Standard Practice for the Installation of Inductive Loop Detectors[1]

This standard is issued under the fixed designation E2561; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes the recommended procedure for installing inductive loop detectors in sawed slots in roadway pavement for use as a traffic monitoring device or to actuate traffic control devices such as a traffic signal. Although the practice is not intended for installing preformed loops, the practice does contain information of value for this type of loop such as recommendations for the number of turns of loop wire, number and direction of twists in the lead-in wire and cable, splice location (if needed), and grounding options.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *electronics unit, n*—a card or free-standing module that transmits energy into the wire loops typically at frequencies between 20 kHz and 100 kHz; special applications such as vehicle classification may use electronics units that transmit at frequencies above 100 kHz; electronics units allow control of sensitivity, frequency, pulse or presence operation, and timing features (that is, delay and extension) in some models and indicate system failures.

2.1.2 *inductance, n*—property of an electric circuit or of two neighboring circuits that generates an electromotive force in one circuit when the current changes in that circuit or in the neighboring circuit; expressed in units of Henrys (H).

2.1.3 *inductive loop detector, n*—those parts of an inductive loop detector system that consist of the wire loops, lead-in wires, and lead-in cable and which responds to the passage or presence of a vehicle with a decrease in inductance of the wire loop.

2.1.4 *inductive loop detector system, n*— a sensor to detect vehicles and their traffic flow properties, whose major components are: *(1)* one or more turns of insulated loop wire wound in a slot sawed in the pavement, *(2)* lead-in wires extending from the loop wire to a curbside or shoulder pull box *(3)* lead-in cable spliced to the lead-in wires that extends from the pull box to the controller cabinet, and *(4)* electronics unit housed in the controller cabinet.

2.1.5 *insulation resistance, n*—the resistance measured with a megohmmeter between a conductor and the outer insulating jacket of a wire or cable.

2.1.6 *lead-in cable, n*—shielded wire that is spliced to the lead-in wires in the pull box and which extends from the pull box to the controller cabinet, where it is connected to the electronics unit; also known as home-run cable, transmission line, or feeder cable.

2.1.7 *lead-in wires, n*—a continuation of the loop wire that runs from the physical edge of the loop to the pull box; usually twisted together to form a wire pair.

2.1.8 *loop system sensitivity, n*—smallest change of inductance at the electronics unit terminals that will result in a signal that indicates the passage or presence of a vehicle.

2.1.9 *loop wire, n*—one-conductor insulated wire used for both the wire loop and the lead-in wire; may be jacketed or encased in tube.

2.1.10 *pull box, n*—a container that encloses the splices between the lead-in wires and the lead-in cable; when installed underground, the removable cover is aligned flush with the ground surface; also known as a handhole, splice box, or junction box.

2.1.11 *quadrupole loop, n*—typically a rectangular wire loop configuration with a longitudinal slot extending along the center of the loop so that the wire can be installed in a

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figure-eight pattern; the quadrupole loop produces four electromagnetic poles instead of the normal two, thus improving the sensitivity to small vehicles and minimizing splashover; quadrupole loops are also used in a diagonal configuration to detect bicycles (**1**)[2].

2.1.12 *saw cut, n*—opening made in the roadway pavement using a pavement saw into which the wire loop or lead-in wires are inserted; also referred to as a slot.

2.1.13 *splashover, n*—unwanted actuation caused by a vehicle in a lane adjacent to the lane in which a sensor is located.

2.1.14 *traffic monitoring device, n*—equipment that may count and classify vehicles and measure vehicle flow characteristics such as vehicle speed, lane occupancy, turning movements, and other parameters typically used to portray traffic movement.

2.1.15 *wire loop, n*—one or more turns of loop wire wound in a slot sawed in the pavement.

3. Summary of Practice

3.1 The major steps in installing an inductive loop detector system are:

3.1.1 Preparing plans and specifications,
3.1.2 Securing the work zone,
3.1.3 Installing underground conduit and pull box,
3.1.4 Cutting a slot for the loop wire and lead-in wires,
3.1.5 Installing the wires,
3.1.6 Twisting the lead-in wires,
3.1.7 Testing for proper operation of the wire loop and lead-in wires,
3.1.8 Sealing the saw cuts,
3.1.9 Splicing the lead-in wires to the lead-in cable in a pull box,
3.1.10 Connecting the lead-in cable to the terminal strip in the cabinet,
3.1.11 Testing for proper operation of the wire loop, lead-in wires, and lead-in cable assembly, and
3.1.12 Connecting the terminal strip to the electronics unit.

3.2 Procedures needed to ensure work zone safety, traffic control, and installation of conduit, pull box, controller cabinet, and any equipment usually placed in the cabinet, such as the electronics unit, are not covered by this practice.

4. Significance and Use

4.1 This practice provides a method for the in-road installation of an inductive loop detector that consists of wire loops, lead-in wires, and lead-in cable. The practice is intended for installing wires in saw cuts made in the roadway surface and not for installing preformed loops that may be encased in a protective enclosure such as plastic conduit. Typical components of an inductive loop detector system are illustrated in Fig. 1. Modern inductive loop detector electronic units are capable of detecting vehicles even if the wire loop is laid on reinforcing steel before concrete is placed.

5. Procedure

5.1 Scale drawings of the installation site showing the geometry of the roadway and the exact location of the components of the inductive loop detector in relation to the pavement or lane markings are required. The drawings shall indicate the location and specifications for the wire loop (typically centered in the middle of the lane) and lead-in wires, lead-in cable, pull boxes, conduit, power sources, pavement materials and sealants, cabinets, and electronic units required for the installation. The accuracy of the drawings has a primary effect on the quality of the installation as it provides fundamental guidance for the installation crew and becomes part of the procurement package used to acquire the needed components.

5.2 The dimensions of the loops and number of turns are selected according to the types of vehicles to be detected, vehicle under-carriage height, lane width, length of lead-in cable, and, for some applications, the data desired. Inductive loops should not be wider than 6 ft (183 cm) in a 12 ft (366 cm) lane. Loops should not be less than 5 ft (152 cm) wide because the detection distance between the road surface and the vehicle undercarriage becomes limited as the detection distance is approximately equal to one-half to two-thirds of the loop width (such as, the minimum loop dimension). Since the inductance

