FAULTFINDING IRRIGATION FIELD WIRING

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Preface.

The purpose of this booklet is to explain how to find electrical faults in the low voltage wiring used in irrigation systems. Tonick produce a range of modestly priced diagnostic aids to help in this regard.

The methodology explained below is not complicated. However much can be gained from a thoughtful measured approach. More haste, less speed is very much the case, especially with multiple faults.

The booklet is short enough to be read right through. It is hoped that the lessons within prove useful. Please do not hesitate to pass any comments back to Tonick.

Basic Electricity.

The measurement of electrical 'pressure' (think of water pressure) is in Volts, usually abbreviated as 'V'. e.g. 30V is thirty volts.

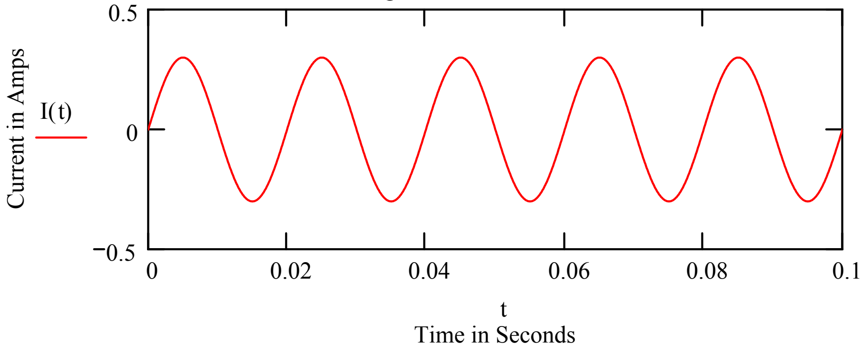
The measurement of electrical current (think of water flow) is in Amps or sometimes milliamps (1/1000 Amp), usually abbreviated to 'A' or 'mA'. e.g. 100mA is one hundred milliamps (=100/1000 Amps) = 0.1A, which is nought point one of an Amp.

The measurement of the resistance to current (flow) for a given voltage (pressure) is in ohms. Think of a narrow bore pipe resisting water flow at a given pressure compared to a wide bore pipe with the same pressure behind it. That is the narrow bore pipe has a higher resistance. Ohms are abbreviated to the Greek letter Omega and written Ω e.g. 100Ω is one hundred ohms.

There are two main types of voltage which produce correspondingly two types of current. A DC or Direct Current which is steady, remaining at one value all the time. An AC or Alternating Current on the other hand fluctuates regularly from positive to negative and back again, in our case 50 times a second or 50Hz pronounced fifty hertz. The waveshape of the alternating current is called a sine wave and has the shape drawn in figure 1.

$f := 50 \cdot Hz \qquad I_{pk} := 300 \cdot 10^{-3} \cdot amp \qquad t := 0, 0.1 \cdot 10^{-3} .. 100 \cdot 10^{-3} \qquad I(t) := I_{pk} \cdot \sin(2 \cdot \pi \cdot f \cdot t)$

Figure 1. An AC Current



Common usage is to refer to a DC voltage or an AC voltage. The AC voltage will have the same shape as the current just illustrated but will of course have the units of Volts. The AC voltage measured corresponds to the heating power of the voltage. For example, your kettle would boil in the same time whether you connected it to the mains (240V AC) or to 20 series connected 12V car batteries (20 X 12 = 240V DC). The peak value of the 240V AC mains is as high as plus or minus 340V, however it just doesn't stay there for long.

The flow of current is limited by the resistance of the circuit (i.e. cable). The higher the resistance the lower the flow of current for a particular voltage impressed. A simple law called Ohm's Law relate the entities.

V = I x R (V equals I times R) Where: V is volts, I is current in amps and R is resistance in Ohms

Using Algebra, also I = V / R and R = V / I(I equals V divided by R etc.)

