Student Workbook

Introduction to Two-Wire Technology

By
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Edited by
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Developed for the
Irrigation ASSOCIATION®

About the Author

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Tone Ware is the chief engineer for Underhill International Corporation based in Aberdeenshire, Scotland. He holds a bachelor's degree in electronic engineering at the University of Manchester Institute of Science and Technology.

Tone's career spans four decades designing electronic equipment for the medical, scientific, and process control industries. He entered the irrigation industry in 1995, designing a functional equivalent to decoders to eight different two- and three-wire control systems predominately for the United Kindgdom and Ireland golf markets.

He has designed more than seven different irrigation controllers including the development of the world's first two-wire plug-in converter module to retrofit a multiwire irrigation controller allowing for "hybrid" operation of a two-wire and multiwire management from the same controller. Tone has also developed a cable leakage location system using a transformer and clamp meter. This includes training over 100 decoder system installation teams in fault detection and location throughout the world.

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Please note: Glossary terms are ***bold italic*** the first time they appear in text.

Introduction

Two-wire systems are becoming more popular, but they present different challenges from conventional control systems. This course is designed to introduce the reader to the concepts of two-wire systems, some of the advantages and disadvantages of the systems, and some basics of how they operate.

Course Objectives

This course is intended to provide an overview of two-wire technology, its components, and typical design criteria.

Course Overview

In this course, the following topics will be presented:

- where and why two-wire technology was developed
- definition of two-wire control systems
- differences between multiwire and two-wire irrigation systems
- identification of two-wire system components
- surge suppression requirements and common surge suppression devices
- variables to consider when designing a two-wire system based on design and site criteria
- different communication wire layouts and maximum wire lengths
- variables that can impact ***com path*** cable lengths
- advantages and disadvantages of two-wire and multiwire control systems
- reference resources and web links to various manufacturers who offer two-wire control products

A Brief History of Two-Wire Technology

To gain an appreciation for the usefulness of two-wire technology, it's helpful to understand where and why it was developed.

Two-wire technology began in Europe in the mid- to late 1970s as an alternative to multiwire irrigation control systems commonly used in the United States. Similar technology was introduced in the U.S. markets in the early 1960s with poor results.

Three- and four-wire systems were originally developed for agricultural applications as late as the 1960s. Two-wire systems originated in the golf industry in the mid-1970s about the time that individual valve-in-head control was being introduced for tees and greens with undulating surfaces.

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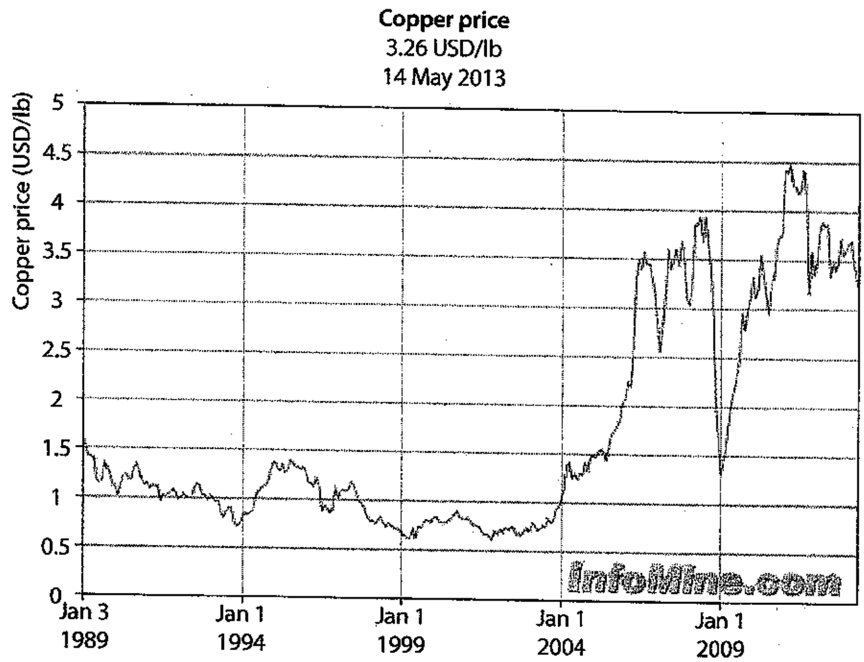
One of the primary drivers for the development of this technology has been the increase in cost of copper wire. Figure 1 depicts a 24-year history of the copper wire pricing.

Figure 1. Copper wire prices



Source: Infomine.com

As this technology gained acceptance into the golf market, it then migrated into commercial and residential applications. This is of particular importance when considering the density and age of many European cities. Routing of a single pair of wires offers considerably less site disruption, particularly when attempting to preserve the historical value of a site.

By the mid-1980s two-wire systems began to find a way into the American irrigation marketplace, again initially in golf and then migrating to commercial applications. Today the Northeast, Southeast, upper and middle Midwest and Pacific Northwest areas of the United States are firmly entrenched with this technology.

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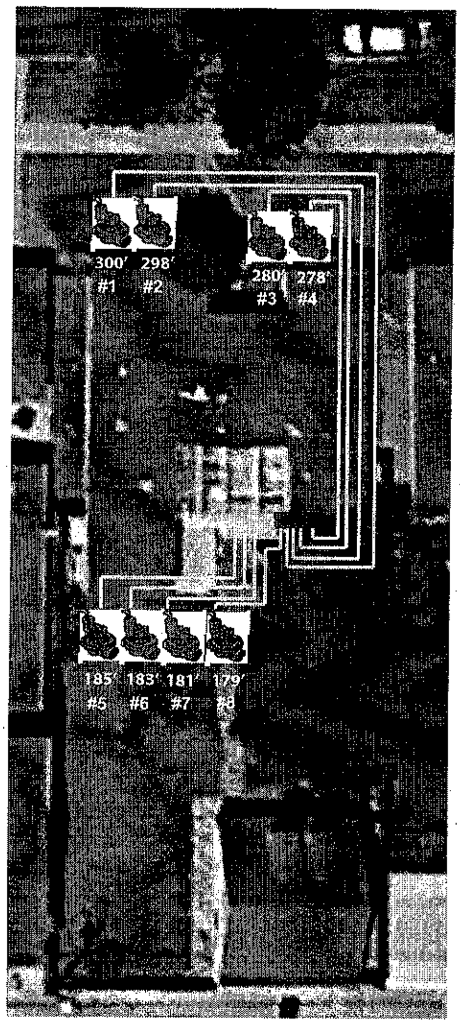
Definition of a Multiwire System

Before providing a definition of a two-wire system, this section will confirm the definition of a multiwire system.

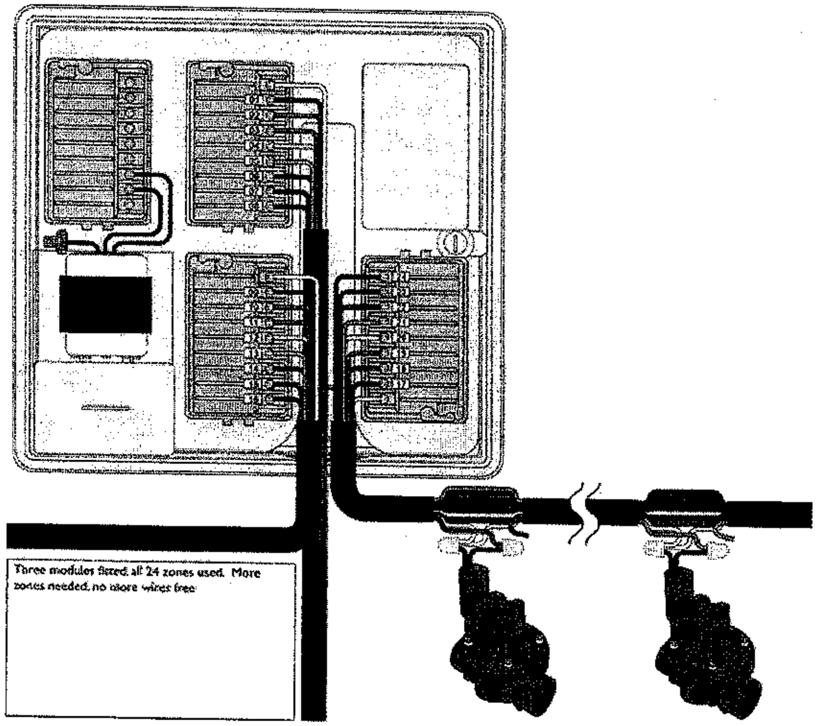
Multiwire systems are the most commonly referenced control systems found in the United States as part of most irrigation design courses. Figure 2 depicts a typical multiwire system for a large residential application.

Figure 2. Typical multiwire layout



In this example, each zone valve has an individual "pilot" or "power" wire with a "common" looped to complete the electrical circuit. The controller communicates to each station independently through each pilot wire as defined by a user-entered program. Figure 3 is an example of a wiring of a typical multiwire controller.

Figure 3. Typical multiwire system layout



Source: Underhill International

Definition of a Two-Wire System

A two-wire system incorporates the same design principles in terms of head layout, pipe sizing, and routing while maintaining minimal friction losses. The primary difference in this control system is communication to the ***zones*** in the field.

Typical irrigation controller functions such as setting time and date, establishing a water window, water day mode, assigning stations to a program and run times to stations are the same in both two-wire controllers and multiwire controllers.

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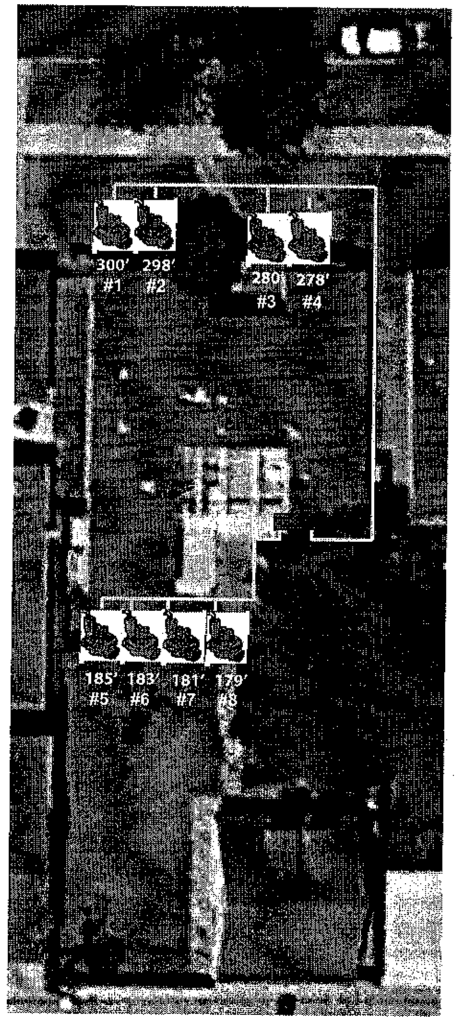
Figure 4 depicts a typical two-wire layout for a large residential application.

Figure 4. Typical two-wire layout



In this example, two wires interconnect all zone valves. ***"Decoders"*** or encapsulated printed circuit boards [PCBs] intercept broadcast messages from the controller down the two-wire path. If the decoder hears its specific station number or "address" it will execute the controller's command. Figure 5 depicts typical two-wire controller wiring layout.

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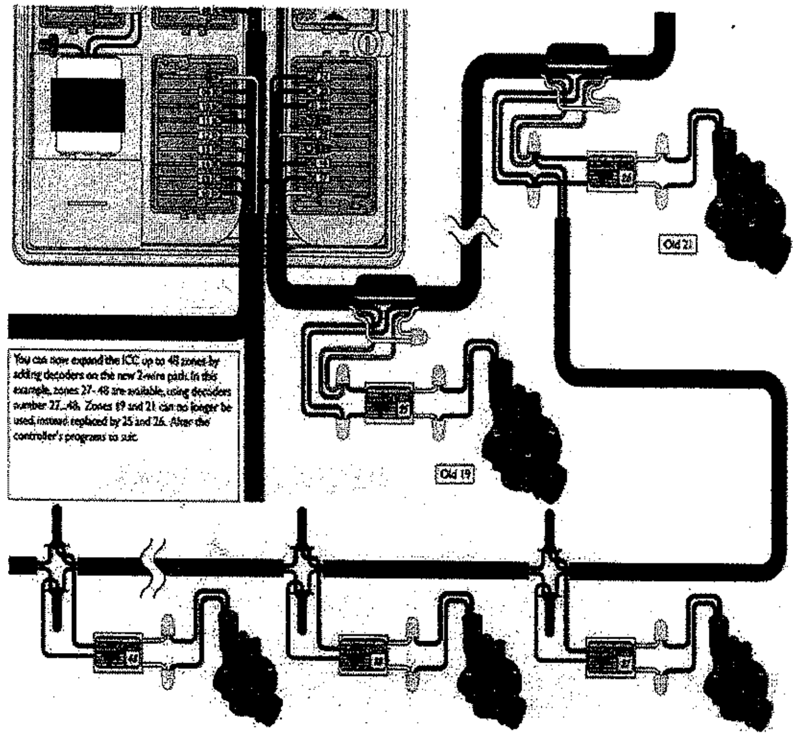
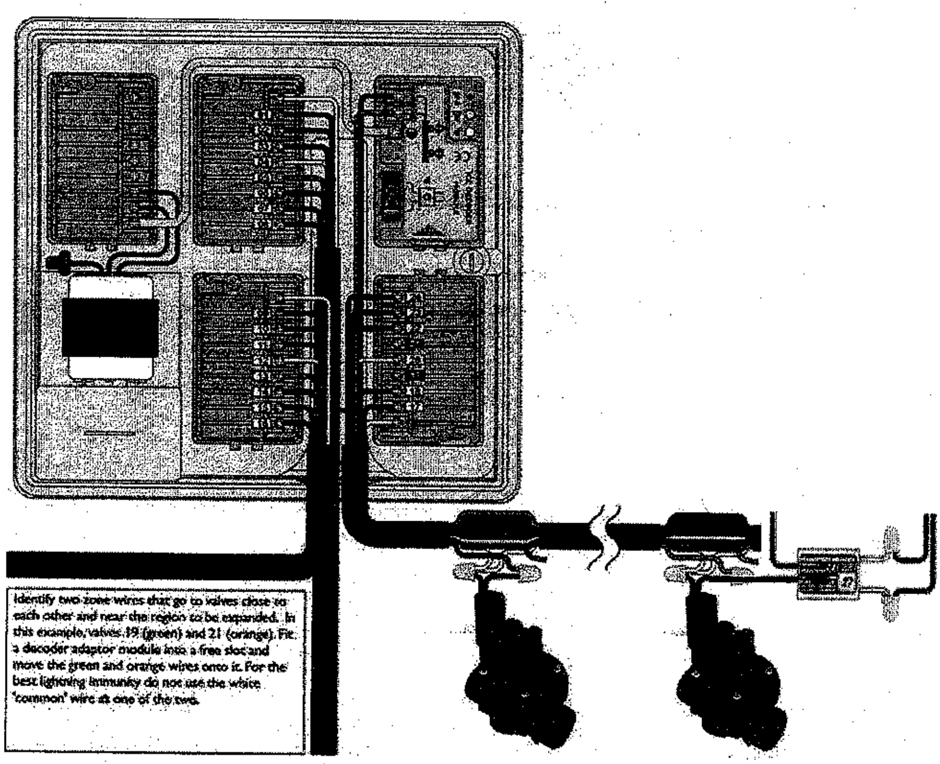
Figure 5. Typical two-wire layout



Source: Underhill International

This product is commonly applied in retrofit applications or projects built in phases (see fig. 6).