[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

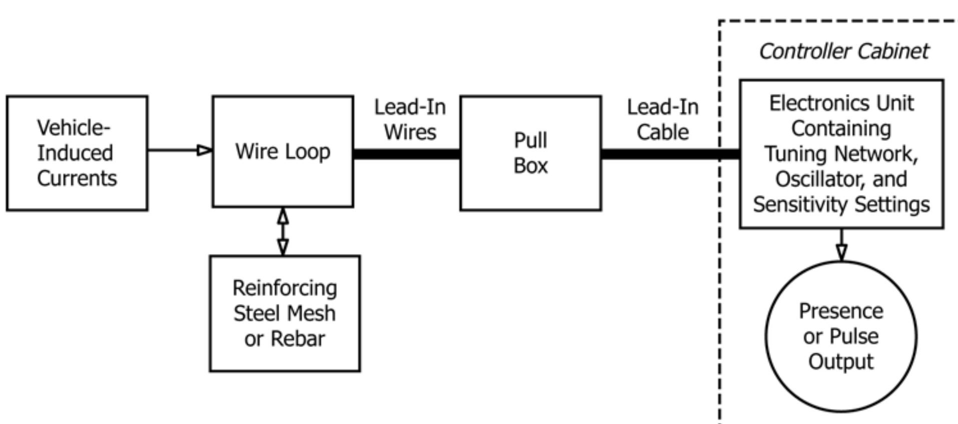

FIG. 1 Inductive Loop Detector System (Notional) (2)

of the loop must be greater than the inductance of the lead-in cable [that is, 21 µH per 100 ft (69 µH per 100 m) of #14 AWG lead-in cable] for the loop system to have sufficient sensitivity, Klein et al (2) recommend that the inductance of single loops and series, parallel, or series-parallel combinations of loops be greater than 50 mH to ensure stable operation of the inductive loop detector system. Guidance for the number of turns needed to produce the required inductance value is found in Klein et al (2) as follows: "If the loop perimeter is less than 30 ft (9 m), use three turns of wire; if the loop perimeter is greater than 30 ft (9 m), use two turns of wire." Appendix X1 contains tables showing the inductance values for various size loops and shapes (such as, rectangular, quadrupole, and circular).

5.3 Manpower and the type and amount of installation material and equipment must be determined before the installation is begun. The required materials should be available in sufficient quantities to avoid any interruptions in the installation process. Table 1 contains a typical materials list for constructing an inductive loop detector. Table 2 contains typical equipment needed to install inductive loops. The equipment required for traffic control and installation of conduit, pull box, controller cabinet, and any equipment usually placed in the cabinet are not included.

5.4 To protect the integrity of the pavement and loop installation, cracks and joints in the roadway pavement should not be located closer than 18 in. (45 cm) upstream or downstream of the inductive loop detector being installed. Some agencies relax this constraint to 1 ft (0.3m) (5). Saw cuts for other wire loops or other in-roadway sensors must not be located closer than 2 ft (0.6 m) upstream or downstream of the inductive loop detector being installed (6). The distance between lead-in saw cuts shall be 6 in. (15 cm) minimum until they are within 1 ft (0.3 m) of the edge of the pavement or curb, at which point they may be placed closer together (7). Lead-in saw cuts shall not be closer than 12 in. (30 cm) from adjacent loop edges (6).

TABLE 1 Typical Materials List for 6-ft × 6-ft (1.8-m × 1.8-m) 3-Turn Inductive Loop

Description	Quantity/Loop
Loop and lead-in wires, such as., IMSA 51–3 or 51-5 (3)	200 ft (60 m)[A]
Lead-in cable, e.g., IMSA 50-2 (3)	200 ft (60 m) or more[A]
Tape ¾ in. (20 mm) rubber splicing[B]	1 roll per 6 loops
Loop sealant (per loop)	6 tubes or appropriate number of gallon containers
Sealant [per 4 ft (1 m) of lead-in cable]	1 tube
Caulking gun	1
Backer rod	As required
Cement, sand, or talc	1 bag
Duct seal for conduit	1 block
Pull box (sized as required)	1 per splicing location
Concrete	As required per pull box
Splice kits	1 per loop
Solder	As required
Surge voltage protector	As required
Conduit	As required

[A] Quantity varies according to site requirement including loop location.

[B] Some states specify a first layer of PVC tape followed by a layer of rubber tape or heat shrinkage polyolefin tubing as insulation on the lead-in wire-to-lead-in cable splice (4).

TABLE 2 Typical Installation Equipment List for Inductive Loop Detectors

Item	Description and Use
Pavement saw	Creates saw cut for inserting wires. Typically a self-propelled 18- to 65-hp saw equipped with ¼- to ⅜-in. (6- to 10-mm) thick blade (abrasive or diamond), water valve, depth gauge, and horizontal guide
Water supply	Cools diamond blade and cleans out sawed slots
Jackhammer	Bores holes through concrete curb
Air compressor	Used with jackhammer and to clean and dry sawed slots
Chisel and hammer	Removes sharp edges at corners of saw cuts
Blunt tool	3⁄16-in. to ¼-in. (5-mm to 6-mm) thick wood paddle for seating wire in sawed slot
Wire twisting tool	Provides symmetrical twists in the lead-in wires
Template/Straight edge	Marks outlines of loops on pavement
Trenching machine	Creates trench for burying cable underground
Volt-ohm meter and megohmmeter	Tests wires for continuity and insulation resistance
Inductive loop system analyzer	Tests continuity and inductance of inductive loop detector system
Soldering device	Enables soldering of wire connections using a butane torch with a soldering tip or an electric soldering iron
12-ft (4-m) straight edge, chalk line, marking paint, crayons,imdb.com or chalk	Marks location of all saw cuts
Wire cutters, lineman's pliers	Aids in cutting and splicing wires
Fish tape	Aids wire pulling
Measuring tape or wheel	Minimum of 100-ft (30-m) tape to facilitate measurements for placement of loop wires and lead-in wires
Power drill	Facilitates sealant mixing

5.5 After securing the work zone with appropriate barricades, cones, and so forth to divert traffic from the work area, mark the pavement to show the size and shape of the loop and lead-in wires to be installed and the required saw cuts. Lumber crayon, chalk, or spray paint is typically used for this purpose. If available, a template of the proper size and shape for the wire loop is recommended. However, a straight edge or a tightened string can be used as a marking guide. It is critical that the markings reflect the location shown on the construction plans.

5.6 Cut slots into the roadway pavement for the loop wire and lead-in wires using a pavement saw. Do not allow the saw cut in the pavement to deviate by more than 1 in. (25 mm) from the markings for the cut (7). The depth of the saw cut shall be sufficient to allow at least a 1-in. (25-mm) cover of sealant to be placed above the top loop wire or backer rod if such is used (7, 8). Some agencies use 3 and 4 in. (76 and 102 mm) slot depths for multiple wire-turn loops to prevent future grinding and overlay procedures from destroying the loop (8). Saw cut depth should be verified at several points during the cutting process to ensure a constant value. The width of the saw cut shall be sufficient to allow encapsulation of the wires by the sealant. Several methods are available to prevent damage to the wire at the corners of a square or rectangular loop by removing the 90-deg angle. In the first method, diagonal cuts are sawed at the four corners, allowing a minimum margin of 1 ft (30 cm) from the apparent corner as shown on the left of Fig. 2. When