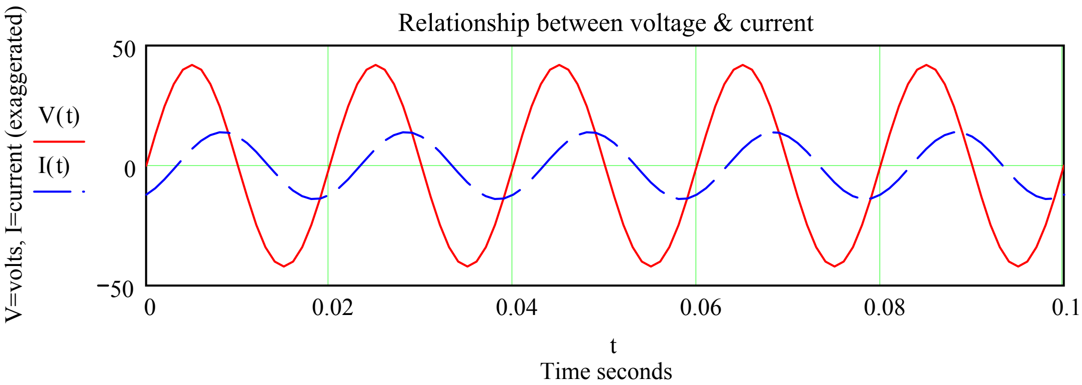
e.g. Putting 30V across 10Ω results in a current of 30 / 10 = 3A.

Ohm's Law applies for both DC and AC voltages and currents. However some components like solenoid coils have both a DC and an AC resistance which add up, so making the current through the coil smaller than the measured DC resistance would first suggest.

There is another very important property about the AC current taken by a coil. Although it is the same shape a the impressed AC voltage, the current lags the voltage by a measurable amount. Figure 2 illustrates this point. (please ignore the aweful formulae, just look at the graph!)

$f := 50 \qquad V_{pk} := 42 \qquad t := 0, 1\cdot10^{-3} .. 100\cdot10^{-3} \qquad V(t) := V_{pk}\cdot\sin(2\cdot\pi\cdot f\cdot t)$

$$I(t) := \frac{V_{pk}}{3}\cdot\sin\left[(2\cdot\pi\cdot f\cdot t) - \frac{\pi}{3}\right]$$



Many controller designs measure the lag of the solenoid current with respect to the voltage they are putting out. If the current does not lag the voltage they can decide that a solenoid is not energised after all. For example, experimentally replacing a solenoid with a light bulb of similar current drain (200mA) on a decoder in a Watermation TW2 system will fool the controller into a 'station fail' (Error 2). Correspondingly leaving a light bulb across the red and black main cable wires will not affect the TW2, but a solenoid connected the same way will eventually cause irrigation to stop with a 'Solenoid Permanently On' (Error 1).

Equipment Available

Power Transformer.
Most controllers will refuse to power up a zone (or CSG) that has more than a certain amount of load or leakage on it. Fuses may blow, software may shut the zone down or even worse a drive transistor in the controller may overheat. If at any time faults are suspected, or the controller behaves erratically, it is best to test the wiring and decoders using a power transformer.

A big power transformer, such as the Tonick TX/30-5 plugs into the mains and produces 30V AC to power up one zone. The field wiring is removed from the controller and the transformer's output is connected to it instead. Because of its size, the transformer can still produce a powerful voltage in the presence of quite serious field wiring faults. Because it lacks signalling circuitry, the transformer itself cannot turn decoders on or off. However this is not a disadvantage for the sort of faults that would shut down or damage a controller.

When used with a current clamp meter, digital voltmeter and the good old Mk.1 hand, the transformer allows fault finding with the minimum of effort and confusion. The detailed use of the transformer will be covered in the section 'Fault Tracing'.

Digital Multimeter.
A measuring meter that reads AC volts and resistance is a valuable tool in diagnosing faults. When the readout is a sensitive digital display rather than a pointer it can be used to even better effect. If a sensitive current measuring capability without breaking the wire is available too, the multimeter becomes almost indispensable.