Figure 6. Typical hybrid system layout



Source: Underhill International

System Components

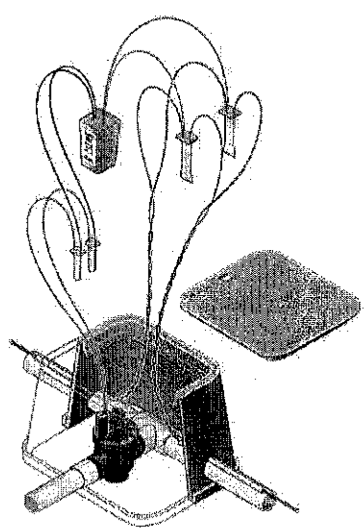
System components of a two-wire system include

- a controller or intermediary device capable of communicating to decoders.
- station decoders. These might be individual or multistation decoders depending on the manufacturer and design of a zone grouping.
- a portable programmer to assign station numbers to corresponding decoders. In some cases, the control product has "self-realization" capabilities, meaning it will assign station numbers automatically as part of a specific task, then allow the order to be changed as needed.
- communication wire (also called "com path" wire).
- surge suppression components.

Station Decoders

Figure 7 depicts how a decoder is commonly wired into a zone ***solenoid***. Note the wire path coming into and leaving the valve box as part of the two-wire path layout. Depending on the manufacturer, individual or multiple decoders are available. This can also include surge suppression decoders and/or flow and moisture sensing decoders (see fig. 7).

Figure 7. Typical decoder installation



Source: Hunter Industries

Decoders are commonly "potted" or encapsulated waterproof devices with a minimum of four conductors, two for the two-wire path and two for each valve solenoid. The wires for the zone solenoid are nonpolarized, so it doesn't matter which wire is connected to the solenoid identical to a multiwire connection. Figure 8 depicts typical decoders used in the irrigation industry. Most decoder wire is solid-core, 14-gauge wire suitable for outdoor applications.

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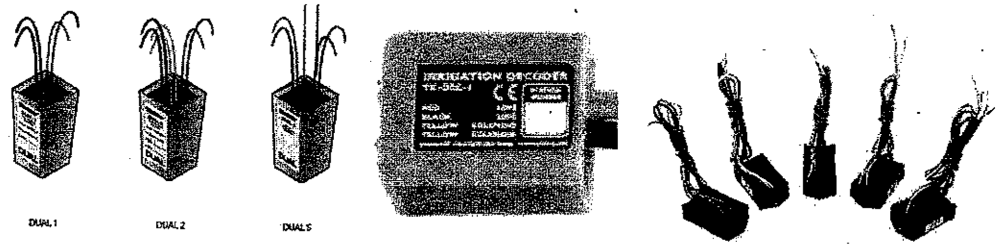
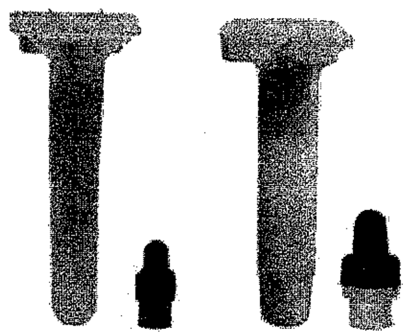
Figure 8. Typical station decoders



Source: Hunter Industries, Underhill International, and Baseline Systems

Since wire splices are typically made in valve boxes (that can be submerged from time to time), most manufacturers recommend field wire connections with 3M DBR/Y-6 or DBO/B-6 connectors to provide a *waterproof* field splice (see fig. 9). A path to ground for some two-wire systems can prevent irrigation of a portion of zones and can be difficult to troubleshoot.

Figure 9. Typical waterproof connectors



Source: Paige Electric

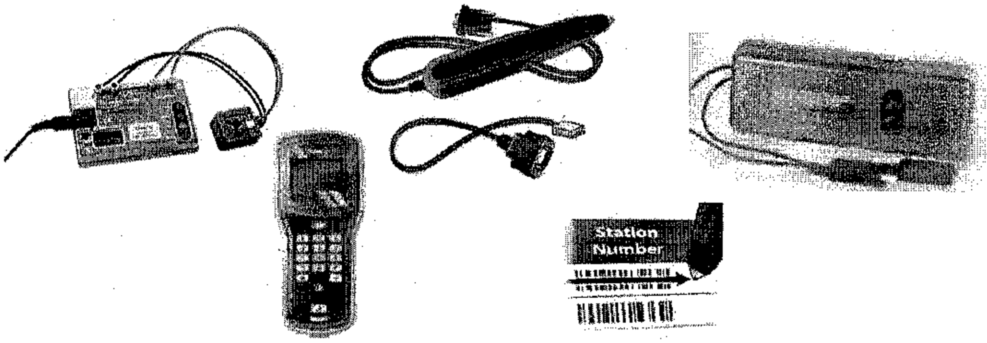
Decoder Programmers

Each manufacturer typically offers some means of programming a decoder with a portable device. Some are battery operated while others require a 120-volt source, and others offer programming at the controller.

The purpose of these devices is to program a corresponding zone number for each remote ***control valve***. Failure to program a decoder or improper programming will prevent a zone(s) from operating from a two-wire controller. At least one manufacturer does not require a portable programmer and has the capability to "self-realize" or automatically assign an order to each decoder found in the field. Once completed, the controller software will allow the user to reorder the numbering sequence as needed.

Figure 10 depicts a wide range of decoder programmers. Each is unique to the manufacturer of a two-wire product.

Figure 10. Typical decoder programmers



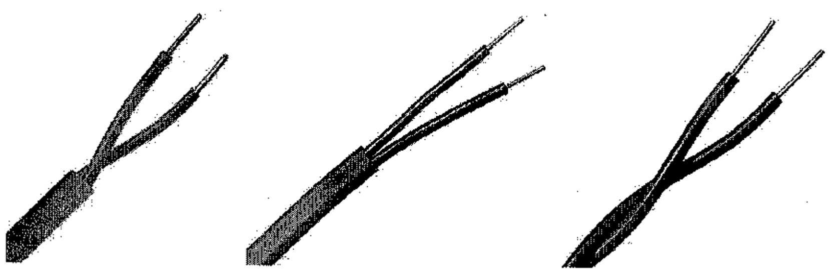
Source: Underhill International, Hunter Industries, Rain Bird, and Hit Products

Two-Wire Communication Cable

Most manufacturers require a specific version of communication cable typically in 12 and 14 American Wire Gauge [AWG]. While smaller diameter wire can be used, the number of zones being operated at one time and the maximum length of wire are limiting factors to consider. Communication, or "com," wire is typically color-coded, direct-burial wire within an encapsulated jacket for protection against animal and human interruption once installed.

Some two-wire controllers offer the ability to have multiple com cable terminals to accommodate different site conditions. In some cases, the manufacturer will recommend different colored wire pairs for each terminal to quickly and more efficiently isolate wiring problems should they occur. Figure 11 shows some of the different types of com wire used with two-wire technology.

Figure 11. Communication cables



Source: Paige Electric

Common Two-Wire Voltages

Voltages on the two-wire com path may range from 24 to 30 volts alternating current and from manufacturer to manufacturer. Manufacturers certify their products to be compliant with state and federal electrical codes or other statutes. Local requirements may differ from state and federal requirements, and installers should verify that local requirements are met.

Voltages may change from alternating current to direct current in a decoder and may vary from manufacturer to manufacturer.

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Maximum Wire Runs

Each manufacturer typically identifies maximum wire run depending on the following variables:

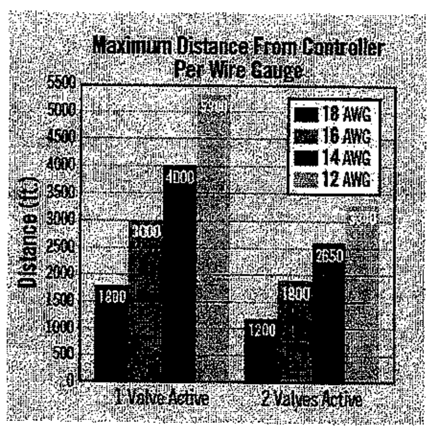
- design requirements (the number of valves and distance from the proposed controller location)
- size of wire to be used
- number of valves expected to be operated at one time as part of the overall irrigation schedule
- solenoid ***current*** draw (meaning the ***in-rush*** and ***holding current*** of the valves specified, which can vary widely from manufacturer to manufacturer)
- wire integrity, meaning new vs. existing wire

Figure 12 represents examples of typical wire sizing charts found in various manufacturers' design guidelines.

Figure 12. Typical wire sizing charts

Maximum concurrent valves – #12 wire						
biCoder and sensor load count	Wire length (ft)					
	1,000–3,000	4,000	5,000	6,000	7,000	8,000
100	15	14	13	8	6	4
90	15	15	14	9	7	5
80	15	15	15	10	8	6
70	15	15	15	11	9	7
60	15	15	15	12	10	8
50	15	15	15	13	11	9
40	15	15	15	14	12	10
30	15	15	15	15	13	11
20	15	15	15	15	14	12
10	15	15	15	15	15	13

Maximum concurrent valves – #14 wire					
biCoder and sensor load count	Wire length (ft)				
	1,000	2,000	3,000	4,000	5,000
100	13	11	8	4	2
90	14	12	9	5	3
80	15	12	10	6	4
70	15	13	11	7	5
60	15	14	12	8	6
50	15	15	13	9	7
40	15	15	14	10	8
30	15	15	15	11	9
20	15	15	15	12	10
10	15	15	15	13	11



Maximum critical path lengths for two-wire paths					
Nominal wire size	Ohms/1,000' or ohms/km (per conductor) miles	Maximum length for critical path			
		Star		Loop	
		(km)	(mi)	(km)	(mi)
2.5 mm²	7.50 ohms/km	3.00	1.86	12.00	7.46
14 AWG	2.58 ohms/1,000'	2.66	1.65	10.63	6.61
12 AWG	1.62 ohms/1,000'	4.23	2.63	16.93	10.52

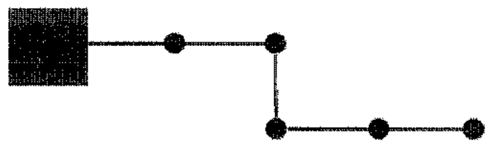
Source: Hunter Industries, Underhill International, and Rain Bird

Typical Two-Wire Communication Cable Layouts

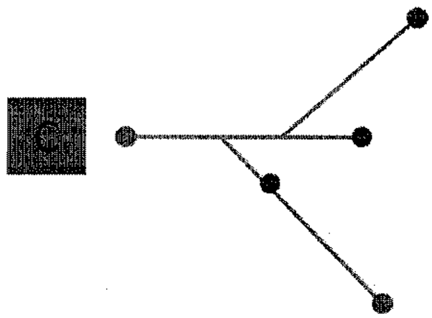
Every manufacturer typically recommends different com cable layouts based on their system capabilities.

Typical com cable layouts or patterns are identified as follows and may reflect site conditions or valve layout or both.

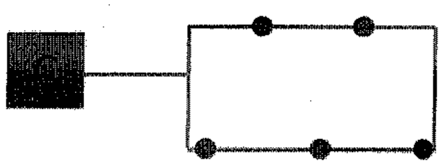
Single-leg — One continuous wire path starting at the controller to the last valve.



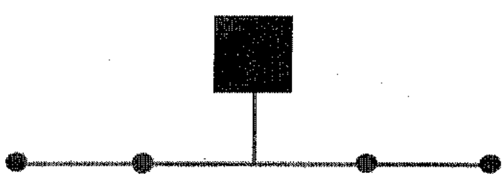
Fishbone or star — Splits off into one or more branches resembling fish bones or stars.



Looped — The wire path comes back onto itself in a looped pattern.



Opposing — Com path is laid in opposing directions from the controller (a type of single-leg layout).