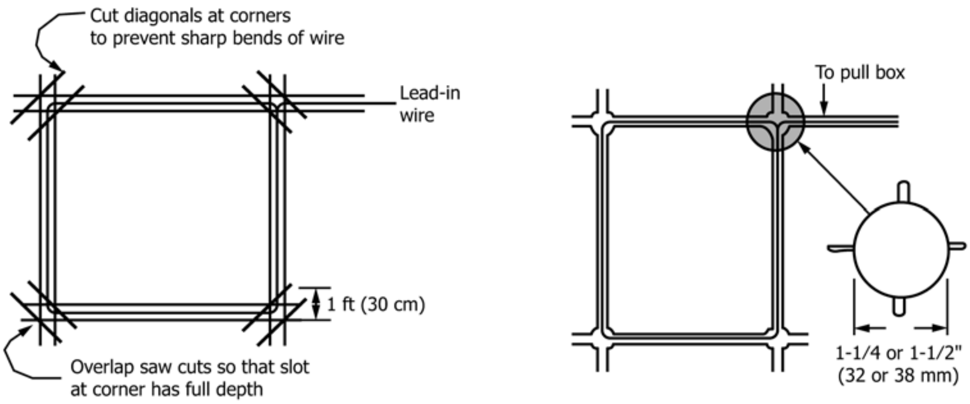

FIG. 2 Saw Cut Corner Treatments (8)

applying this method, ensure that the bottom of the saw blade completely passes through all intersections creating saw cuts that are clean and well defined. All jagged edges and protrusions must be removed with a small chisel and hammer. In the second method depicted on the right of Fig. 2, 1¼- or 1½-in. (32- or 38-mm) holes are drilled at the corners of the loop before the slots are sawcut. Drilling the corners is faster (15 sec per drilled hole) than cutting diagonal slots and the integrity of the pavement is better preserved (5, 9, 8). A 3-in. (76-mm) hole centered on the circumference of a circular loop may be drilled to reduce stress on the lead-in wires run to the pull box (9). In the third method (not illustrated), straight sawcuts are overlapped at the corners (i.e., no diagonal sawcuts are made) and then the inside corner is removed using a small hand chisel and hammer or small air-powered impact chisel, thus creating a smooth curve for the wire to follow.

5.7 Clean out debris from saw cuts. Cleaning should take place immediately after the sawing is complete. Cutting dust, grit, oil, and contaminants must be removed from the slots by flushing them clean with pressurized water and then drying with compressed oil-free air. Any dirt or mud stuck to the bottom or sides of the saw cuts must be removed. The saw cuts must be clean and dry before inserting the wires.

5.8 Confirm that the roll of loop wire contains sufficient length to lay the specified number of turns in the loop saw cut, plus a length equal to twice the distance from the pull box to the first corner of the loop saw cut, plus 3 to 5 ft (91 to 152 cm) of slack to be laid in the pull box for each of the start and finish ends of the loop wire, depending on agency policy. Small holes in the insulation caused by manufacturing flaws or damage during transport may be found prior to installation by immersing the rolls of loop wire in a barrel of water and using a megohmmeter to verify the insulation resistance.

5.9 Starting at the pull box location (or first entered pole or pedestal), allow 3 to 5 ft (91 to 152 cm) for slack and then lay the wire alongside the lead-in wire saw cut and run it to the point where the lead-in wire saw cut meets the loop saw cut. Place the wire into the loop saw cut and wrap it the prescribed number of turns and direction around the saw cut to form the loop. The first turn of loop wire is placed in the bottom of the saw cut, with each subsequent turn placed on top of the preceding one (7). Fig. 3 shows the winding detail for a typical square loop, round loop, and rectangular quadrupole loop. If a bead of sealant is placed at the bottom of the cut to aid encapsulation, apply the sealant before inserting the turns of wire. Each turn of a given loop must be wound in the same

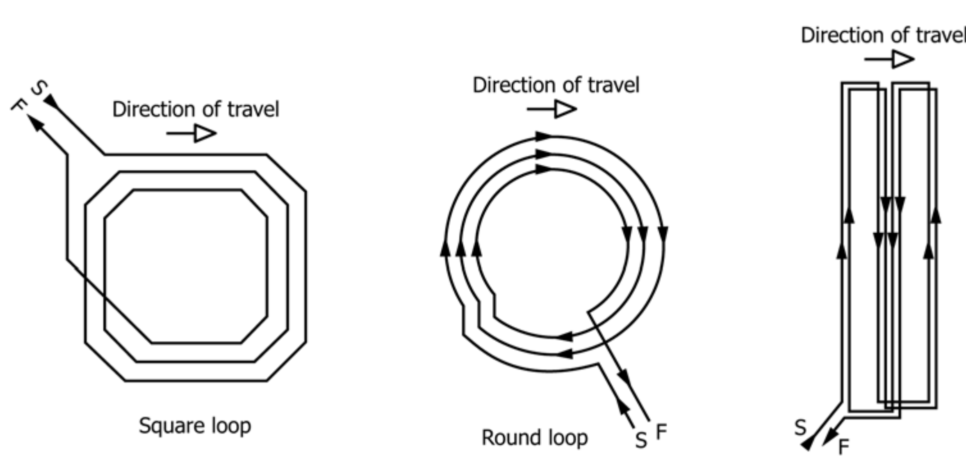

FIG. 3 Inductive Loop Winding Detail For Square, Round, And Rectangular Quadrupole Loops (Typical). S And F Indicate The Start And Finish Of The Loop, Respectively (1).

direction. Be sure to carefully count the number of turns in the slot as it is a common error to miscount. Adjacent loops using the same electronics unit shall be wound in the opposite direction to minimize interference. Run the remaining length of wire alongside the lead-in wire saw cut to the pull box location. Cut the wire remembering to keep 3 to 5 ft (91 to 152 cm) of slack at each end.

5.10 Twist the lead-in wires belonging to the start and finish ends of the loop turns to reduce crosstalk and noise pickup and insert the twisted wires into the slot cut for them. Between three and five twists per foot (10 and 16 twists per metre) are recommended, depending on agency policy and manufacturers' recommendations. Procedures for twisting lead-in wires are found in Klein et al (**7**). A maximum of one (**5**, **7**, **9**) or two (**6**) lead-in wire pairs shall be placed in a sawed slot that runs to the hole or conduit that leads to the pull box. Wire pairs from adjacent loops shall be twisted in opposite directions.

5.11 Use a blunt instrument such as a 3⁄16-in. to 1⁄4-in. (5-mm to 6-mm) thick wood paddle to seat the wires in the saw cuts as close to the bottom of the cut as possible. Make certain that the outer jacket of the wire is not damaged. Never use a sharp instrument such as a screwdriver for this procedure as it will easily penetrate the wire insulation.

5.12 Insert the twisted lead-in wires into the pull box. Mark the loop pairs in the pull box with the loop number, start (S) and finish (F) labels, and signal phase (when loops are installed at signalized intersections (**6**, **7**).