AC volts is used to detect the location of high resistance joints and open circuits. Resistance allows testing of solenoid coils. It can also be used for the measurement of end-to-end resistance of the cable. Current measuring capability is used with great effect to detect the point of short circuits, high currents in decoders and the whereabouts of earth leakage.

Current Clamp Meter.
When a current flows it produces a magnetic field. This is how the solenoid can lift its plunger. If a ring of magnetic material is placed around a wire carrying a current, it can be used to detect and measure that current. If the ring can open like the jaws of a crab's claw, be placed around the wire, then closed, there is no need to break the wire to measure the current. Such a device is called a Current Clamp Meter. This feature is normally included in the features of a multimeter. However most clamp meters have been designed to measure hundreds of amps and are not sensitive enough to measure the current taken by an individual decoder. The Tonick YF-8060 multimeter can easily measure to one half a milliamp (1/2 mA) and can be used to check a decoder's standby current which is often a reliable indication of its goodness. Also knowing the standby currents of decoders allows an estimate of the number on a branch of the cable! (A table of typical decoder standby currents is given later on in this booklet.)

Decoder Tester.
Should an individual decoder be suspected of malfunction, it can be cut out and tested on the Tonick 2 or 3 wire decoder tester. Using either mains or vehicle battery power, the tester will cycle through all possible decoder station numbers looking for a response. If found, the tester will display that number and a green pass light. If no response a red fail light will illuminate. The setting of switches on the older decoders can be checked for water damage or vandalism without trying to laboriously interpret them. The tester can also be used to encode a station number into a replacement Tonick decoder.

With the decoder disconnected, the resistance of the solenoid coil can be checked using the multimeter.

Types of Faults.

There are a variety of wiring and decoder faults that can occur. They are described as follows.

Short Circuits.
Short circuits are vary rarely a zero resistance across the controller. This is because the cable itself has a significant resistance e.g. 16Ω per 1000 metres for 2.5mm^2 cable. This has the effect of limiting the current, which by Ohm's Law in the above example, with 30V AC at the controller end, would result in a current of 30 / 16 = 1.87A.

Additionally a 'short circuit' is often caused when a cable is severed using digging or ploughing machines. The exposed copper conductors are usually not touching but are in close proximity when the current has to pass through the earth. This again causes a nonzero resistance.

Nevertheless, currents will flow that are higher than the controller is used to. Therefore using a transformer, which 'doesn't care' will allow the current to flow continuously giving the operator time to find the short with the clamp meter. (See Fault Tracing Procedures). Another technique which works well if the short is severe, (greater than about 3A) is to feel with the fingers for hot cable, decoders or external lightning protectors. The lips are also very sensitive to small temperature differences, they can tell the difference between a slightly warm and cooler wire.

Short circuits on the solenoid side will only show up when the decoder is turned on by the controller. Using the 'zone test' facility or manually turning each decoder on will activate the short. This can then be confirmed with the resistance measuring multimeter after the wires are cut at the decoder.

High Resistance Joints.
Joints are a necessary evil. They are probably the worst offenders in irrigation unreliability. It is unusual however for a joint to go open circuit. Usually, as corrosion films build up, the resistance in the joint increases to several ohms. This does not always cause a problem when all the solenoids 'downstream' are off, because decoders take very little current on standby. Remember Ohm's Law: A small current through a fixed resistance causes only a small voltage drop. This may not impede a decoder from responding to an 'on' signal. However when the solenoid engages the current increases by perhaps 0.25A. The increased voltage drop may cause a further signal to be misread by the decoder which may not then turn off!

High resistance joints can be identified by connecting the transformer then measuring the voltage down the line at each joint with Load Probe and multimeter. A voltage drop greater than about 3 or 4 volts when pressing the 'load apply' switch on the probe indicates a high resistance in one of the joints. (See Fault Tracing Procedures).