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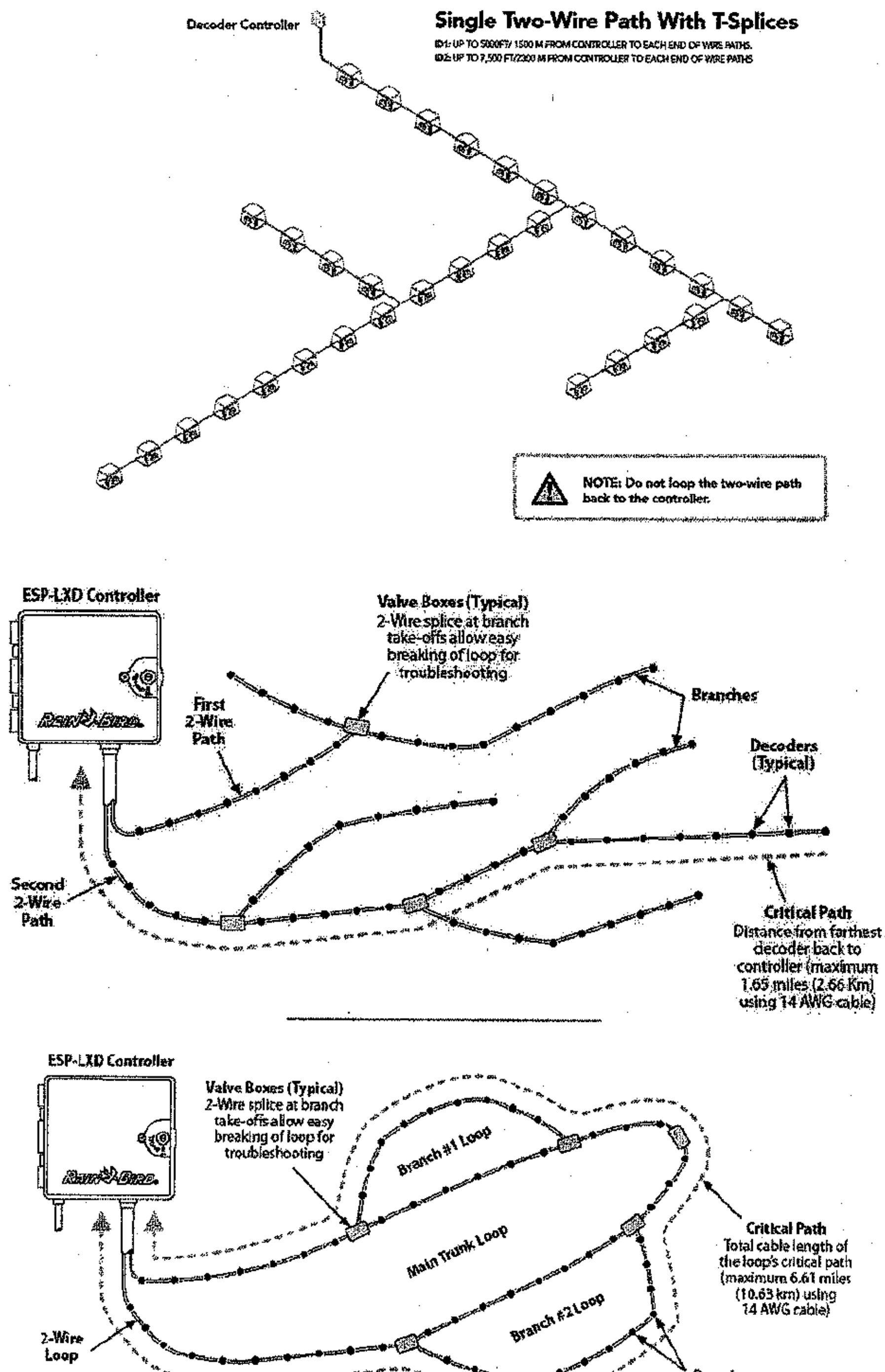
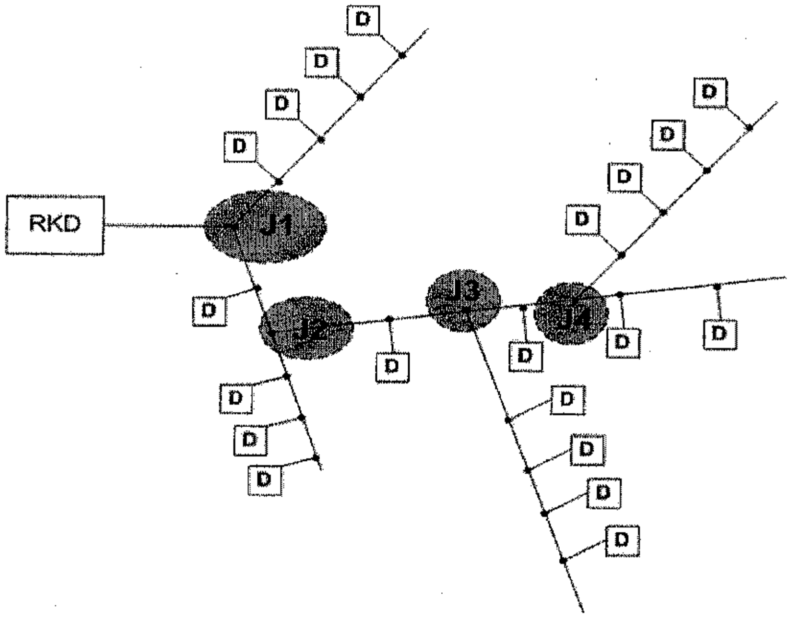
While most manufacturers recommend single-leg or "star" pattern com cable layouts, others are compatible with looped com cable layouts (see figs. 13 and 14).

Figure 13. Common communication cable layouts



Source: Hunter Industries and Rain Bird

Figure 14. Typical communication layouts



Source: Tucor

Another industry-recognized reference specific to communication can be found on the American Society of Irrigation Consultants [ASIC] website at www.asic.org/uploads/assets/011007_121631_COMM_CABLE_GUIDELINE%5B1%5D.pdf (accessed June 10, 2014).

Lightning and Surge Suppression

While some areas of the United States are prone to a higher number of daily ground strikes compared to others, this is *not* a reason to limit or eliminate surge suppression devices.

All two-wire manufacturers recommend grounding of the controller and typically grounding devices at specific intervals along the two-wire com path, as well as at the terminus of each single leg com path run. Some manufacturers require surge decoders with ground rods or plates adjacent to or at a recommended distance from "main" com cable path. Figure 15 represents a typical grounding scenario per a manufacturer's design guidelines.

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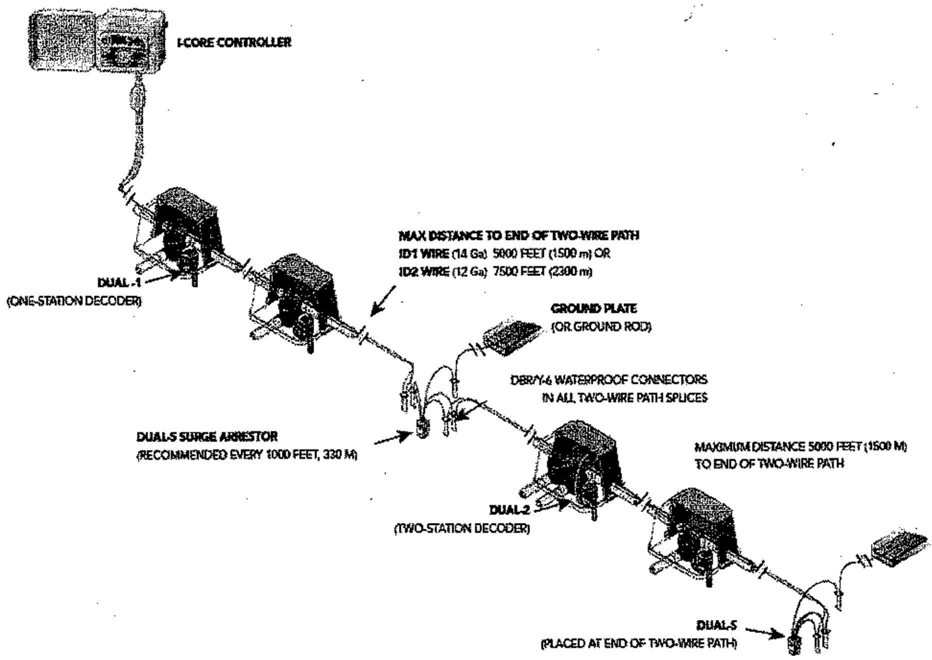
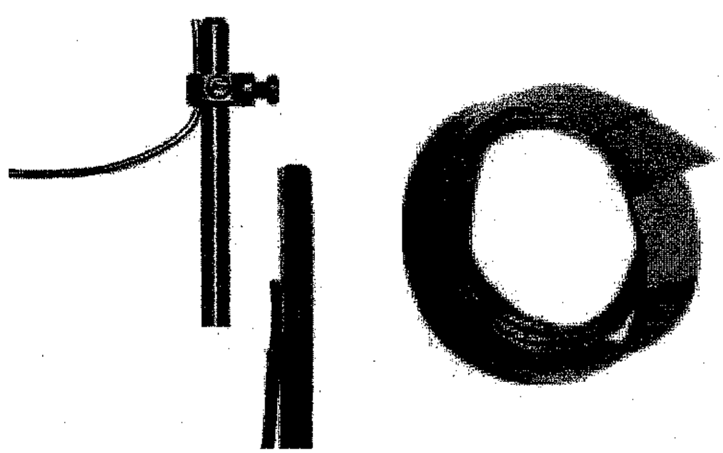
Figure 15. Typical grounding



Source: Hunter Industries

The type of grounding equipment (ground rods vs. ground plates) will vary not only by manufacturer but might be dictated by local soil conditions (see fig. 16). The size of the conductor between the grounding equipment and decoder surge suppression device is also equally as important. This information is commonly found in each manufacturer's design guidelines or installation instructions.

Figure 16. Ground rod/plates

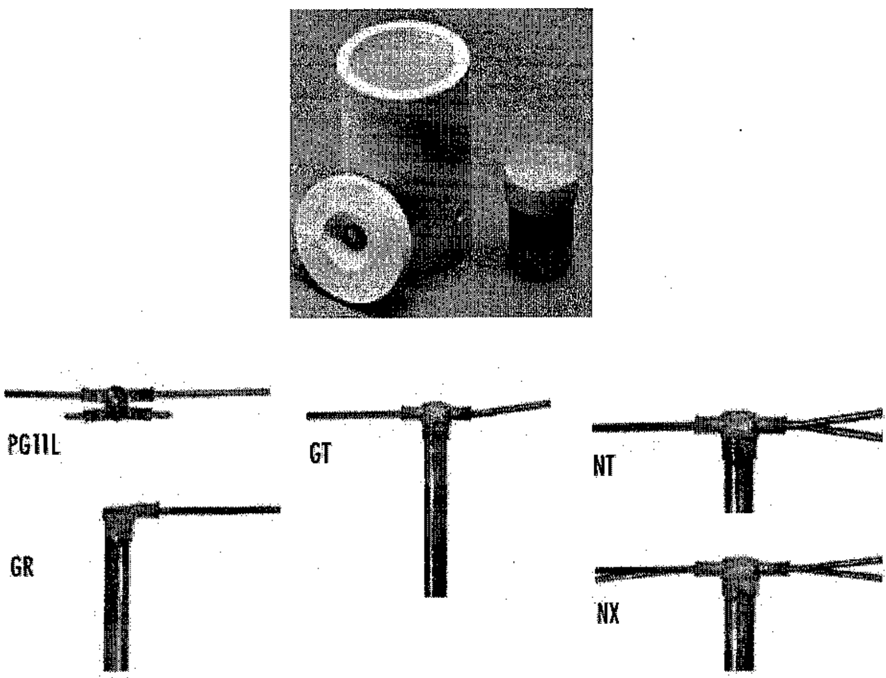


Source: Paige Electric

Dry or sandy soils that have low water-holding capacity may require a ground rod or ground plate to be in close proximity to a sprinkler to ensure good conductive contact over the entire surface of the grounding product.

Improper connection between a ground rod or ground plate may also be difficult to troubleshoot. Using a radiator clamp or copper ground clamp may loosen over time due to thermal expansion and contraction of the fastener. A method to ensure permanent connection is to use a Cadweld connection that is an exothermal method of attaching a copper conductor to a ground rod or ground plate. Figure 17 depicts this device along with several methods of connection commonly used when grounding irrigation products.

Figure 17. Cadweld device and typical connections



Source: Paige Electric and Erico

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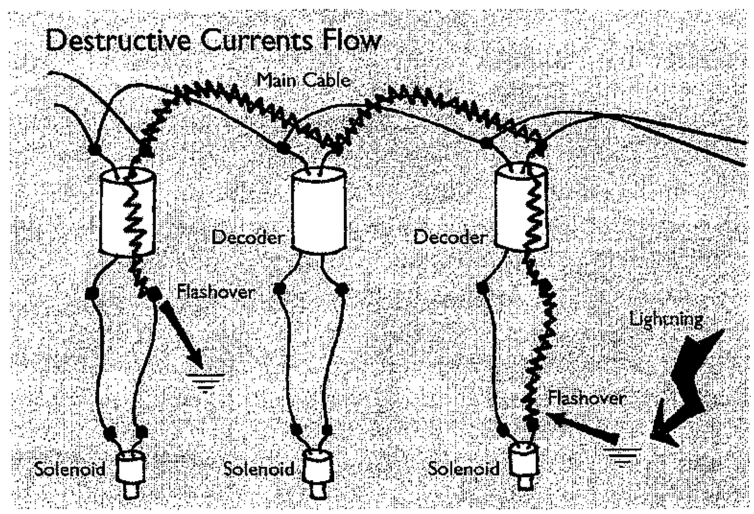
Examples of Ground Strikes on a Two-Wire System

The following diagrams depict what can occur to a two-wire irrigation system in the event of a ground strike both with and without proper surge suppression devices.

Figure 18 shows a typical two-wire installation depicting three decoders connected to three solenoids representing three individual zones *without* surge protection. The diagram shows the impact of a ground strike in proximity to this system and how the ground strike is then transmitted over the copper conductors of the two-wire com path to decoders.

The lack of adequate surge suppression could result in the loss of controller (if in close proximity), the decoder, zone solenoid, and even a portion of the field wire, depending on the duration and intensity of the strike.

Figure 18. Unprotected decoders in a ground strike



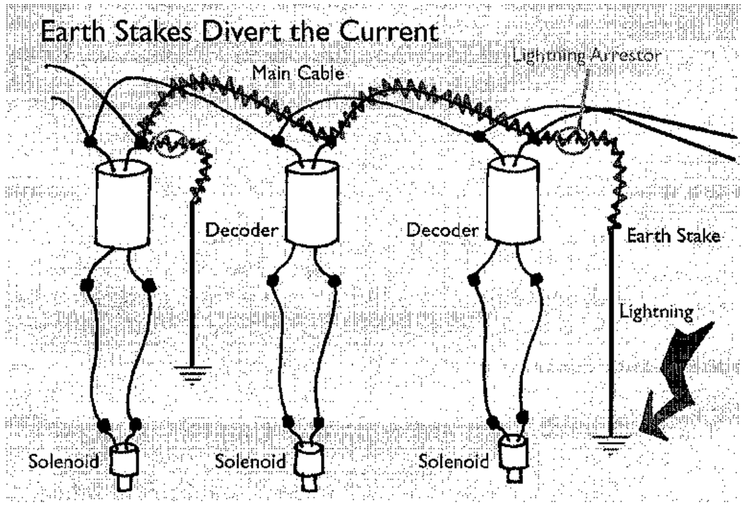
Source: Underhill International

Figure 19 shows the same example incorporating a ground rod allowing the voltage from the ground strike to be shunted away from the decoder and solenoids.