5.13 Test each loop and lead-in wire-pair combination at the pull box for continuity, circuit resistance, and insulation resistance before filling the saw cuts. The circuit resistance between the ends of the inductive loop detector lead-in wires should be less than 1 ohm/100 ft (3 ohms/100 m) of wire when measured with a volt-ohm meter. The insulation resistance should be greater than 100 megohms when measured with a megohmmeter. A method for measuring the inductance of the wire loop and lead-in wire-pair combination and verifying that the installed number of turns is the correct value is described in Appendix X2.

5.14 Secure the wire loop and lead-in wires in the roadway by applying loop sealant to the slots to cover the wires. A 3⁄16 to 1⁄4-in. (5 to 6-mm) thick wood paddle should be used to hold down the wire as the sealant is being poured. Some installers place a bead of sealant at the bottom of the cut to aid encapsulation as illustrated on the left of Fig. 4 (**7**). Others force backer rod into the slot over the wires as shown on the right of Fig. 4. The remainder of the slot is then filled with sealant. The backer rod assures a shallow layer of sealant, reducing tensile stresses and leaving the wires free to adapt to shifting of the pavement. Backer rod may also be inserted into the slot in short pieces of approximately one inch (2.5 cm) length every 1 to 2 ft (0.3 to 0.6 m) to anchor the wire in the slot before applying the sealant. The middle of Fig. 4 shows the simplest sealant application technique, that of only applying sealant over the wires. For installation in an existing roadway, loop sealant should be poured to within 1⁄8 in. (3 mm) of the surface, although some agencies require the sealant to be flush with the pavement surface to inhibit water collection and consequent damage from freeze-thaw cycles. For installation prior to an overlay, the saw cut should be filled completely with sealant before paving. For installations in an existing roadway, allow sufficient time for the loop sealant to form a surface film. Then dust the sealant with cement, sand, or talc to prevent tracking of the sealant. Remove excess sealant from the road surface without the use of solvents when the sealant is dry enough to prevent impairing the quality of the saw-cut seal (**10**). Ensure that the sealant has cured completely before allowing vehicular traffic to travel over the sealant (**7**).

5.15 Measure and cut a length of lead-in cable to connect the lead-in wires in the pull box to the terminal strip in the cabinet. No less than 18 in. (46 cm) of cable should be

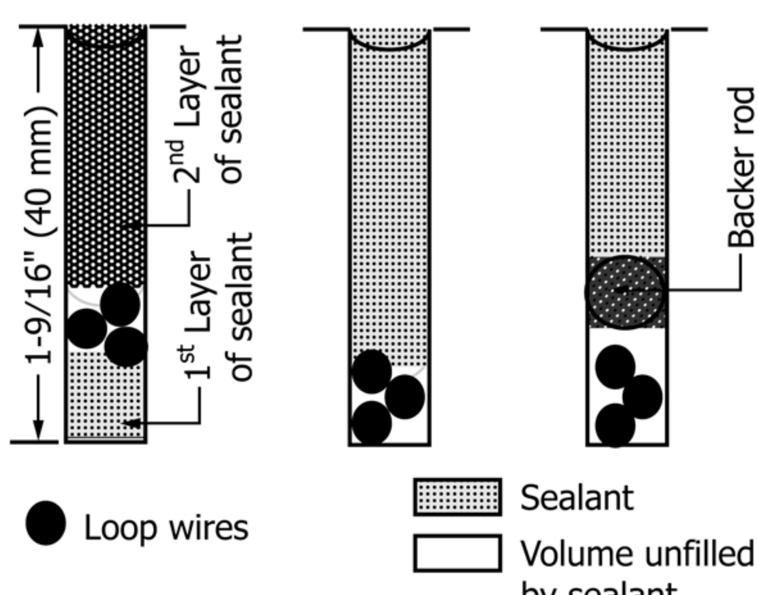

FIG. 4 Sealant Application Methods (8)

provided as slack in the cabinet. The lead-in cable should have high quality insulation such as polyethylene, a polyethylene jacket, and a shield. Multiconductor lead-in cable shall be used with three to six twists per foot (10 to 20 twists per meter).

5.16 Solder each end of the lead-in wires to a corresponding end of the lead-in cable in the pull box to form a single spliced wire using splicing, insulating, and waterproofing methods described in Klein, et al (**8**). All splices must be easily accessible for inspection and maintenance. Insulate the end of the cable located in the pull box. The lead-in cable shall not be connected to ground at the pull box. Fig. 5 shows the interconnections of the twisted wire pairs, splice location in the pull box, and grounding of the shield at the cabinet (if required).

5.17 Where drainage is a problem, it may be beneficial to use wire hangers to suspend the twisted-pair loop wires and the splice to the shielded lead-in cable as near as possible to the top of the pull box to prevent their immersion in water (**4**).

5.18 The lead-in cable from the pull box to the controller cabinet is buried bare or placed in conduit below the surface of the ground and run to the cabinet. In either case, the cable should be buried in a trench at least 18 in. (46 cm) below the surface as specified in the installation plans. If conduit is used, it should be waterproof. The number of lead-in cables placed in one trench or conduit shall be appropriate to the trench or conduit size. To the extent possible, adjacent cables in the same trench or conduit should have pairs twisted in opposite directions. Lead-in cables shall not be spliced between the pull box and the controller cabinet terminals.

5.19 After placing the cable in the trench, the trench should be backfilled in layers not to exceed 6 in. (15 cm). Each layer should be compacted with mechanical tampers to the approximate density of the surrounding ground. No extra material should be left over when the backfill of the trench is complete.

5.20 Terminate the lead-in cable inside the controller cabinet at the field terminal strip.

5.21 Grounding of the loop at the cabinet shall be in accordance with the recommendations of the equipment manufacturer and agency policy (**8**). Fig. 6 illustrates the recommended method of connecting the shield to ground if grounding is used. This allows most electrical disturbances or interference to be safely grounded without affecting the performance of the lead-in cable and inductive loop detector. Some equipment manufacturers and agencies recommend that the shield of the cable not be connected to a ground terminal. The justification for not grounding is that the inductive loop detector system operates at low voltage and may, therefore, be sensitive to current flows induced by more than one grounding point. Such ground loops can be produced by grounding the shield at the cabinet since the cabinet and electronics unit are already connected to ground.

5.22 Verify that each loop circuit is installed and performing properly by measuring its continuity, circuit resistance, and insulation resistance at the roadside cabinet. The circuit resistance measured between the ends of the two conductors corresponding to the loop circuit should be less than 1 ohm/100 ft (3 ohms/100 m) of wire. The insulation resistance should be greater than 100 megohms. Measure the frequency at which the inductive loop detector system resonates using a frequency tester or inductive loop system analyzer to determine the loop system inductance. If these checks are satisfactory, the inductive loop detector is ready for use.