Open Circuits.
Open circuits usually delineate the point in the wiring beyond which there will be no more voltage. An exception occurs where the main cable is looped all the way back to the controller forming a 'ring main'. Obviously for faultfinding purposes one end of the ring main will <u>not</u> be connected to the transformer. Another problem occurs in three wire systems where the signal lead starts to take some current in place of a broken power wire. A lower voltage may be measured between the power leads due to signal wire voltage feedthrough inside decoders. With the main cable's signal lead attached to the transformer centre tap (middle), probing in the box with the multimeter to measure the voltage between the signal lead and each power lead in turn will identify which of the power conductors is broken. (See Fault Tracing Procedures).

Leakage to Earth.
Normally the main cable will be insulated from the earth (ground). There should be little or no current flow to earth when connected to the controller. The effects of earth leakage are often subtle, usually resulting in erratic operation of the controller. Leakage may not only be to earth, but also from the power wires to the signal wire in 3 wire systems. As the latter is more sensitive, the resulting interference can cause apparent malfunction of decoders. Causes of leakage include non-waterproof joints in flooded boxes or similar joints buried directly in the ground. Obviously cable insulation damage or degradation could be a cause. The leakage current may not be high i.e. in the order of 10's of mA, but it can cause havoc. Sometimes the leakage varies with time, for example, a box flooding during the irrigation cycle, so the system starts correctly but then malfunctions!

Without the test equipment described previously, finding earth leakage can be almost impossible. However using the transformer, earthing link and current meter, it is possible to do a simple check at the controller end of the cable to determine if earth leakage exists. (See Basic Wiring Checkout). Further work in the field with the current clamp will allow the site(s) of leakage to be identified. Also damp fingers may be used to detect the leakage point because of a progressively worsening tingling the nearer to the fault the cable is touched!

Decoder Failure.
Decoders are actually quite sophisticated pieces of electronics which are asked to work in the most appalling conditions (for electronics, that is). Add to this the need to make them as low cost as possible and the design and construction problem becomes a difficult one.

Older generation decoders fail in several ways. Most have less robust lightning protection and can get damaged by indirect lightning strikes. Many rely on rather a lot of integrated circuits (called ICs or chips) rather than one modern, sophisticated, small microprocessor (called a micro). The more chips the more connections. The more connections the more unreliability. Another common reason for failure is their switches which set the decoder address or station number. These, be they 'sealed' or otherwise, are not designed to be proof against immersion under 10 inches of muddy water for 10 years. Moisture gets in and can short adjacent switches so scrambling the station number set. Even more insidious is the corrosion of contacts left open. If the decoder is ever re-coded, closed switches may not make contact. This means the decoder will not respond to the address set. Last, but not least, is the quality of the encapsulation (also called potting). It is essential to eliminate voids in the potting material. Any sign of pockmarks on the surface of the encapsulant indicates the likelihood of voids within. The adhesion of the encapsulant (known as material compatibility) to all the different plastics, metals, ceramics and epoxies which go to make up a decoder, is absolutely crucial. The adhesion may look good immediately after manufacture, but temperature cycling in damp conditions can radically affect it after time. Those who have warranted their decoders for an extended period are likely those who have addressed these problems.

Failed decoders that are taking a higher than normal standby (quiescent) current can be isolated using the current clamp multimeter, or detecting warmth with the fingers or lips. (A table of normal decoder standby currents is in the Basic Wiring Checkout section).

Other than a high standby current, the best way to detect station failure is with the controller. The suspect decoder can then be cut out and tested using the Tonick decoder tester. The solenoid connections can also be tested using the multimeter on resistance.