The resiliency of the decoder and solenoid will greatly depend on the storm intensity, duration, and voltage of the strike.

It's important to recognize that in lightning-prone areas, electronic components may survive a storm but may be weakened. A subsequent storm of similar or stronger intensity could ultimately result in failure of previously weakened components.

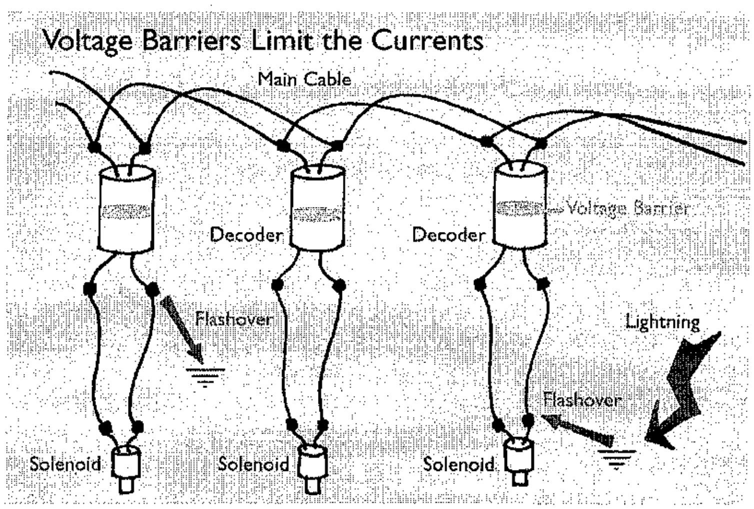
Figure 19. Protected decoders in a ground strike



Source: Underhill International

Figure 20 is an example of a system incorporating "floating" lightning protection. A voltage barrier incorporated into the decoder design prevents voltages from passing through the decoder and onto the solenoid.

Figure 20. Floating lightning protection



Source: Underhill International

Once again, refer to the specified manufacturer's design guidelines for recommended lightning protection requirements.

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Two-Wire vs. Multiwire Control Systems

Tables 1 and 2 outline the advantages and disadvantages of two-wire vs. multiwire control systems.

Table 1. Multiwire systems

Advantages	Disadvantages
• It is easy to install. • Fault detection is relatively simple. • Multiple simultaneous station operation is generally limited by ***transformer*** size and hydraulic capacity. • Wire runs are limited to ¾ of a mile with 14-gauge and up to a mile with 12-gauge wire. • Generally, only the controller requires grounding and not the field wire.	• Each zone valve requires a separate pilot or power wire, so more wire is required. • Cost of copper wire has increased dramatically in recent years. • If a bundle of wires is severed, it requires a significant amount of time by a skilled worker to reconnect the wires. In doing so, the potential for a future splice failure is created. • It is not well suited for sites that are built in phases without pre-installing additional field wire to pick up later. • It has poor expandability, particularly in a well-developed site if a zone(s) needs to be added. • A wire tracking diagnostic tool can be very expensive to purchase and requires skilled labor to use. • Wire tracking can be both time-consuming and frustrating.

Table 2. Two-wire systems

Advantages	Disadvantages
• Significantly less field wire lowers material and labor costs. • Installation is much faster — potentially up to a third less time. • Wire runs are considerably longer, in some cases several miles. • It is easy to expand. A field splice can be made anywhere into the existing two-wire com path. • Hybrid controllers can manage both two-wire and multiwire systems. • It is easier to troubleshoot with the right tools. • Nonpolarized two-wire com path doesn't require match of color-coded wire.	• It has two times the wire connections compared to a multiwire system, so the potential for a failed splice could be higher. • Each decoder must be programmed to a corresponding zone(s). • Typically requires more grounding than a multiwire system, resulting in additional materials and labor costs. • Many systems require a minimum of 14-gauge two-wire communication cable specific to a manufacturer. • Some systems are sensitive to leakage to ground and may not be suitable for retrofit applications. • Some systems that use direct current to open and close a solenoid may block electrical faultfinding past the decoder, requiring separate solenoid troubleshooting methods. • It can be intimidating to troubleshoot until familiarity with a system is obtained.

Cost Effectiveness: Multiwire vs. Two-Wire Control Systems

A commonly asked question is, when does a two-wire system become more cost effective than a multiwire system?

This high-level analysis recognizes that some of the following variables will determine the break-even point more than others:

- labor costs based on regional differences (including soil types)
- a contractor's level of discount (Depending on a contractor's credit history, discounts could be between 20 and 35 percent, sometimes even deeper depending on their business relationship with the distributor and size of the project.)
- a user's preference of the type and features of a multiwire system selected
- a user's choice of a two-wire system based on site requirements and design criteria
- the amount of surge suppression required for the two-wire system selected inclusive of ground rods vs. plates, ground rod to grounding wire connections, valve boxes for surge suppression decoders, and distance (if required) between the surge suppression decoder and the ground device

Figure 21 is a representative layout of a large residential irrigation system showing eight zone valves and the controller location within a utility room on the back of the house. This figure shows the zone valve locations and distances from each valve to the controller including the common wire length and projected pricing.

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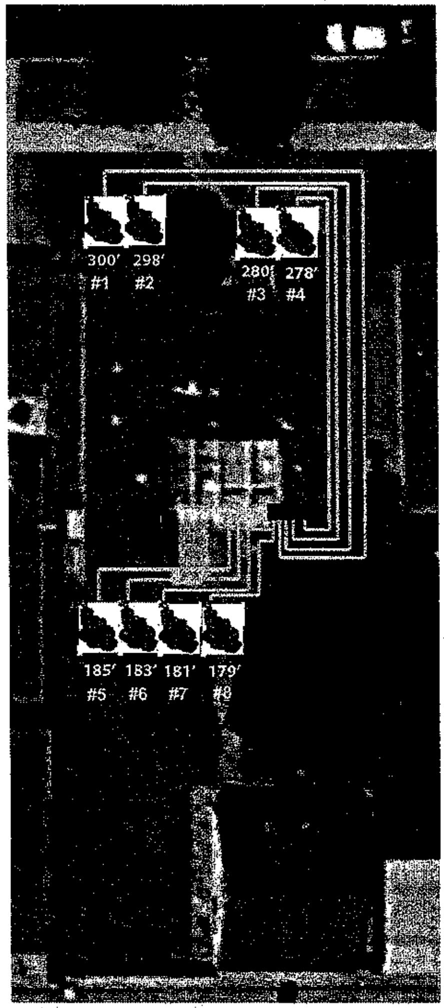
Figure 21. Typical multiwire system layout



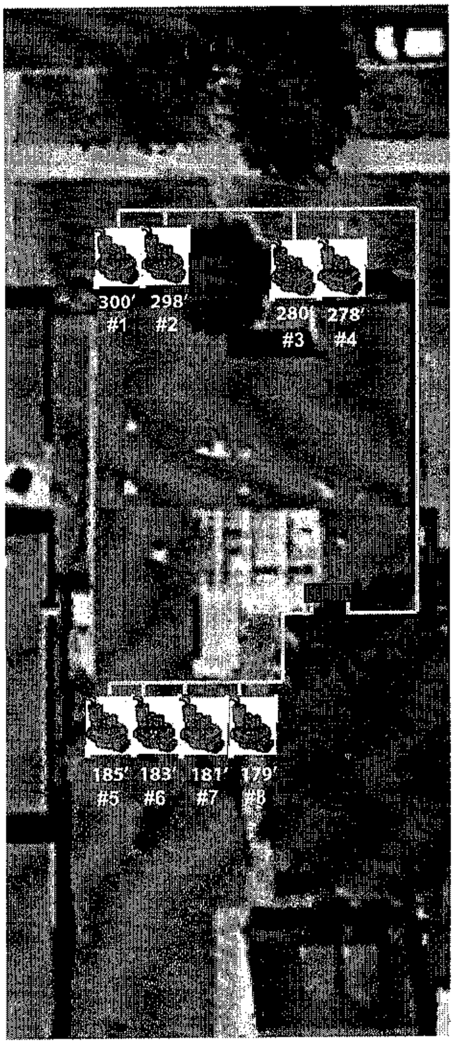
Value no.	Linear feet of wire (ft)
1	300
2	298
3	280
4	278
5	185
6	183
7	181
8	179
VC	485

- All zone and valve common wire total 2,369 ft.
- Cost of wire at $0.45/ft = $1,066.05*.

*Typical contractor pricing. Local pricing may vary.

Figure 22 represents the same large residence using a two-wire system. Once again, the total length of wire and projected costs are shown.

Figure 22. Typical two-wire system layout



Value no.	Linear feet of wire (ft)
1–8	485
VC	485

- All zone and valve common wire total 970 ft.
- Cost of wire at $0.45/ft = $436.50.
- Eight decoders at $50 each = $400.00.
- Projected cost = $836.50*.

*Typical contractor pricing. Local pricing may vary.

The projected cost for each zone and a common wire for a multiwire system is projected to be $1,066.50. For the same property, two-wire projected costs are $836.50 for the same number of valves, including the cost for a decoder for each zone. Labor savings are also expected, as there are fewer wires to run, smaller conduit for wire pulls, etc.

This analysis does not include equipment mobilization, proximity to a local irrigation distributor, and other suppliers that should be contemplated as part of a cost estimate.

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References and Suggested Supplemental Reading

There are several domestic and some international manufacturers of two-wire technology offering a wide variety of products depending on the application.

It is the professional irrigation designer's responsibility to pair the site and user requirements to a particular product.

The following manufacturers and web links (see table 3) represent a wealth of product information, recommended design guidelines, and installation techniques unique to the product selected. This information should be followed to ensure an operational and long-lasting control system.

Table 3. Manufacturers of two-wire systems

Manufacturer	Web link*
Baseline Systems	www.baselinesystems.com
Hit Products	www.hitproductscorp.com
Hunter Industries	www.hunterindustries.com
Irritrol	www.irritrol.com
Paige Electric	www.paigeelectric.com
Rain Bird	www.rainbird.com
Toro	www.toro.com
Tucor	www.tucor.com
Underhill International	www.underhill.us
Weathermatic	www.weathermatic.com

*Web links accessed June 2014.

Glossary of Terms

The following terms have been stated throughout this workbook.

com path: This references the two-wire communication path between a two-wire controller and decoders in the field.

control valve: A plastic or ferrous metal device used to activate or control one or more sprinklers or emission devices. A control valve is typically actuated via 24 volts alternating current or direct current.

current: A complete path over which electrical current can flow. It includes a power source, conductors, and a load connected together allowing electricity to flow.

decoder: A potted device that is wired in series with a valve solenoid. This device is programmed with the corresponding zone number that "decodes" a message from the controller to open or close a zone valve.

holding current: The amount of current required to maintain a valve solenoid plunger in the "up" or open position for the duration of the user-defined run time. Current is typically displayed in milliamps [mA] and can vary from manufacturer to manufacturer.

inductance: The ability to measure electrical current as a result of an electromotive force being created by a change of current in the same circuit.

in-rush current: The amount of current initially required to pull a valve solenoid plunger off the valve seat as part of the valve opening process. Current is typically displayed in mA and can vary from manufacturer to manufacturer.

open circuit: An electrical path with an open switch (off position) that interrupts the flow of electric current through the wires to the load. The open switch could also be represented by a break in electrical path.

solenoid: A spiral of conducting wire wound helically so that when an electric current passes through, it acquires magnetic properties similar to those of a permanent magnet. Most of the irrigation valves in use for irrigation purposes incorporate this type of design for electric valve actuation.

transformer (power supply): A device used to increase (step-up transformer) or decrease (step-down transformer) incoming voltage.

zone: Section of an irrigation system served by a single control valve. Zones are comprised of similar sprinkler types and plant material types with similar water requirements and types.

Notes

PRACTICE PROBLEMS
Two-Wire Technology

Name______________________________

Date______________________________

1. What is the primary difference between a two-wire and multiwire system?

____

____

2. Define what function a decoder performs?

____

____

3. List three advantages of a two-wire system vs. a multiwire system?

(1) ____

(2) ____

(3) ____

4. List the four variables to consider when sizing two-wire communication cable.

(1) ____

(2) ____

(3) ____

(4) ____

5. Is grounding necessary for a two-wire system?

____

____

6. Name the three common types of com path layouts.

(1) ____

(2) ____

(3) ____

About IA

The Irrigation Association is the leading membership organization for irrigation companies and professionals. Together with its members, IA is committed to promoting efficient irrigation technologies, products, and services and to long-term sustainability of water resources for future generations. IA serves its members and the industry by

- improving industry proficiency through continuing education.
- recognizing and promoting experience and excellence with professional certification.
- influencing water-use policy at the local, state, and national levels.
- ensuring industry standards and codes reflect irrigation best practices.
- providing forums that promote innovative solutions and efficient irrigation practices and products.

For more information, visit www.irrigation.org.

APPENDIX A

Troubleshooting

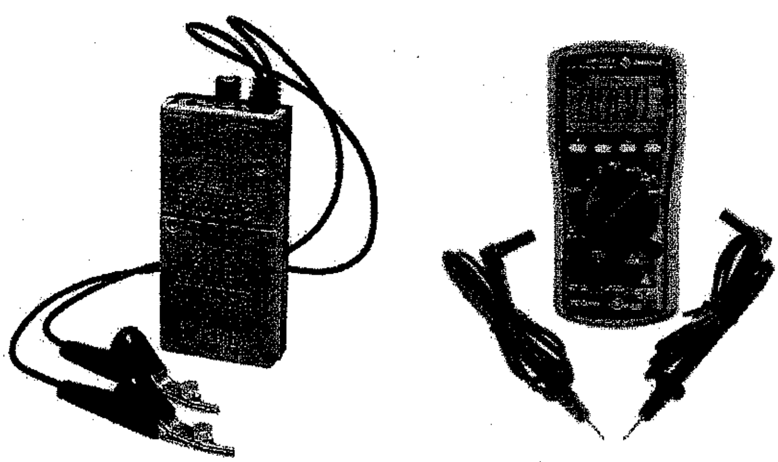
Troubleshooting

While there are safeguards and precautions that can be taken, field issues are inevitable, particularly if one "inherits" someone else's installation. How field issues are diagnosed can be different and requires different tools than multiwire systems. Once these techniques are developed, troubleshooting can be as fast or faster than similar field issues with a multiwire system. This section is intended to highlight recommended tools and common field issues, potential causes, and methodologies to troubleshoot two-wire systems.