5.23 The measured values from the tests should be recorded on the wiring plan or on an inspection report, a copy of which

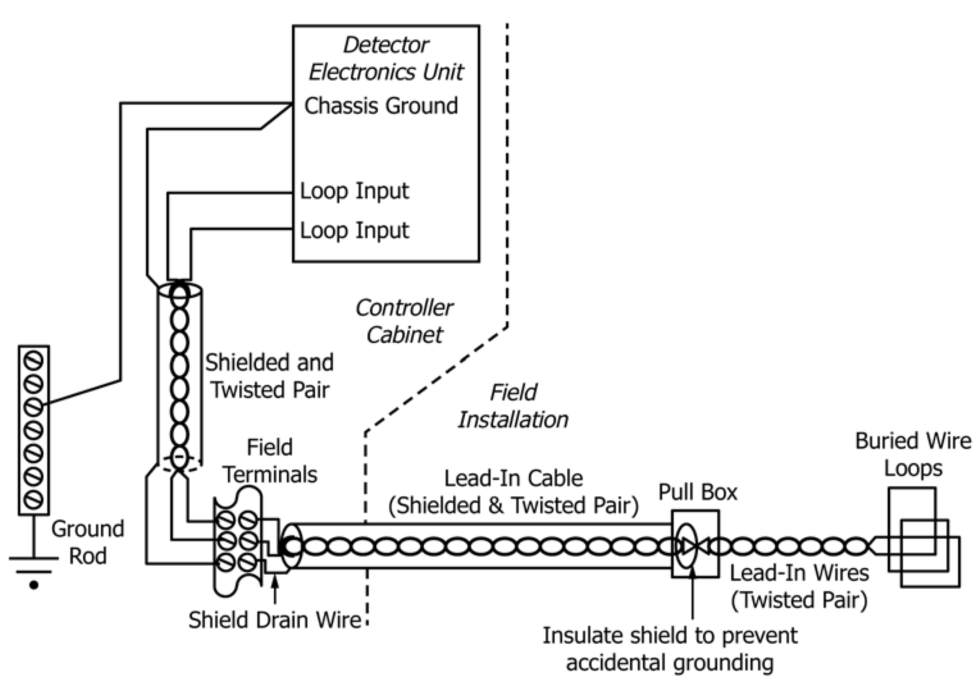

FIG. 5 Inductive Loop Detector System Interconnections (8)

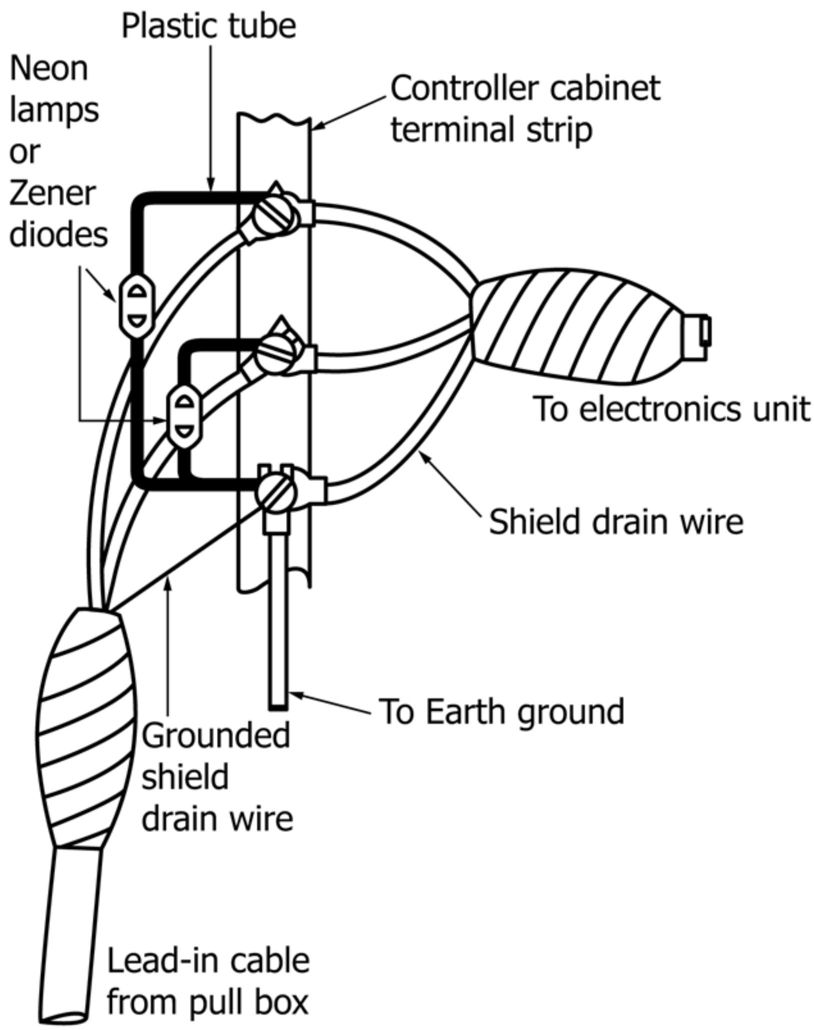

FIG. 6 Lead-In Cable Grounding At The Field Terminal Strip In The Cabinet (8)

is left in the controller cabinet. This information is used for future testing and maintenance.

6. Keywords

6.1 grounding; inductive loop; inductive loop detector; lead-in wire; lead-in cable; loop wire; sealant; splice; wire loop

APPENDIXES

(Nonmandatory Information)

X1. LOOP INDUCTANCE TABLES

X1.1 Significance and Use

X1.1.1 Loop inductance values calculated for rectangular, quadrupole, and circular loops at excitation frequencies of 1, 20, 40, and 60 kHz are given in these tables (**11**). The frequency *f* at which the values apply is shown as part of the table title. The applicable length of a 6-ft (1.8-m) wide retangular or quadrupole loop or the diameter of a circular loop is given in the first column, while the number of turns is stated in the first row.

X1.2 Loop Dimensions for Which Inductance Values Are Provided

X1.2.1 Rectangular and quadrupole loop inductance values for 6-ft (1.8-m) wide loops are displayed for 6 through 20 ft (1.8 through 6 m) loop lengths in 1 ft (0.3 m) increments and for 20 through 50 ft (6 through 15 m) loop lengths in 5 ft (1.5 m) increments. Circular loop inductance values are listed for loop diameters of 4, 5, 6, 7, and 8 ft (1.2, 1.5, 1.8, 2.1, and 2.4 m). All tables show inductance values for 1 through 7 turns of loop wire.

X1.3 Interpretation of Inductance Value

X1.3.1 The loop inductance shown in Tables Tables X1.1-X1.11 to Table X1.12 is the apparent value expressed in mH that includes loop resistance and capacitance effects. It thus represents the value actually measured when an appropriate measuring device is used.