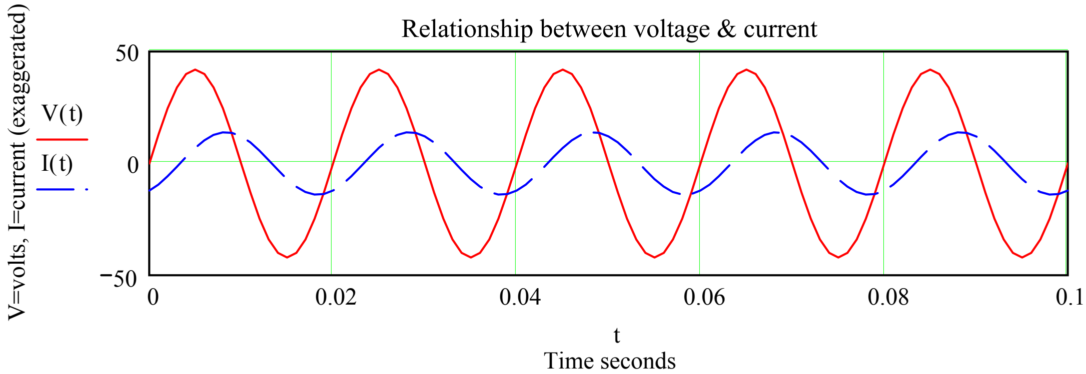
Solenoid Failure.
Nearly all the irrigation controllers on the market today use the extra current drawn by the solenoid to decide whether a station is working or not. Thus it is usually not possible to tell from the controller whether a station failure is wiring, decoder or solenoid.

A solenoid is a coil made of many turns of insulated wire over a hollow iron former. When a current flows, the magnetic field produced attracts an iron plunger into the centre of the former. A spring pushes the plunger back out when the current ceases. The coil wire has a DC resistance in the same way as the main cable. The coil has a resistance measured by a multimeter of typically 30Ω to 55Ω . Using Ohm's Law, a 24V AC voltage across the solenoid would produce a current of 24 / 30 = 0.8A (or 800mA). However observation with the clamp meter indicates a current of only around 200mA. The reduction in current is caused by an additional resistance to AC which is present in all coils. This resistance is lowest in the solenoid when the plunger is out and greatest when the plunger is in. An interesting test can be carried out on some solenoids where the plunger can be removed completely. The current observed will be much higher, nearer the 0.8A mentioned previously until the plunger is replaced. If left in this condition for more than half an hour the solenoid will probably overheat! Thus, when a solenoid is first energised, its current is high for perhaps 0.2 second until the plunger retracts. This is called the surge current.

There is another very important property about the AC current taken by a coil. Although it is the same shape a the impressed AC voltage, the current lags the voltage by a measurable amount. Figure 2 illustrates this point. (please ignore the aweful formulae, just look at the graph!)

$f := 50 \qquad V_{pk} := 42 \qquad t := 0, 1\cdot 10^{-3} .. 100\cdot 10^{-3} \qquad V(t) := V_{pk}\cdot \sin(2\cdot\pi\cdot f\cdot t)$

$$I(t) := \frac{V_{pk}}{3}\cdot \sin\left[(2\cdot\pi\cdot f\cdot t) - \frac{\pi}{3}\right]$$



Some controller designs measure the lag of the solenoid current with respect to the voltage they are putting out. If the current does not lag the voltage they can decide that a solenoid is not energised after all. For example, experimentally replacing a solenoid with a light bulb of similar current drain (200mA) on a decoder in a Watermation TW2 system will fool the controller into a 'station fail' (Error 2). Correspondingly leaving a light bulb across the red and black main cable wires will not affect the TW2, but a solenoid connected the same way will cause irrigation to stop with a 'Solenoid Permanently On' (Error 1).

Having dwelt on AC resistance, it is sufficient to measure around 30Ω using the multimeter on resistance to determine if a solenoid is good. An unusually high AC current is indicative of a plunger jammed out or even missing. A simple wiring adapter off a Tonick Battery Power Supply can be used to observe plunger movement when a solenoid is connected.

Using the Test Equipment.