Similar to troubleshooting a multiwire system, having the right tools will save both time and labor, as well as reduce the frustration that is often associated with locating field wiring issues with irrigation systems. Locating and diagnosing electrical wiring issues within an irrigation system can be intimidating particularly if language or fundamental knowledge of electricity is a barrier.

Diagnostics tools such as a multimeter and valve checker commonly associated with multiwire systems are also applicable for two-wire systems to confirm delivery current starting from the controller and/or isolating a site condition to an individual solenoid. Figure A.1 depicts both of these tools.

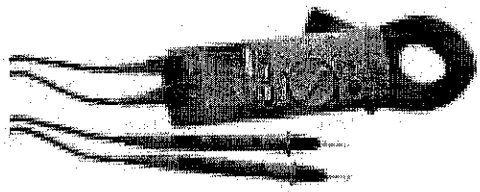
Figure A.1. Multiwire field diagnostic tools



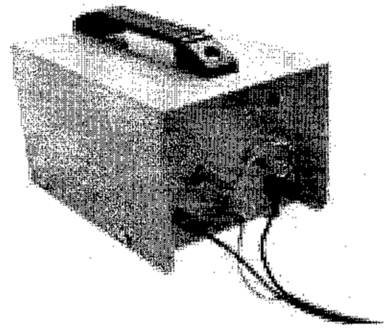
Source: Progressive Electronics and Greenlee

Additional two-wire diagnostic tools are identified as a "clamp-type" leakage meter, a portable power supply, and faultfinding probe shown in figure A.2.

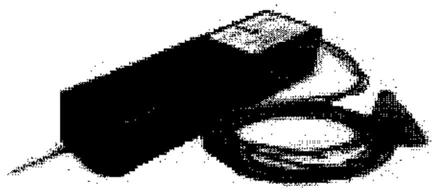
Figure A.2. Diagnostic tools



Clamp-type digital meter



Portable power supply



Faultfinding load probe

Source: Underhill International

The clamp-type digital meter can be used to clamp over one or more of the com path wires using ***inductance*** to measure current to avoid having to expose the wire conductor for troubleshooting and, more importantly, exposing the potential for leakage into the earth at some point in the future.

A portable power supply is used to provide current down the two-wire com path if a path to earth exists. Some controllers will not operate when an electrical fault of this type occurs. The two-wire com path can be disconnected from the controller and reconnected to the portable power supply to help isolate a break or some other field issue as needed.

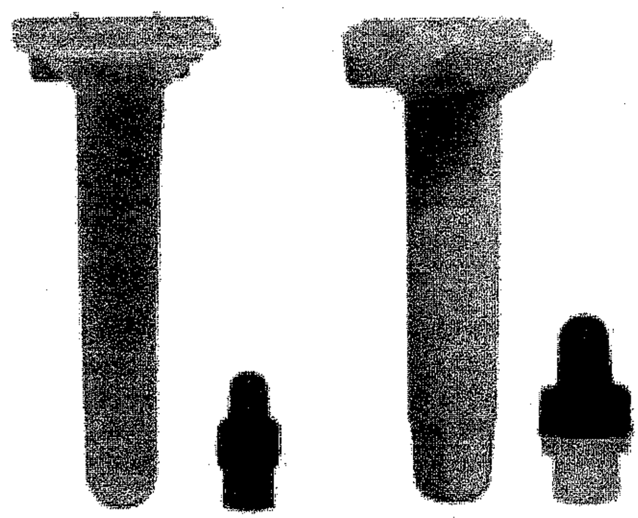
A faultfinding load probe is another tool to test for current in wire splices without the need to completely disconnect the conductors.

While some of these tools carry a high initial purchase price, the net value in terms of labor saving capabilities will quickly justify the expense.

Having the right tools and knowing how to use them are important fundamentals for working with any two-wire system. In addition to diagnostic tools previously identified, the following is a list of additional tools to consider as part of any two-wire installation:

- *selectable gauge wire cutters* — These are often substituted for a utility knife, needle-nose pliers (with a wire cutting capability), and/or diagonal pliers, all of which can nick the solid-core portion of the conductor weakening it to a point of failure as two conductors are twisted together. Oftentimes, a problem is isolated to a solenoid when it's really the wire connection. But, once repaired the net result is still the same.
- *wire splice kits* — A small quantity of 3M DBR/Y-6 or DBO/B-6 or equivalent waterproof connectors should be a part of every repair kit. Often, a previously removed connection will be reused where insufficient waterproofing material no longer provides the prevention and can almost certainly lead to another failure (see fig. A.3).

Figure A.3. Typical waterproof field wire connection



Source: Paige Electric

- *spare wire* — Partial spools of wire are also considered helpful. If necessary to replace a damaged section of field com wire, it should be done with the same gauge and, whenever possible, the same material to match the existing wire. Replacing wire with smaller gauge wire will only serve as a "choke-point," which could impact overall system performance, particularly when long wire runs are utilized. The spare wire might also help in stringing wire above ground temporarily to bridge a suspected fault.
- *spare decoders* — It is helpful to have spare decoders of the same make and model found in the field, as well as a portable programmer should the problem be isolated to a defective decoder requiring programming a new decoder.
- *spare solenoids* — Having at least one that can be quickly wired into a decoder to confirm operation can be time-saver. It's important to identify the solenoid with some marking to know it's a functional solenoid vs. one that may have found its way into a toolbox from another repair.
- *ground rod or ground plate* — These are useful if it is determined that no grounding or insufficient grounding exists.

Troubleshooting Methodology

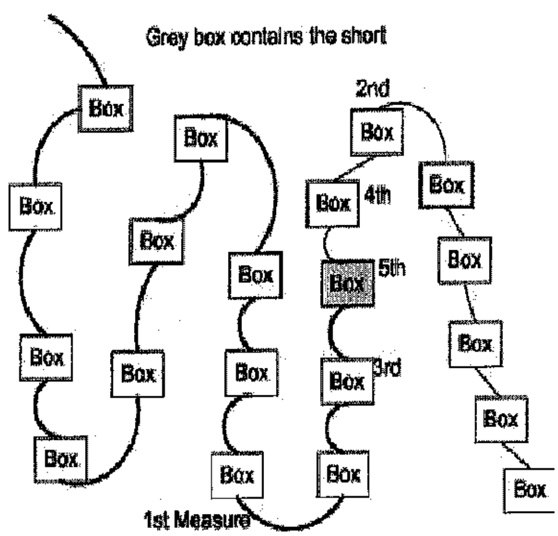
Electrical troubleshooting field wiring issues can be time-consuming and frustrating because electricity does not have the same visual indicators common to troubleshooting hydraulics.

Learning to develop a methodical way to troubleshoot electrical issues can minimize labor and potential loss of a landscape due to lack of scheduled irrigation. Basic knowledge and the use of tools can also be a sought-after and marketable skill set for any employer.

As previously noted, investing in the right diagnostic tools will reduce in-field wire troubleshooting when it occurs. The clamp-type digital meter and portable power supply offer one of the fastest and easiest methods of troubleshooting two-wire field issues.

In the absence of investing in all of these tools, consider the following method using the "halving procedure" to minimize the number of measurements needed to isolate a field issue. The concept is fairly simple by starting halfway through the total number of stations then taking a measurement. This may help isolate which half the problem is located in. Select a second halfway point from the first halving and take additional measurements. Repeat the process until you've isolated the problem. Figure A.4 provides a schematic of how this might be accomplished.

Figure A.4. Halving procedure

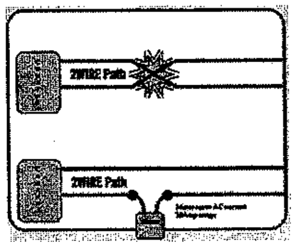
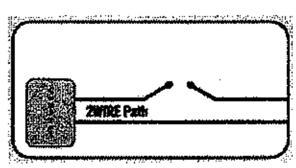


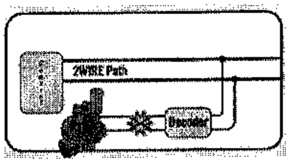
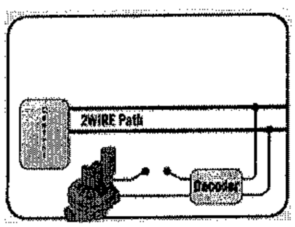
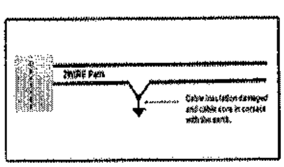
Source: Underhill International

Common Two-Wire Field Issues

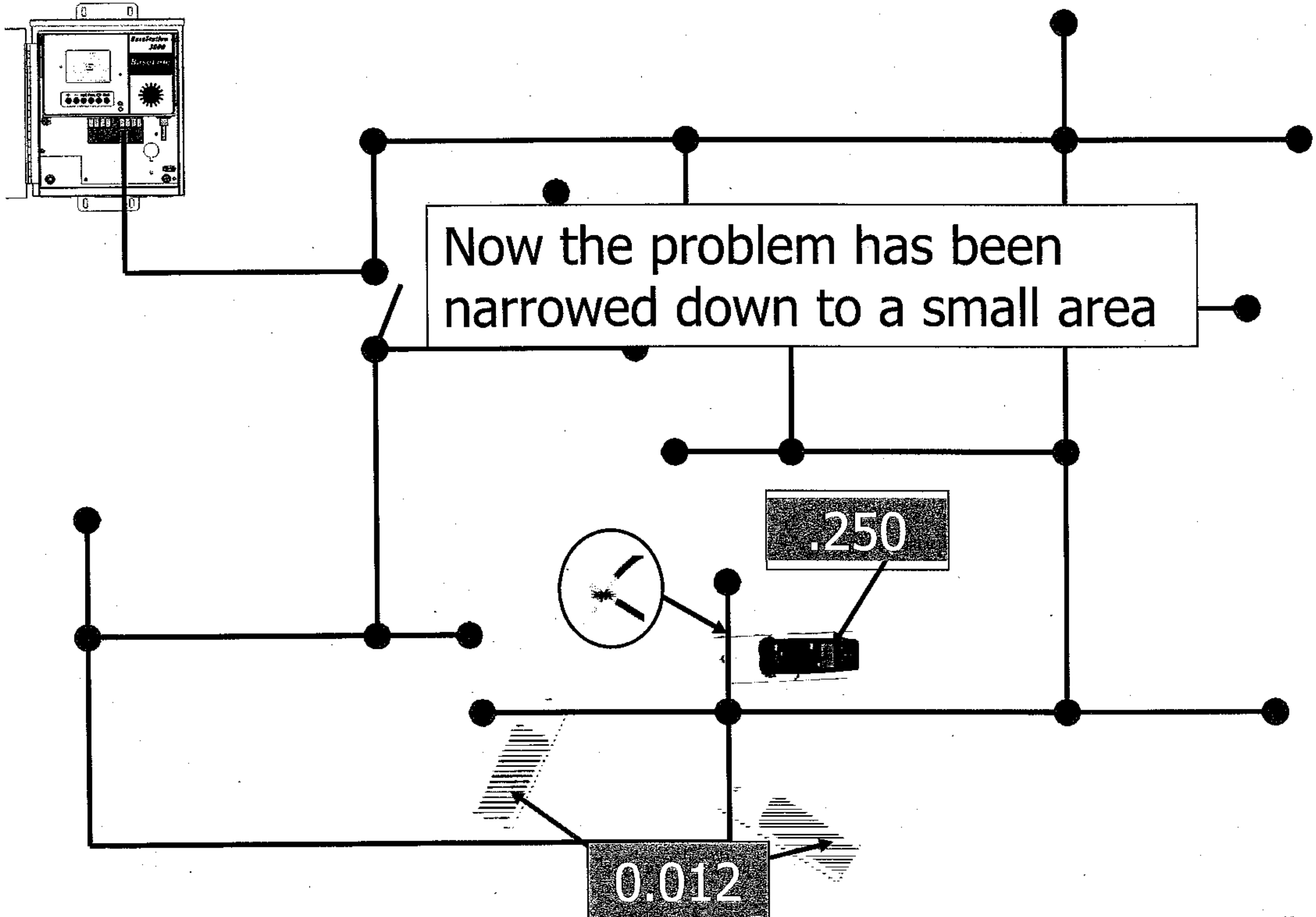
Table A.1 identifies some of the more common two-wire field issues encountered, possible root causes, and possible methods to troubleshoot and repair.

Table A.1. Troubleshooting two-wire systems

Field condition	Possible root cause	Method to troubleshoot
The controller is reporting a short circuit fault.	An overcurrent condition may exist. 	• Determine if some or all stations can be operated manually. • Conduct a visual observation of field conditions to determine if some form of site disruption has occurred as a possible cause to the observed condition. A recent irrigation repair, tree removal, gopher damage, and damaged sign might all be indicators of where to look first. • If all stations cannot be operated manually from the controller, disconnect the two-wire path at the controller and connect a programmed decoder with a working solenoid and determine if it can be operated manually from the controller. If so, there is a two-wire com path issue. • Temporarily disconnect the two-wire com path for half the stations and attempt to manually operate any station downstream. If the highest station can be operated, then reconnect the two-wire com path and locate the next block of stations to recheck by halving the stations again. If only a portion of the originally halved stations can be operated, then determine the highest station that can be operated manually. Check the two-wire com path connection at the next station or use the clamp-type meter located where the signal drops. Make all wire connections with waterproof connections and locate the splice in a round valve box to locate in the future if needed.
There is an *open circuit* in the two-wire com path.	A break in the two-wire com path exists. 	• A limited number of decoders operate manually but one or more may not beyond a certain point. • Conduct a visual observation of field conditions to determine if some form of site disruption has occurred as a possible cause to the observed condition. • Use the halving procedure to isolate where a break is located. • Use the clamp-type leakage meter and portable power supply to take measurements along the two-wire com path to isolate the break.