X1.4 Loop Inductance Tables

TABLE X1.1 Rectangular Loop Inductance in µH at *f* = 1 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	10.53	36.02	74.46	124.67	185.81	257.24	338.44
7 (2.1)	11.52	39.49	81.72	136.94	204.23	282.91	372.40
8 (2.4)	12.51	42.94	88.94	149.12	222.52	308.38	406.08
9 (2.7)	13.50	46.38	96.12	161.25	240.71	333.71	439.58
10 (3.0)	14.48	49.80	103.28	173.32	258.83	358.94	472.94
11 (3.3)	15.46	53.22	110.42	185.37	276.90	384.09	506.20
12 (3.7)	16.44	56.63	117.54	197.39	294.93	409.19	539.38
13 (3.9)	17.42	60.04	124.65	209.39	312.93	434.25	572.51
14 (4.3)	18.40	63.44	131.76	221.38	330.91	459.27	605.59
15 (4.6)	19.37	66.84	138.85	233.35	348.87	484.27	638.63
16 (4.9)	20.35	70.23	145.95	245.32	366.81	509.24	671.64
17 (5.2)	21.32	73.63	153.03	257.27	384.74	534.09	704.63
18 (5.5)	22.30	77.02	160.12	269.22	402.66	559.13	737.59
19 (5.8)	23.27	80.41	167.20	281.16	420.57	584.06	770.54
20 (6.1)	24.25	83.80	174.27	293.10	438.47	608.97	803.47
25 (7.6)	29.12	100.74	209.63	352.73	527.89	733.42	967.96
30 (9.1)	33.98	117.66	244.95	412.31	617.22	857.75	1132.29
35 (10.7)	38.84	134.57	280.25	471.85	706.51	982.00	1296.52
40 (12.2)	43.71	151.48	315.55	531.38	795.76	1106.21	1460.70
45 (13.7)	48.57	168.38	350.83	590.89	885.00	1230.40	1624.85
50 (15.2)	53.43	185.28	386.11	650.39	974.22	1354.56	1788.98

[A]of a 6-ft (1.8-m) wide loop

TABLE X1.2 Rectangular Loop Inductance in µH at f = 20 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	10.50	35.96	74.39	124.62	185.85	257.48	339.07
7 (2.1)	11.49	39.43	81.65	136.90	204.32	283.27	373.23
8 (2.4)	12.48	42.88	88.87	149.10	222.66	308.88	407.26
9 (2.7)	13.46	46.31	96.05	161.24	240.92	334.37	441.10
10 (3.0)	14.44	49.73	103.21	173.34	259.12	359.80	474.86
11 (3.3)	15.42	53.15	110.35	185.42	277.28	385.17	508.58
12 (3.7)	16.40	56.56	117.48	197.47	295.41	410.53	542.29
13 (3.9)	17.37	59.96	124.60	209.51	313.54	435.87	576.01
14 (4.3)	18.35	63.36	131.71	221.54	331.65	461.22	609.76
15 (4.6)	19.32	66.75	138.82	233.57	349.76	486.58	643.54
16 (4.9)	20.30	70.15	145.92	245.59	367.87	511.95	677.38
17 (5.2)	21.27	73.54	153.02	257.61	385.99	537.35	711.28
18 (5.5)	22.24	76.93	160.12	269.62	404.11	562.78	745.24
19 (5.8)	23.21	80.32	167.21	281.65	422.25	588.24	779.28
20 (6.1)	24.19	83.71	174.31	293.67	440.40	613.73	813.41
25 (7.6)	29.04	100.65	209.79	353.85	531.41	741.89	985.51
30 (9.1)	33.90	117.58	245.31	414.22	622.99	871.46	1160.59
35 (10.7)	38.75	134.52	280.89	474.83	715.29	1002.77	1339.33
40 (12.2)	43.60	151.47	316.54	535.75	808.46	1136.14	1522.43
45 (13.7)	48.45	168.43	352.28	597.01	902.63	1271.89	1710.61
50 (15.2)	53.30	185.41	388.13	658.67	997.93	1410.37	1904.64

[A] of a 6-ft (1.8-m) wide loop

TABLE X1.3 Rectangular Loop Inductance in µH at f = 40 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	10.44	35.86	74.28	124.61	186.13	258.43	341.24
7 (2.1)	11.43	39.33	81.55	136.94	204.76	284.58	376.22
8 (2.4)	12.41	42.77	88.78	149.19	223.28	310.63	411.12
9 (2.7)	13.39	46.20	95.97	161.40	241.75	336.65	446.04
10 (3.0)	14.37	49.62	103.14	173.59	260.21	362.21	481.07
11 (3.3)	15.34	53.03	110.30	185.76	278.66	388.76	516.24
12 (3.7)	16.32	56.43	117.45	197.92	297.14	414.92	551.61
13 (3.9)	17.29	59.83	124.60	210.09	315.64	441.17	587.21
14 (4.3)	18.26	63.23	131.74	222.27	334.18	467.54	623.08
15 (4.6)	19.23	66.62	138.88	234.46	352.77	494.04	659.24
16 (4.9)	20.20	70.02	146.03	246.66	371.42	520.68	695.72
17 (5.2)	21.17	73.41	153.18	258.89	390.13	547.49	732.56
18 (5.5)	22.14	76.81	160.33	271.13	408.91	574.47	769.77
19 (5.8)	23.11	80.20	167.48	283.40	427.76	601.63	807.38
20 (6.1)	24.07	83.59	174.64	295.69	446.70	628.99	845.42
25 (7.6)	28.91	100.57	210.56	357.63	542.74	769.19	1043.04
30 (9.1)	33.75	117.57	246.71	420.50	641.54	916.19	1255.80
35 (10.7)	38.58	134.62	283.16	484.52	743.73	1071.72	1488.10
40 (12.2)	43.42	151.72	319.96	549.90	849.98	1237.75	1745.46
45 (13.7)	48.25	168.88	357.16	616.85	961.04	1416.63	2035.03
50 (15.2)	53.09	186.12	394.82	685.62	1077.75	1611.21	2366.36

[A] of a 6-ft (1.8-m) wide loop

TABLE X1.4 Rectangular Loop Inductance in μH at *f* = 60 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	10.40	35.79	74.25	124.77	186.85	260.30	345.26
7 (2.1)	11.38	39.25	81.53	137.19	205.75	287.11	381.59
8 (2.4)	12.36	42.69	88.78	149.56	224.60	313.94	418.12
9 (2.7)	13.34	46.12	96.00	161.90	243.46	340.88	454.97
10 (3.0)	14.31	49.54	103.21	174.24	262.36	367.98	492.24
11 (3.3)	15.28	52.95	110.41	186.59	281.34	395.31	530.03
12 (3.7)	16.25	56.36	117.61	198.96	300.41	422.89	568.41
13 (3.9)	17.22	59.76	124.81	211.37	319.59	450.76	607.46
14 (4.3)	18.19	63.16	132.02	223.81	338.89	478.96	647.24
15 (4.6)	19.16	66.57	139.24	236.29	358.34	507.52	687.83
16 (4.9)	20.12	69.97	146.47	248.83	377.94	536.47	729.31
17 (5.2)	21.09	73.37	153.70	261.41	397.71	565.85	771.74
18 (5.5)	22.05	76.78	160.96	274.06	417.66	595.69	815.22
19 (5.8)	23.02	80.18	168.23	286.77	437.80	626.02	859.83
20 (6.1)	23.98	83.59	175.51	299.55	458.15	656.87	905.65
25 (7.6)	28.81	100.67	212.62	364.62	563.43	850.32	1156.67
30 (9.1)	33.63	117.83	249.52	432.01	675.89	1003.04	1456.51
35 (10.7)	38.45	135.10	287.53	502.29	797.51	1211.88	1828.33
40 (12.2)	43.28	152.49	326.39	576.05	930.74	1456.41	2312.27
45 (13.7)	48.11	170.04	366.24	653.98	1078.66	1750.56	2979.87
50 (15.2)	52.95	187.75	407.21	736.88	1245.26	2115.67	3977.12