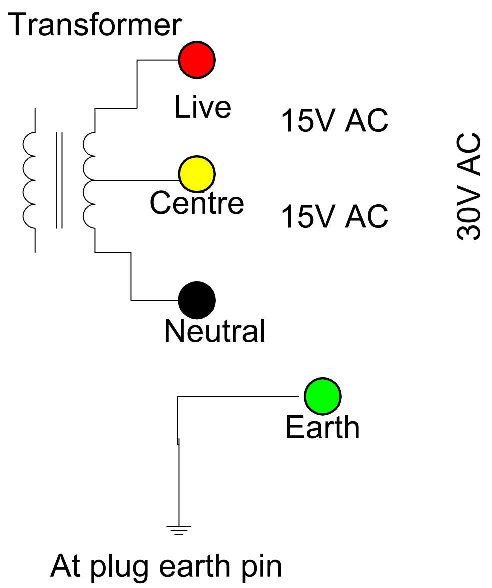
The Tonick Transformer TX/30-5

The transformer is plugged into the 240Vmains powe using the 13A plug. The only fuse is a 13A one in the mains plug. The transformer case is **not waterproof and contains 240V AC inside**. Avoid getting it wet or standing it in water.

It is important during fault diagnosis that the earth connection in the mains socket, into which the transformer is plugged, is electrically close to the controller earth. After plugging in the transformer, use the multimeter on *volts*
terminal on the controller. A reading of more than 1 volt should be investigated. Also, if possible, check the green terminal against the potential of the ground outside the building where the controller is situated. Use one multimeter lead in the moistened ground and the other on the green terminal. Again a reading of

The transformer will produce around 30V AC at currents of at least 5A. This is enough to locate all but a dead short circuit on the wiring. The 30V is produced between the red terminal (live) and the black terminal (neutral). The 30V AC is divided in half at the yellow terminal (centre tap). That is, 15V AC from yellow to black and likewise 15V AC from yellow to red. The two green sockets are connected to the earth pin on the 13A mains plug.

The output of the transformer is isolated from earth unless the green wire is plugged into either the black, yellow or red terminal. Do not under any circumstances connect more than one of these terminals at a time to the green earth. An electrical diagram of the transformer is shown in the figure below.



In the diagram the transformer's 240V primary is not shown.

Only one of the two earth sockets are shown.

The secondary 30V AC is completely isolated from earth (unless deliberately connected).

Tonick TW/YF-8060 MULTIMETER
(with current Clamp)

The multimeter has a rotary selector switch with the following ranges:
AC current: 40mA, 400mA, 4A, 100A
AC voltage: 500V
Resistance: 400Ω