Field condition	Possible root cause	Method to troubleshoot
A station operates intermittently.	• A solenoid is beginning to fail and is drawing too much current. • The short only appears when the decoder is operated. • The solenoid may stop working due to voltage loss down the two-wire com path, preventing an "off" command from reaching the decoder. • Some two-wire controllers may be able to report the fault condition but may be unable to turn on the solenoid. 	• Remove the suspected solenoid from the valve but only after the main line is depressurized. • Install the station decoder and solenoid to the two-wire terminals on the controller once the existing two-wire com path is temporarily disconnected. Then attempt to operate the station manually. If the solenoid does not make a buzzing noise, remove and replace the solenoid. Verify in the same manner prior to reconnecting in the field.
Cannot operate a station from a scheduled start time or manual operation from the controller.	• Decoder may have failed. • Decoder is not programmed to the corresponding station address. 	• Remove the suspected decoder from the valve. • Install the decoder and a known working solenoid to the two-wire terminals on the controller once the existing two-wire com path is temporarily disconnected. Then, attempt to operate the station manually. If the solenoid does not make a buzzing noise, verify the station address is properly programmed into the decoder and retry. If the solenoid does not make a buzzing noise when operated manually, program a new decoder and retry.
Cannot operate a station or several stations.	Poor cable or wire connection integrity is allowing current leakage to earth ground. 	• Conduct a visual observation of field conditions to determine if some form of site disruption has occurred as a possible cause to the observed condition. • Look carefully at the two-wire com path connection to the decoder and from the decoder to the valve solenoid. Remake any wire connections that appear to be suspicious such as nonwaterproof connectors or a connecter that may have little or no waterproof material remaining. • Remake the wire connection and operate the station manually to confirm operation. • Conduct a visual inspection of the two-wire com path in and out of the valve box looking for signs of an exposed conductor or nicked insulation. Repair and replace any damaged wire with waterproof connections as needed.

Using the Clamp Meter



Tracing Two-Wire Shorts

Manufacturer's Chart

Table 2

Valve Wire Sizing
(Maximum One-Way Distance in Feet Between Controller and Valve)

Ground Wire	Control Wire						
	18	16	14	12	10	8	6
18	850	1040	1210	1350	1460	1540	1590
16	1040	1340	1650	1920	2150	2330	2440
14	1210	1650	2150	2630	3080	3450	3700
12	1350	1920	2630	3390	4170	4880	5400
10	1460	2150	3080	4170	5400	6670	7690
8	1540	2330	3450	4880	6670	8700	10530
6	1590	2440	3700	5400	7690	10530	13330

Heavy-duty solenoid: 24 VAC,
370 mA inrush current, 190 mA holding current, 60 cycles;
475 mA inrush current, 230 mA holding current, 50 cycles

Wire Size Calculations

$$L = (AVL \times 1{,}000) / (I \times R \times 2)$$

$$AVL = (I \times R \times L \times 2) / 1{,}000$$

$$R = (AVL \times 1{,}000) / (I \times L \times 2)$$

Effect of Water Pressure on Inrush Current

Table 10-2: Solenoid operating voltage and inrush current (example only)

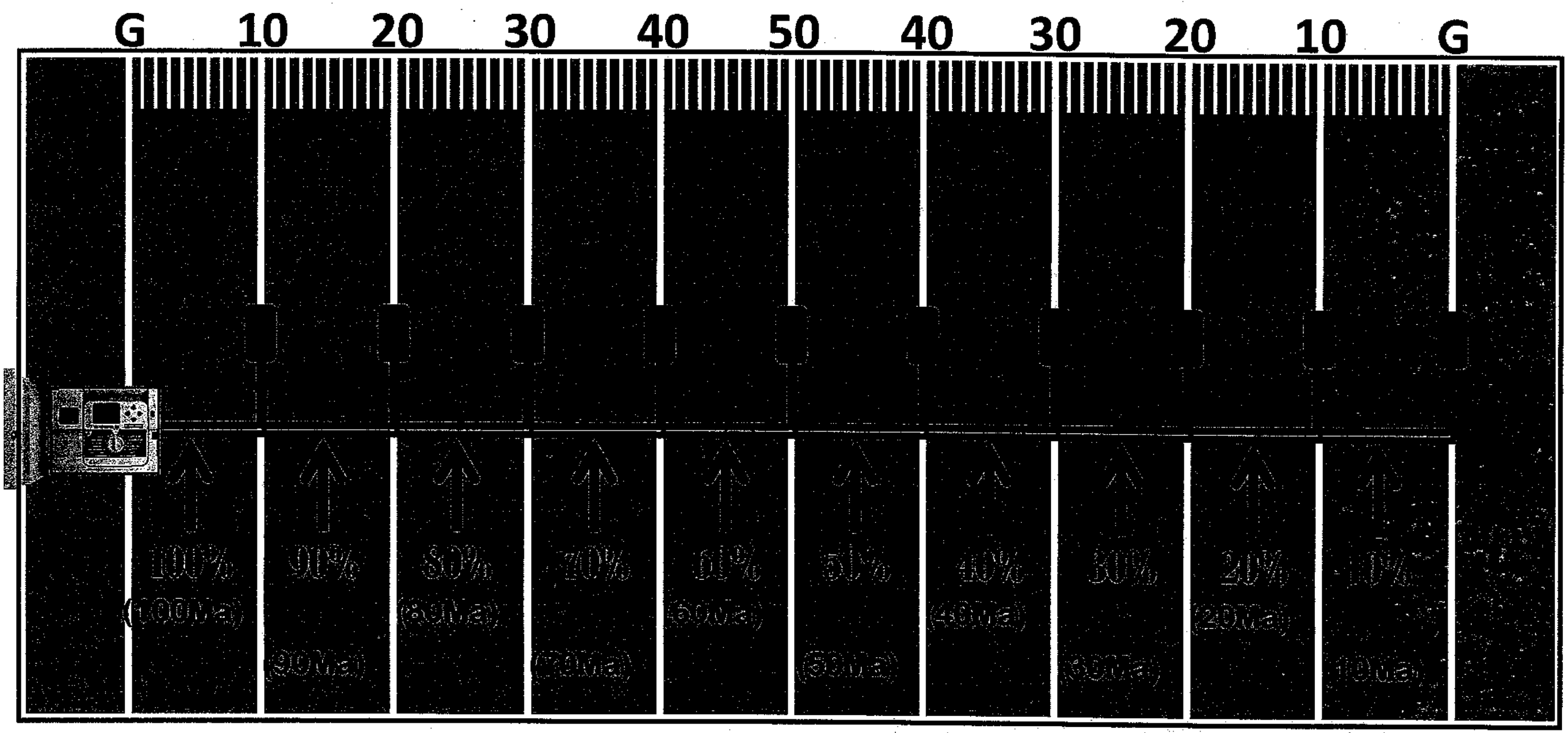
Water Pressure lb/in^2	Minimum solenoid operating voltage	Inrush Current (Amps)		
		1 valve	2 valves	3 valves
50	17.9	0.240	0.480	0.720
75	19.9	0.265	0.530	0.795
100	21.5	0.289	0.578	0.867
125	22.7	0.310	0.620	0.930
150	24.3	0.328	0.656	0.984

Copper Wire Resistance Chart

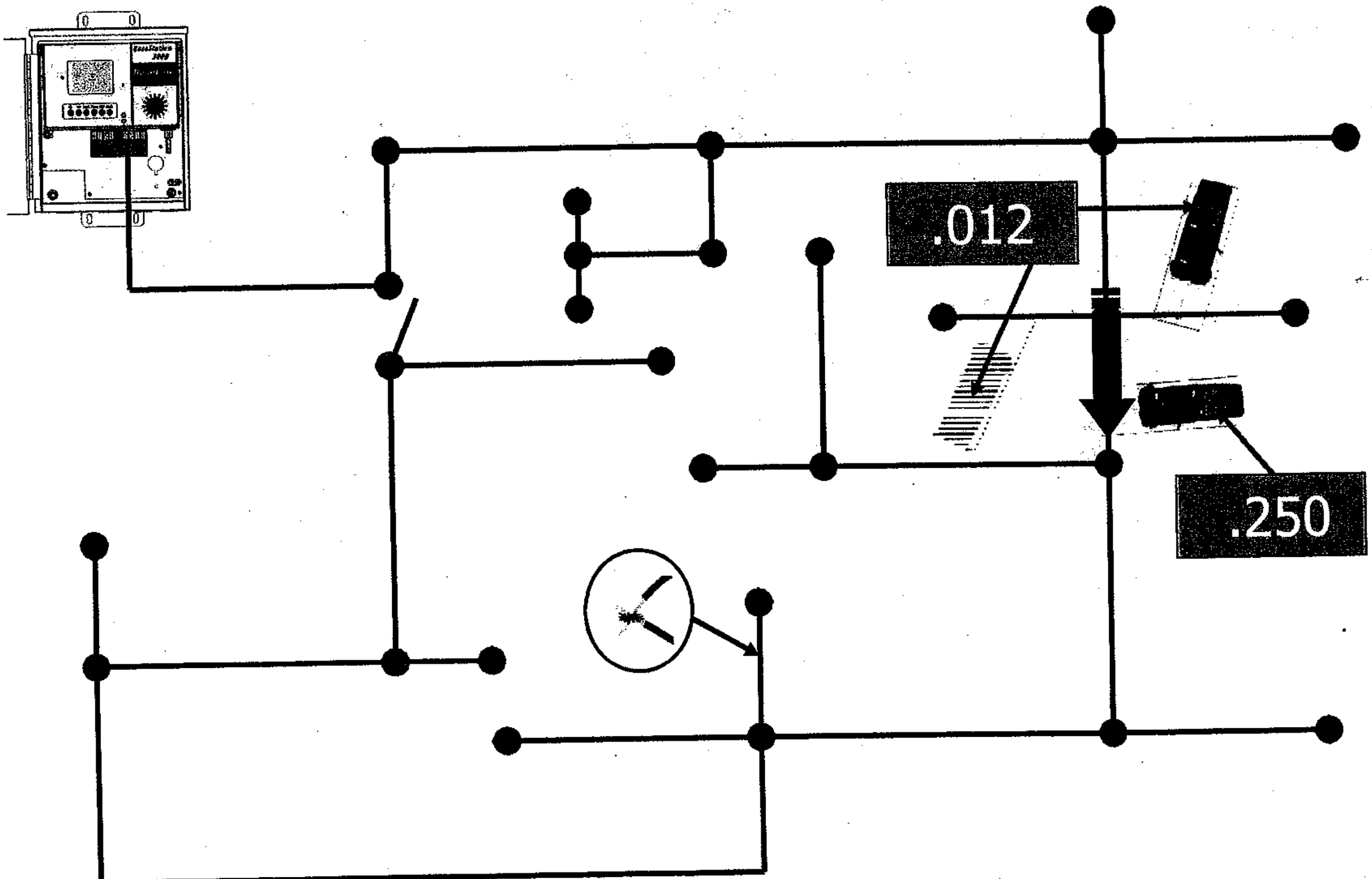
- Ω10 AWG. 1.020 ohms / 1000′
- Ω12 AWG. 1.620 ohms / 1000′
- Ω14 AWG. 2.520 ohms / 1000′
- Ω16 AWG. 4.110 ohms / 1000′
- Ω18 AWG. 6.510 ohms / 1000′