[A]of a 6-ft (1.8-m) wide loop

TABLE X1.5 Quadrupole Loop Inductance in μH at *f* = 1 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	17.73	61.33	127.13	212.86	316.90	438.00	575.12
7 (2.1)	20.06	69.53	144.29	241.80	360.23	498.17	654.45
8 (2.4)	22.38	77.72	161.44	270.73	403.55	558.32	733.75
9 (2.7)	24.70	85.91	178.59	299.65	446.85	618.46	813.03
10 (3.0)	27.02	94.09	195.74	328.57	490.15	678.59	892.31
11 (3.3)	29.34	102.28	212.88	357.49	533.45	738.71	971.58
12 (3.7)	31.67	110.47	230.03	386.41	576.75	798.84	1050.85
13 (3.9)	33.99	118.65	247.18	415.33	620.05	858.96	1130.11
14 (4.3)	36.31	126.84	264.32	444.24	663.34	919.08	1209.38
15 (4.6)	38.63	135.03	281.47	473.16	706.64	979.20	1288.65
16 (4.9)	40.95	143.21	298.61	502.08	749.93	1039.33	1367.91
17 (5.2)	43.27	151.40	315.76	530.99	793.23	1099.45	1447.18
18 (5.5)	45.60	159.59	332.91	559.91	836.52	1159.57	1526.45
19 (5.8)	47.92	167.77	350.05	588.83	879.82	1219.70	1605.73
20 (6.1)	50.24	175.96	367.20	617.74	923.12	1279.82	1685.00
25 (7.6)	61.85	216.89	452.92	762.33	1139.61	1580.47	2081.42
30 (9.1)	73.45	257.83	538.65	906.92	1356.11	1881.15	2477.90
35 (10.7)	85.06	298.76	624.38	1051.52	1572.63	2181.88	2874.48
40 (12.2)	96.67	339.69	710.11	1196.12	1789.18	2482.66	3271.16
45 (13.7)	108.28	380.63	795.85	1340.73	2005.75	2783.49	3667.95
50 (15.2)	119.89	421.56	881.59	1485.36	2222.35	3084.39	4064.88

[A]of a 6-ft (1.8-m) wide loop

TABLE X1.6 Quadrupole Loop Inductance in μH at f = 20 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	17.69	61.26	127.08	212.98	317.49	439.56	578.46
7 (2.1)	20.01	69.45	144.26	242.03	361.15	500.51	659.37
8 (2.4)	22.32	77.64	161.44	271.10	404.88	561.64	740.66
9 (2.7)	24.64	85.82	178.63	300.21	448.71	622.98	822.40
10 (3.0)	26.96	94.01	195.83	329.35	492.64	684.58	904.66
11 (3.3)	29.28	102.20	213.05	358.53	536.70	746.45	987.48
12 (3.7)	31.59	110.40	230.27	387.77	580.88	808.63	1070.92
13 (3.9)	33.91	118.59	247.51	417.05	625.20	871.14	1155.04
14 (4.3)	36.23	126.79	264.76	446.39	669.68	934.00	1239.90
15 (4.6)	38.55	134.99	282.03	475.79	714.33	997.25	1325.55
16 (4.9)	40.86	143.19	299.32	505.25	759.15	1060.91	1412.05
17 (5.2)	43.18	151.40	316.62	534.78	804.16	1125.01	1499.47
18 (5.5)	45.50	159.61	333.95	564.38	849.37	1189.58	1587.86
19 (5.8)	47.82	167.82	351.29	594.05	894.79	1254.64	1677.30
20 (6.1)	50.14	176.03	368.66	623.81	940.43	1320.24	1767.86
25 (7.6)	61.73	217.17	455.85	773.93	1172.42	1657.20	2239.86
30 (9.1)	73.32	258.42	543.75	926.67	1411.89	2012.31	2751.56
35 (10.7)	84.92	299.81	632.50	1082.59	1660.59	2390.42	3315.54
40 (12.2)	96.53	341.36	722.23	1242.29	1920.49	2797.33	3948.06
45 (13.7)	108.14	383.08	813.10	1406.39	2193.80	3240.10	4670.95
50 (15.2)	119.75	425.01	905.26	1575.59	2483.09	3727.59	5514.46

[A]of a 6-ft (1.8-m) wide loop

TABLE X1.7 Quadrupole Loop Inductance in μH at f = 40 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	17.61	61.14	127.09	213.56	319.54	444.65	589.12
7 (2.1)	19.92	69.33	144.35	242.97	364.23	508.03	675.03
8 (2.4)	22.23	77.52	161.64	272.50	409.28	572.25	762.72
9 (2.7)	24.54	85.72	178.97	302.18	454.75	637.45	852.47
10 (3.0)	26.85	93.92	196.35	332.02	500.67	703.75	944.54
11 (3.3)	29.16	102.14	213.77	362.04	547.11	771.28	1039.25
12 (3.7)	31.47	110.36	231.25	392.26	594.11	840.17	1136.92
13 (3.9)	33.78	118.59	248.78	422.70	641.74	910.56	1237.90
14 (4.3)	36.09	126.83	266.38	453.37	690.03	982.62	1342.58
15 (4.6)	38.40	135.08	284.04	484.29	739.06	1056.49	1451.40
16 (4.9)	40.71	143.34	301.78	515.49	788.88	1132.37	1564.81
17 (5.2)	43.02	151.61	319.59	546.97	839.56	1210.42	1683.35
18 (5.5)	45.33	159.90	337.48	578.76	891.16	1290.86	1807.62
19 (5.8)	47.64	168.20	355.46	610.89	943.75	1373.91	1938.27
20 (6.1)	49.96	176.51	373.53	643.36	997.41	1459.80	2076.06
25 (7.6)	62.53	218.33	465.40	811.78	1284.60	1942.02	2907.06
30 (9.1)	73.11	260.61	560.30	992.54	1612.56	2548.33	4123.51
35 (10.7)	84.72	303.46	658.95	1189.34	1998.78	3357.78	6162.33
40 (12.2)	96.40	346.97	762.14	1406.81	2466.77	4524.99	10461.3
45 (13.7)	107.99	391.24	870.79	1650.98	3058.41	6402.00	26153.2
50 (15.2)	119.66	436.39	985.93	1929.88	3841.27	10005.70	68070.5