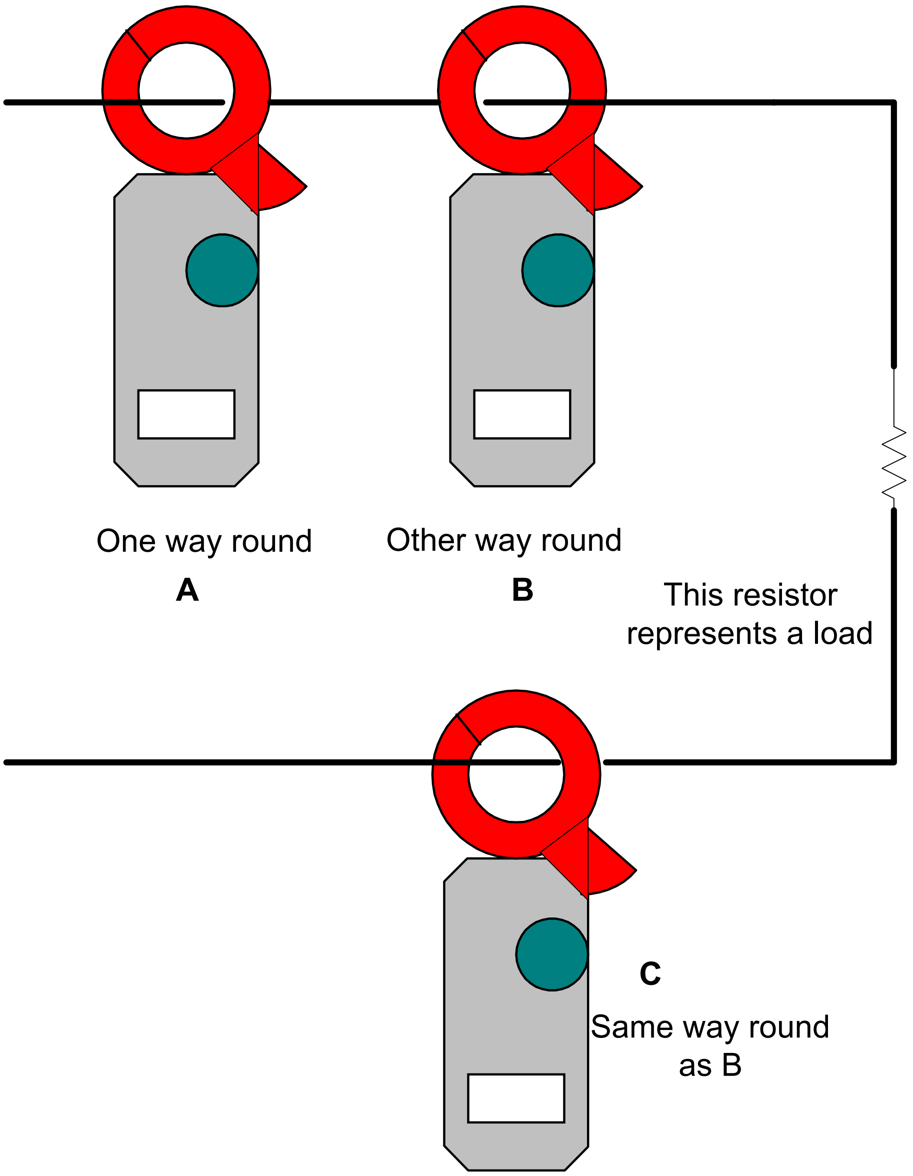
A green on/off button is just below. The battery life is around 200 hours. Do not try and change the battery with the multimeter still connected to the circuit under test.

Voltage and resistance are measured using the test leads. When measuring resistance there must be no voltage on the circuit being measured.

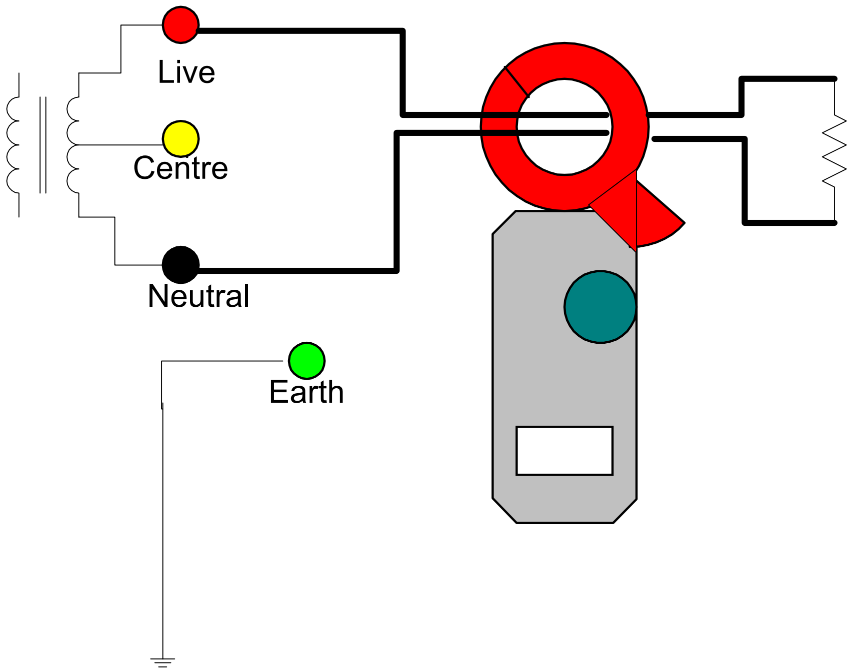
Currents are measured by opening the red jaws by pressing the red trigger with the thumb and clamping the jaws around the wire. Make sure the jaws shut fully. Keep the open ends of the jaws clean and free from grit and water. A build up of rust or deposits will cause false readings.