Decoder Troubleshooting

Basic Concept



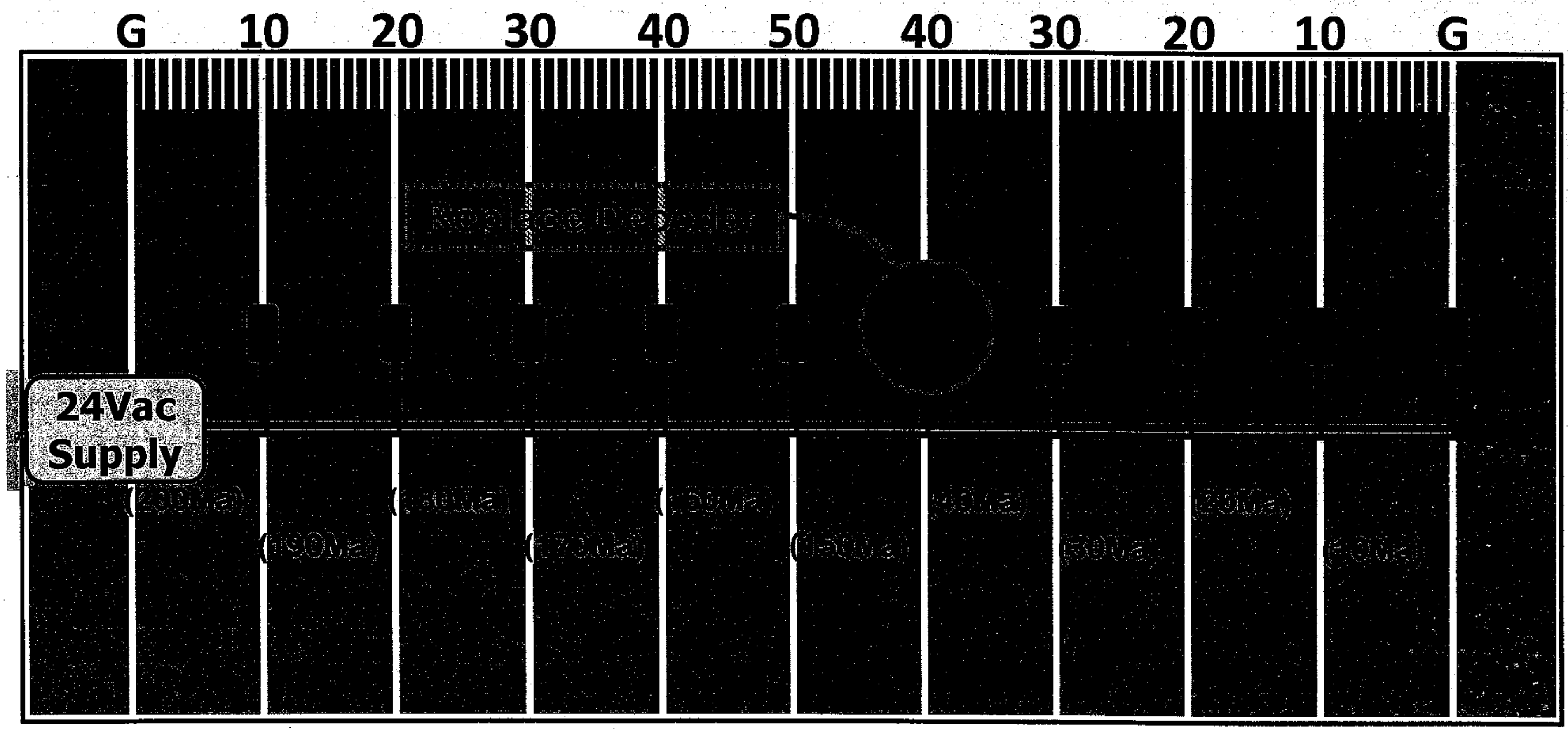
Using the Clamp Meter



Tracing Two-wire Shorts

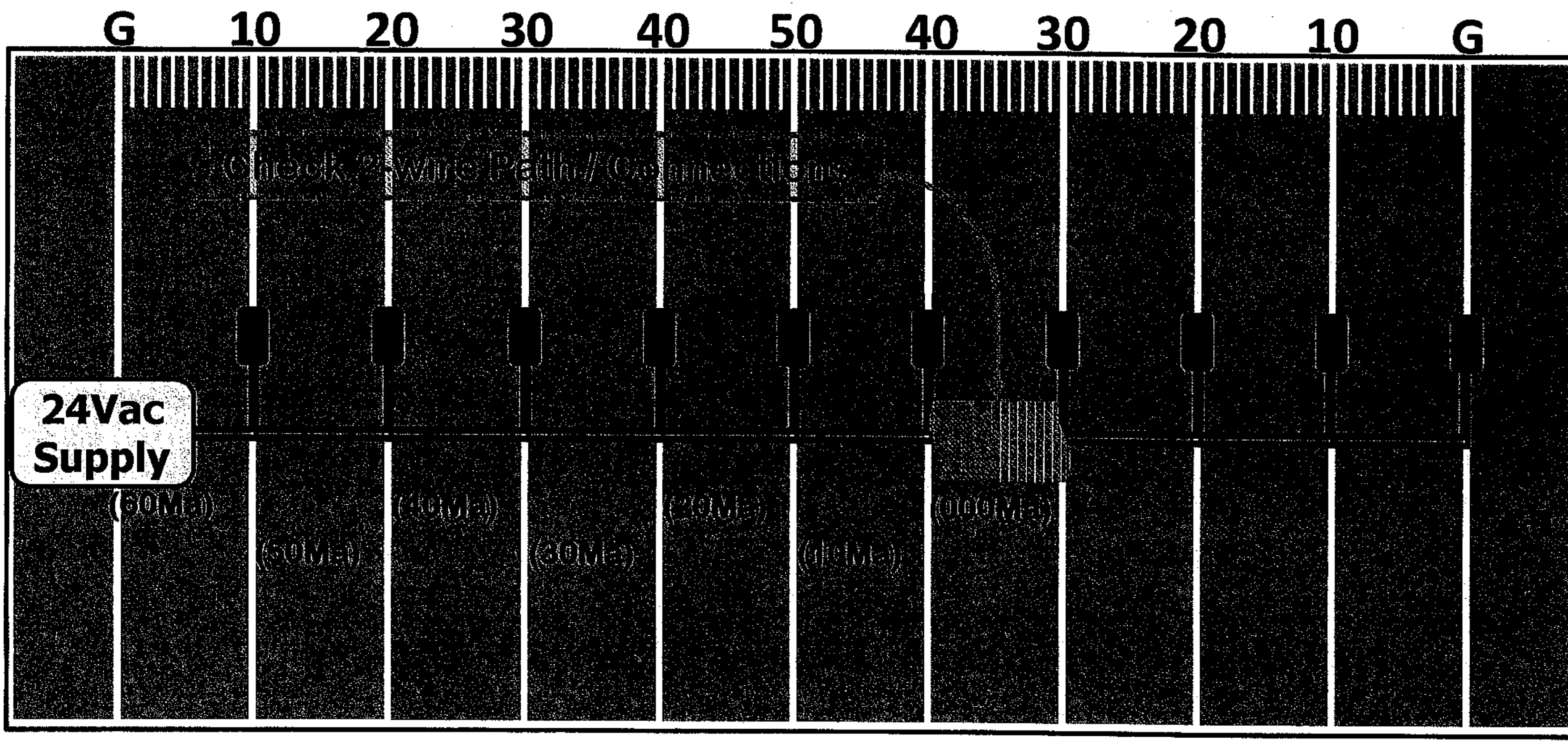
Decoder Troubleshooting

Using a Clamp Meter - Damaged Decoder

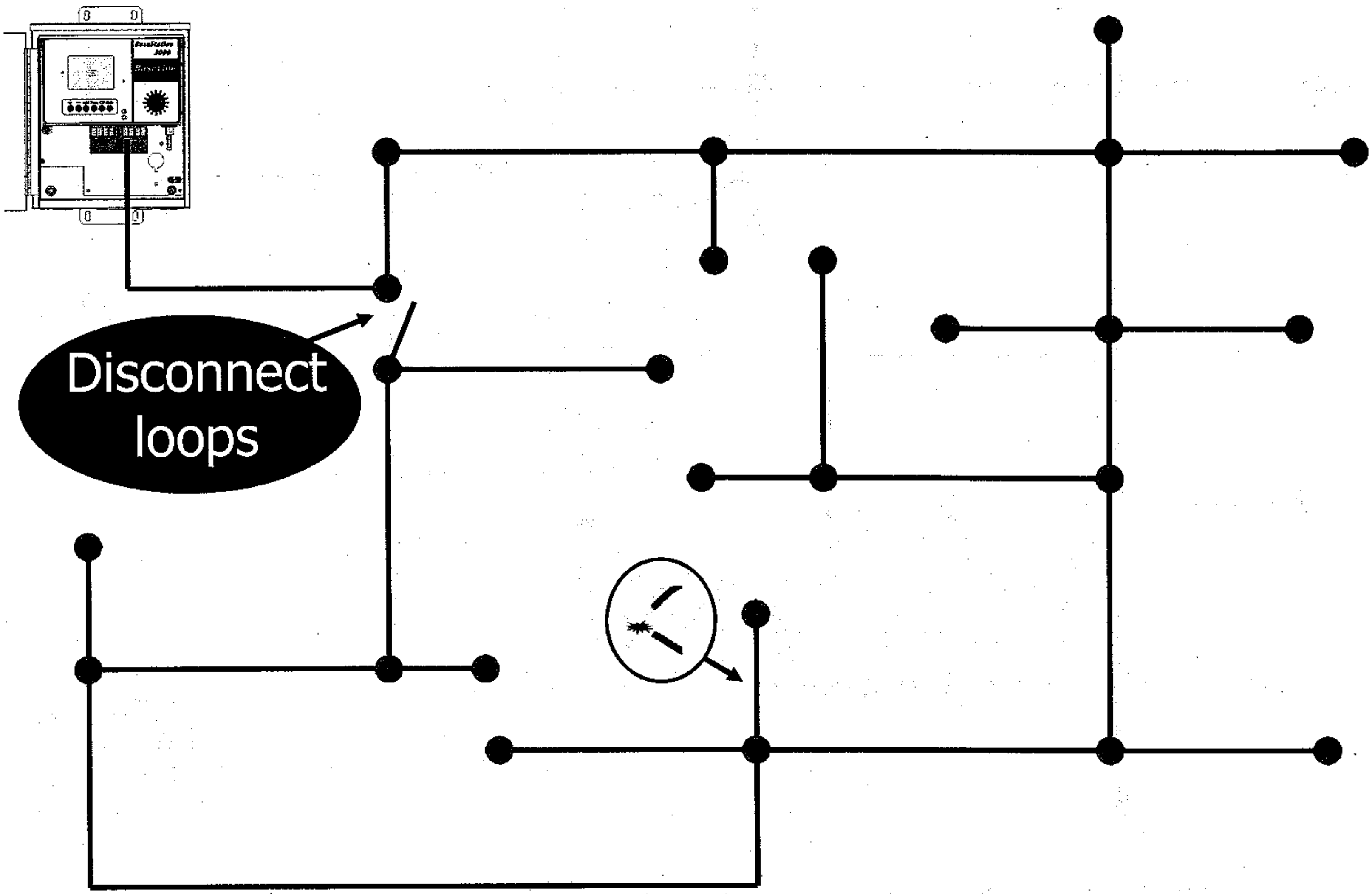


Decoder Troubleshooting

Using a Clamp Meter - Damaged/Broken 2-wire Path

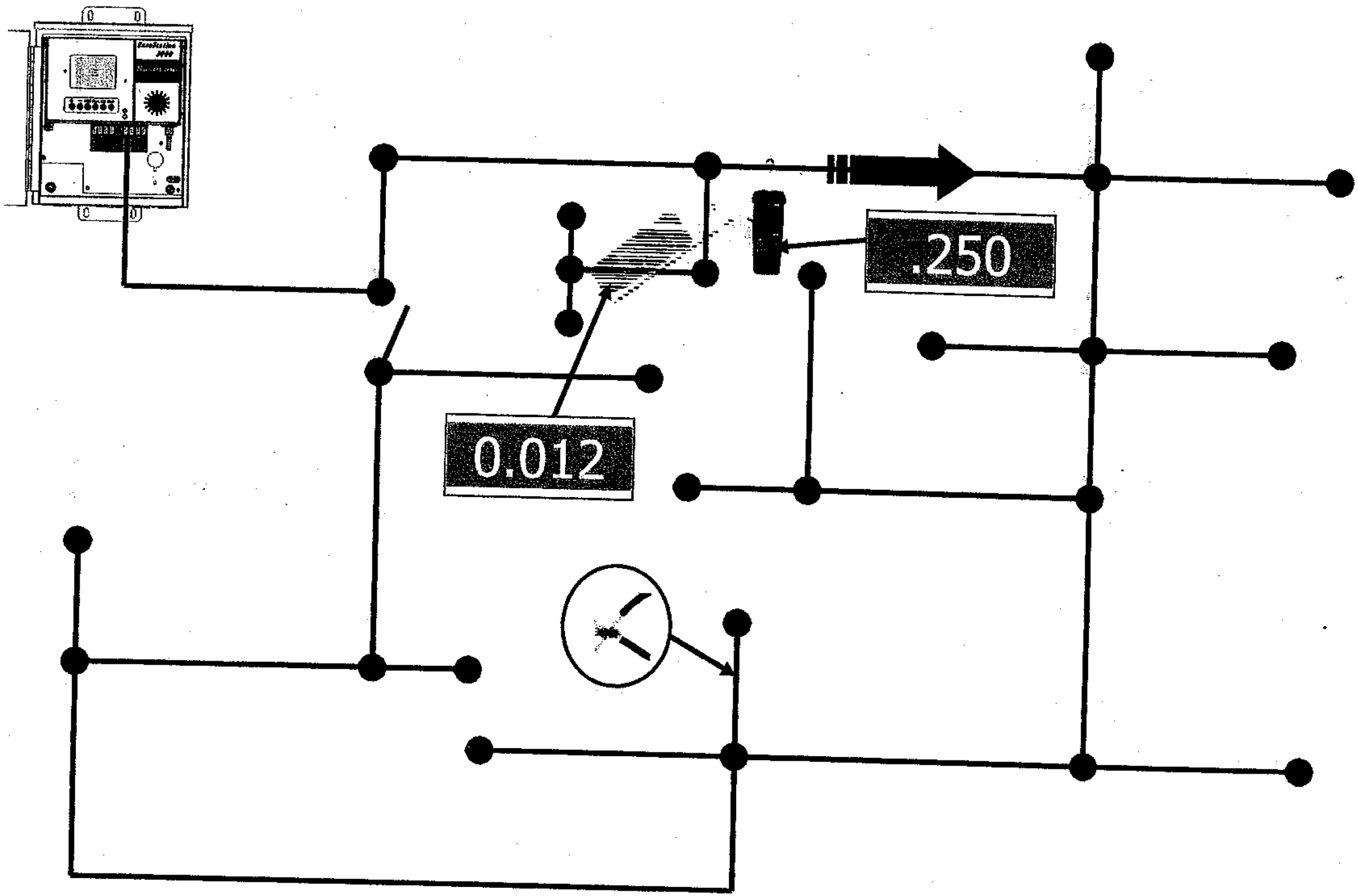


Using the Clamp Meter