[A]of a 6-ft (1.8-m) wide loop

TABLE X1.8 Quadrupole Loop Inductance in μH at *f* = 60 kHz

Length ft (m)[A]	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
6 (1.8)	17.55	61.08	127,31	214.81	323.36	453.84	698.32
7 ft(2.1)	19.85	69.28	144.73	244.86	369.89	521.58	703.48
8 ft(2.4)	22.15	77.50	162.23	275..21	417.28	591.44	803.28
9 ft(2.7)	24.46	85.73	179.82	305.90	465.67	663.76	908.57
10 (3.0)	26.76	93.97	197.52	336.98	515.20	738.91	1020.35
11 (3.3)	29.06	102.23	215.32	368.49	566.00	817.32	1139.78
12 (3.7)	31.37	110.52	233.25	400.48	618.23	899.44	1268.22
13 (3.9)	33.68	118.82	251.32	432.99	672.04	985.81	1407.32
14 (4.3)	35.98	127.15	269.53	466.07	727.63	1077.63	1559.08
15 (4.6)	38.29	135.50	287.90	499.78	785.18	1173.78	1725.94
16 (4.9)	40.60	143.88	306.43	534.17	844.91	1276.87	1910.97
17 (5.2)	42.90	152.28	325.15	569.29	907.05	1387.23	2118.05
18 (5.5)	45.21	160.72	344.06	605.20	971.87	1505.96	2352.17
19 (5.8)	47.53	169.18	363.18	641.98	1039.65	1634.37	2619.87
20 (6.1)	49.84	177.68	382.51	679.68	1110.73	1774.02	2929.90
25 (7.6)	61.41	220.74	482.97	884.97	1530.25	2725.24	5781.94
30 (9.1)	73.02	264.88	591.16	1127.49	2116.11	4590.35	24158.9
35 (10.7)	84.67	310.38	709.46	1425.35	3027.21	10214.52	–14095.7
40 (12.2)	96.36	357.47	840.85	1808.24	4699.56	–77203.2	–5948.3
45 (13.7)	108.11	406.48	989.27	2329.10	8926.13	–10112.4	–3900.7
50 (15.2)	119.91	457.72	1160.02	3093.03	40376.3	–5506.1	–2956.9

[A] of a 6-ft (1.8-m) wide loop

TABLE X1.9 Circular Loop Inductance in μH at *f* = 1 kHz

Diameter ft (m)	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
4 (1.2)	5.32	18.10	37.28	62.23	92.52	127.80	167.79
5 (1.5)	6.87	23.49	48.53	81.21	120.99	167.44	220.21
6 (1.8)	8.45	29.02	60.12	100.80	150.42	208.47	274.51
7 (2.1)	10.07	34.68	71.99	120.91	180.66	250.65	330.38
8 (2.4)	11.71	40.46	84.12	141.46	211.58	293.82	387.60

TABLE X1.10 Circular Loop Inductance in μH at *f* = 20 kHz

Diameter ft (m)	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
4 (1.2)	5.31	18.07	37.24	62.18	92.47	127.76	167.79
5 (1.5)	6.85	23.45	48.47	81.15	120.94	167.44	220.30
6 (1.8)	8.43	28.98	60.06	100.75	150.40	208.54	274.78
7 (2.1)	10.04	34.63	71.93	120.86	180.69	250.85	330.93
8 (2.4)	11.68	40.40	84.05	141.43	211.68	294.21	388.55

TABLE X1.11 Circular Loop Inductance in μH at *f* = 40 kHz

Diameter ft (m)	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
4 (1.2)	5.28	18,02	37.16	62.09	92.40	127.75	167.92
5 (1.5)	6.81	23.38	48.38	81.07	120.92	167.58	220.76
6 (1.8)	8.39	28.90	59.96	100.68	150.48	208.94	275.80
7 (2.1)	9.99	34.54	71.83	120.84	180.92	251.66	332.81
8 (2.4)	11.62	40.30	83.96	141.48	212.16	295.61	391.66

TABLE X1.12 Circular Loop Inductance in μH at *f* = 60 kHz

Diameter ft (m)	1 Turn	2 Turn	3 Turn	4 Turn	5 Turn	6 Turn	7 Turn
4 (1.2)	5:26	17.98	37.10	62.05	92.40	127.89	168.30
5 (1.5)	6.79	23.33	48.32	81.05	121.04	167.99	221.73
6 (1.8)	8.35	28.84	59.90	100.72	150.79	209.83	277.76
7 (2.1)	9.95	34.48	71.79	120.98	181.53	253.27	336.29
8 (2.4)	11.58	40.23	83.95	141.76	214.20	298.26	397.32

X2. USING A DIRECT READING INDUCTANCE METER TO VERIFY THE NUMBER OF TURNS INSTALLED IN A LOOP

X2.1 Significance and Use

The measurement of the inductance of an inductive loop detector may be made at the pull box using a direct reading inductance meter. The measured inductance value may then be used to calculate and verify that the correct number of turns was placed in the buried loop.

X2.2 Procedure

Eq X2.1 provides a simple method for calculating the approximate inductance of any loop configuration or to confirm the number of turns of wire in the loop (**8**). The inductance L is given by

$$L = (K)\,(\textit{Total length of saw cuts in loop}), \quad (X2.1)$$

where K is found in Table X2.1 as a function of the number of turns in the loop.

TABLE X2.1 *K* as a Function of the Number of Turns in the Wire Loop

Number of Turns	*K* (µH/ft)	*K* (µH/m)
1	0.5	1.64
2	1.5	4.92
3	3.0	9.84
4	5.0	16.40
5	7.5	24.61

A better approximation to the inductance measured at the pull box can be obtained by adding a term to the result from Eq X2.1 that accounts for the inductance of the lead-in wire, namely 0.22 µH for each foot (0.72 µH for each meter) of lead-in wire.

X2.3 Example

A three-turn 6 by 6-ft (1.8 by 1.8-m) loop with 20 ft (6 m) of lead-in wire has been installed. The inductance value measured at the pull box with a direct reading inductance meter is 78 µH at 20 kHz. This value represents the sum of the wire loop and lead-in wire inductances.

To verify the number of turns using Eq X2.1, K is chosen equal to 3.0 (for inch-pound units). If the length of the saw cuts in the loop is 24 ft (7 m), the inductance calculated from Eq X2.1 is

$$L = (3)(24) = 72\,\mu H. \quad (X2.2)$$

Accounting for the 20 ft (6m) of lead-in wire gives an additional 4.4 µH.

Since the measured inductance (78 µH) is within 10 percent of the calculated value of 76.4 µH (72 µH + 4.4 µH), the installer would conclude that the specified number of three turns has been properly inserted into the saw cut.

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