such as 'Mulseal', a bitumen-based product, can be used although the technique is different (see TNZ Research Report No. 5).

4.2 Cold-cured 'Plasticast' should be mixed in the proportions of 1 part compound, 1 part hardener, and 2 parts dry silica sand. Thorough mixing is essential and using an electric drill with a paint-mixing bit is strongly recommended.

4.3 Once mixed, the 'Plasticast' and sand mixture is poured into the slot directly on top of the wires, slightly overfilling it before the excess is scraped off. Care must be taken to ensure that no free water is trapped in with the sealant. However, a damp road or slot does not cause problems. Some dry silica sand should be spread over the surface of the slot before the lane is opened to traffic to prevent the epoxy sticking to car tyres before it has set.

5. Junction Box

5.1 If no convenient junction box is already in place, for example for power cables to the signal heads, a small junction box with a hinged lid should be concreted in behind the kerb, close to the loop.

5.2 In the junction-box the loop 'tails' are connected to the feeder cable which is then taken back to the controller by a duct under the berm or footpath. This duct should be concreted into the bottom of the junction-box. It is essential to also provide a protected path or duct for the loop tail wires to enter the junction-box. The loop tail wires from the loop corner to the junction-box are very vulnerable and likely to be the cause of future loop faults.

6. Connections

6.1 Make a good connection between loop wires and feeder cable by using insulated crimped connectors. Place connectors in a small plastic pill bottle, and fill this with epoxy resin to fully encapsulate the connectors and the ends of the wires. Resin is conveniently available on site if it is being used as the loop sealant. Small self-contained kits supplied with resin and bottle are also available.

7. Feeder Cable

7.1 Use a 2-core shielded feeder cable, with at least 0.75 mm^2 wires, for each loop. A multi-pair shielded instrument cable, with twisted pairs, each pair shielded from the others, can be used as a single cable for a number of loops. Feeder cables should be taken by duct back to the controller.

8. Testing

Check the resistance to earth of each loop. This should be 1 Megohm or greater if the wire has just been laid in the slot. Any lesser resistance indicates a definite break in the insulation.