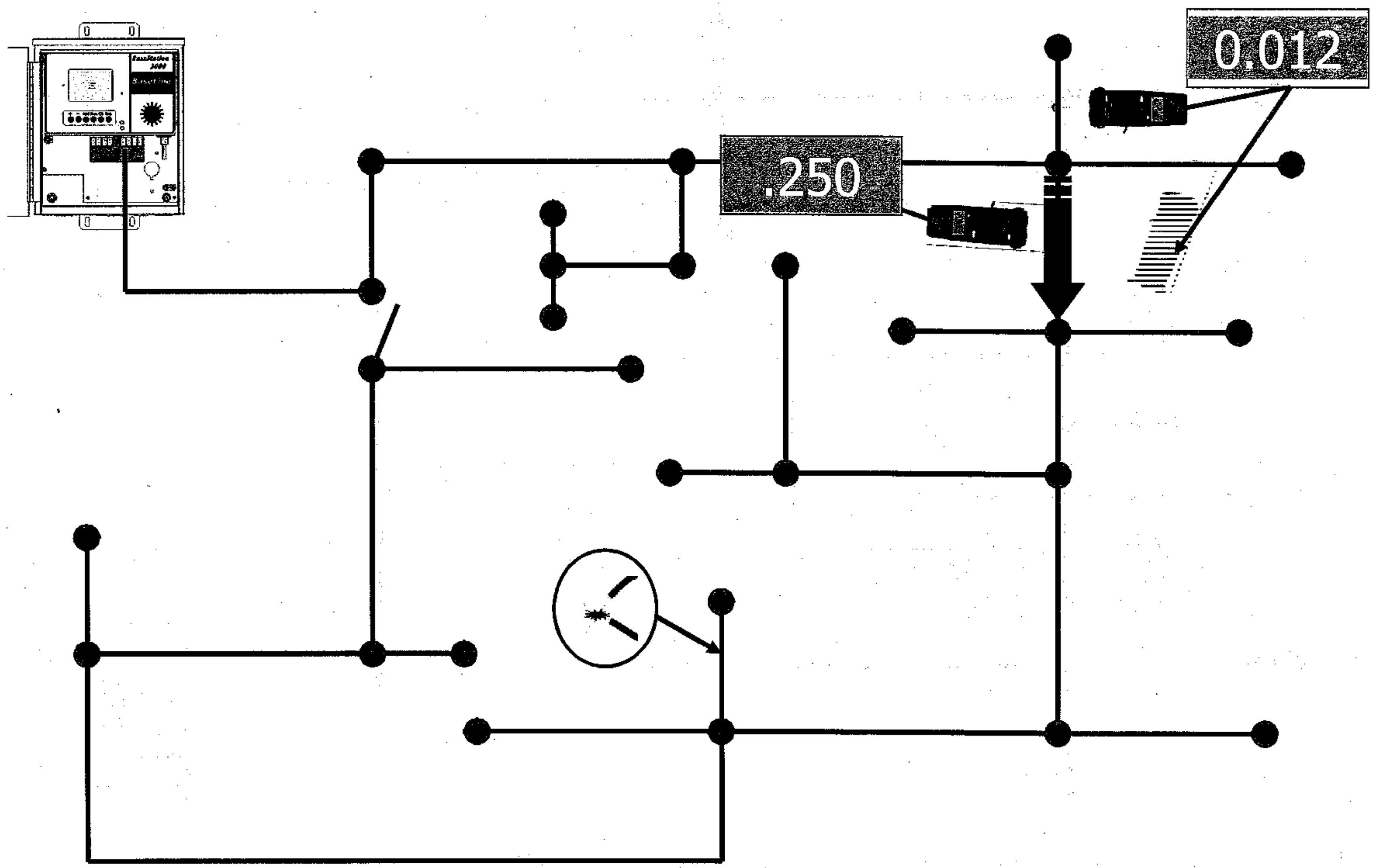
Tracing Two-Wire Shorts

Using the Clamp Meter



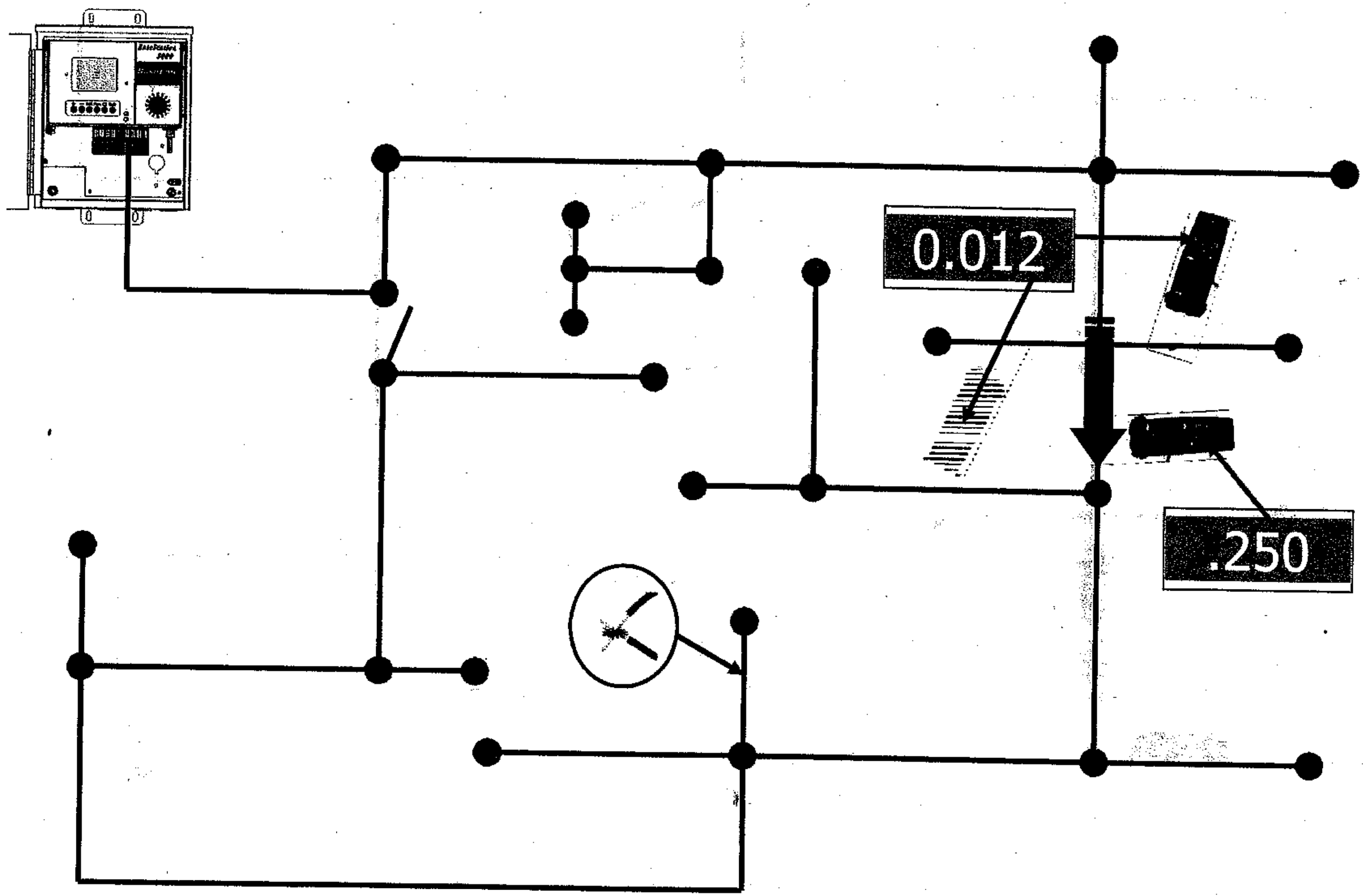
Tracing Two-Wire Shorts

Using the Clamp Meter



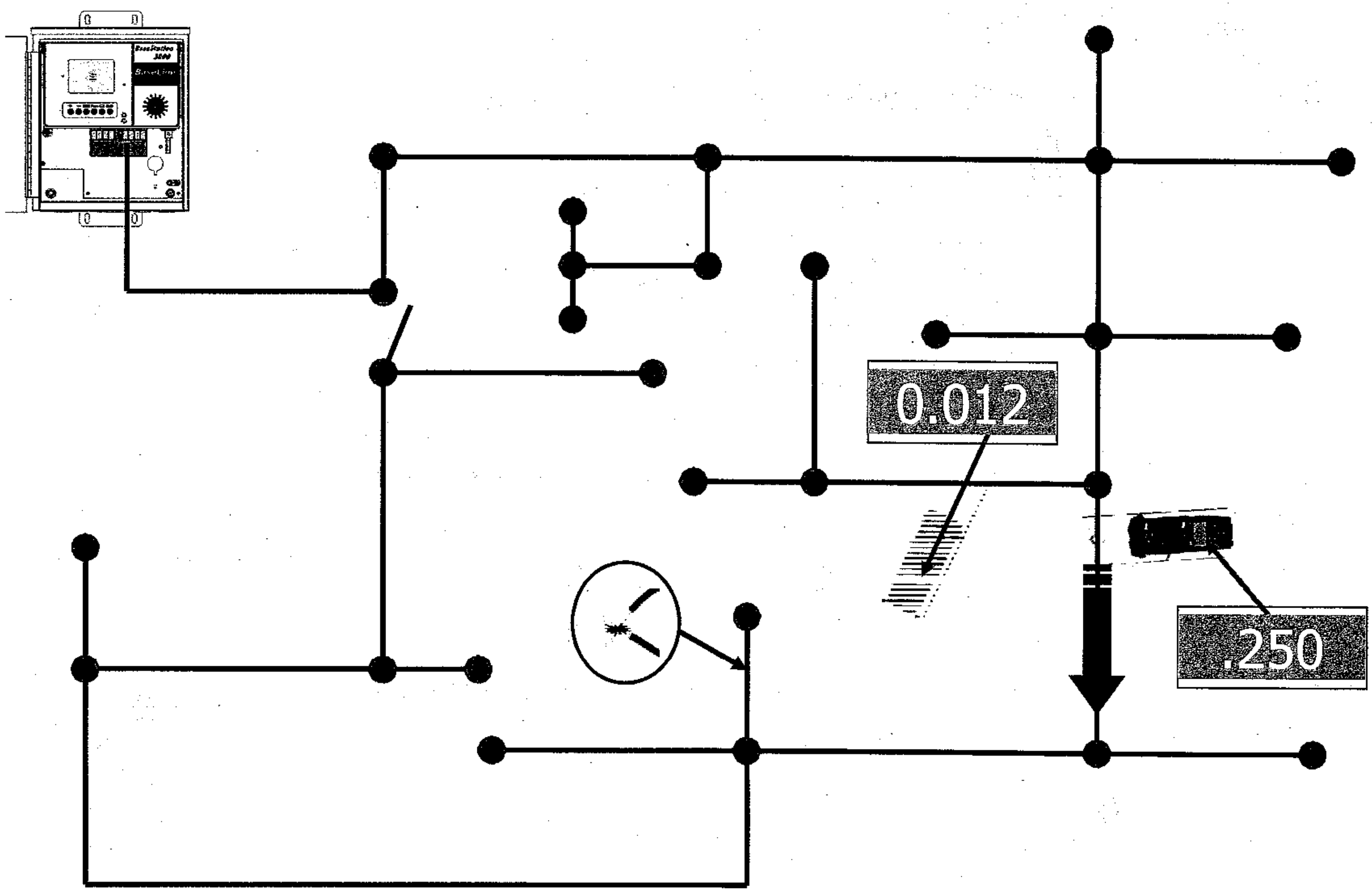
Tracing Two-Wire Shorts

Using the Clamp Meter



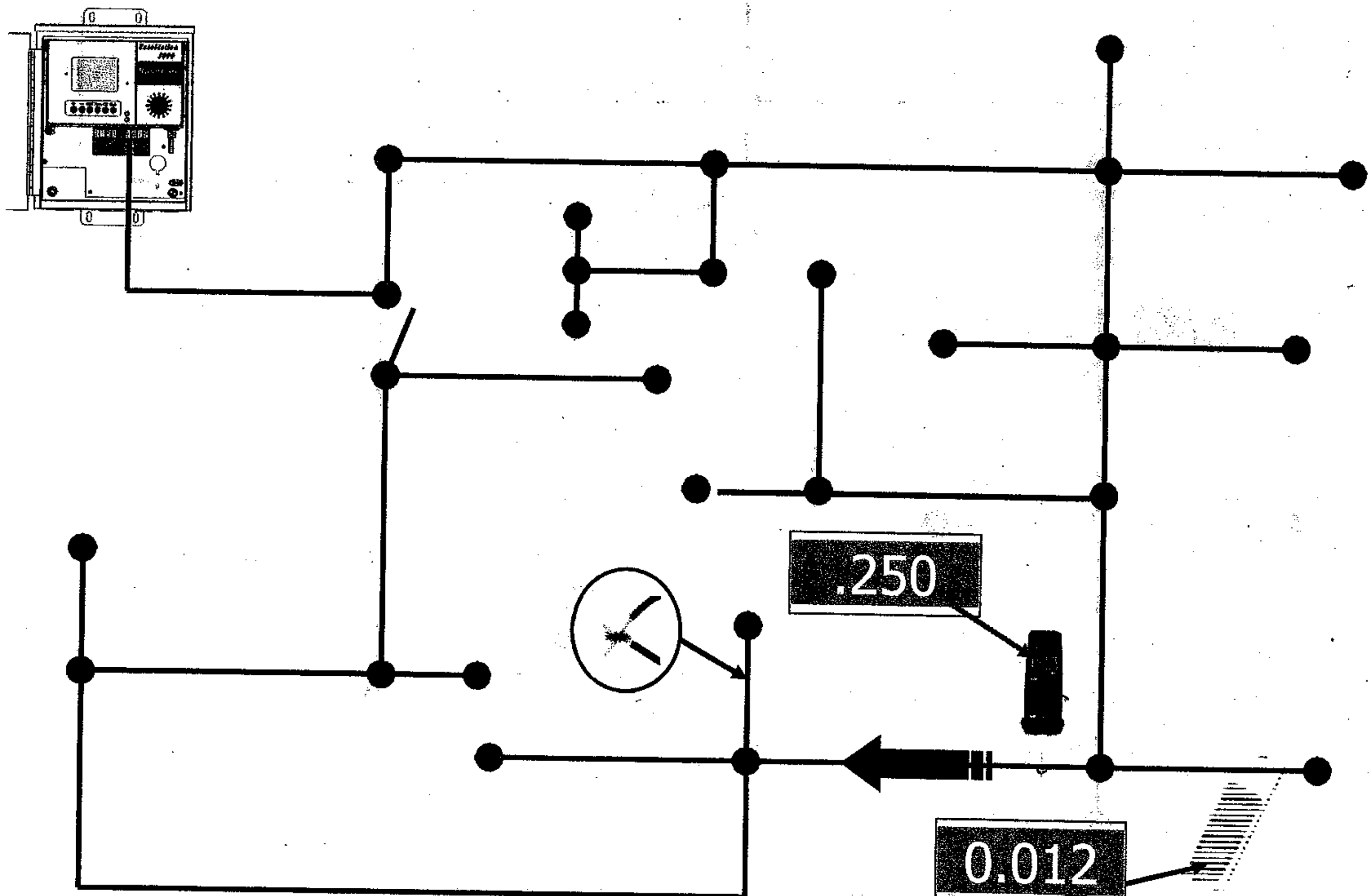
Tracing Two-Wire Shorts

Using the Clamp Meter



Tracing Two-Wire Shorts

Using the Clamp Meter



Tracing Two-Wire Shorts