Because not all currents are exactly the sine wave shape in figure 1, the multimeter meter may read slightly differently depending which way the jaws are clamped around the wire. Try it both ways and see.

In the following figure, **A** may read slightly differently to **B**. **B** and **C** are measuring the same way round so will read exactly the same current

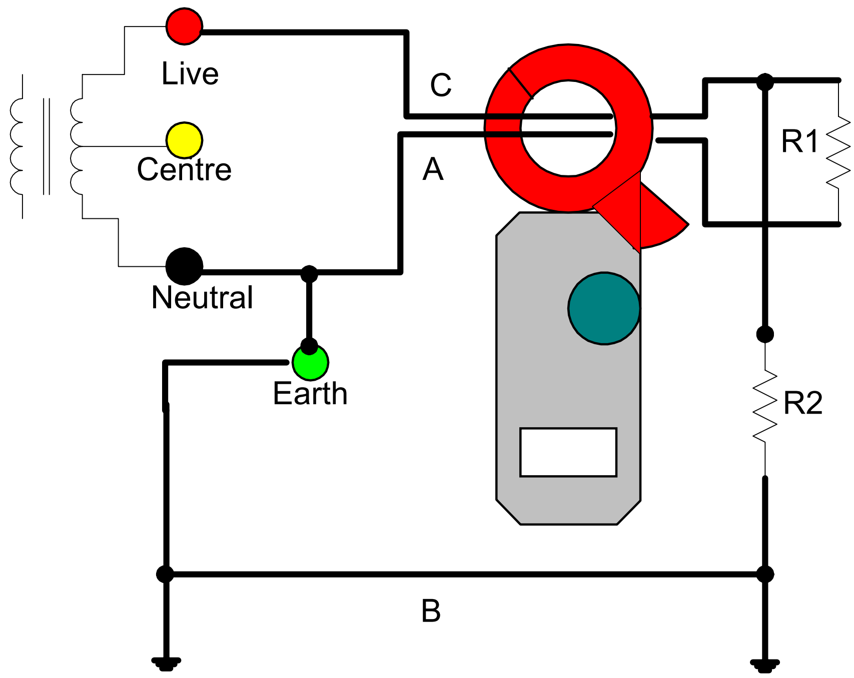

One way round
A
Other way round
B
This resistor represents a load
C
Same way round as B

It is important to understand that if both flow and return wires carry the same current and are placed inside the jaws, *the multimeter will read zero*
out.



In the diagram below however, the current in C is returned partly in A and partly in B. The amounts apportioned according to the relative values of the two resistances R1 and R2. Because A and C are not equal, the current multimeter will read the difference (which is equal to that in B).

This is the method used to determine if there is leakage to ground in the field wiring. In that case the path B is through the earth. See the later section on Fault Tracing.



The Tonick Load Probe. TW/DL-100

The small rectangular probe replaces the normal red test lead of the multimeter. Normally it functions as the red lead, allowing voltage or resistance between it and the black lead to be measured on the multimeter.

However, when the push button on the probe is pressed using the index finger, a 100Ω load is placed across the measuring points. This allows the resistance of the cable to be estimated *whilst power is still connected.*

With 30V AC being measured for example, the extra current drawn will be 30 / 100 = 300mA. If the voltage without the load is noted, then the button pressed and the new lower voltage measured, the ratio of the two according to the formula below gives the resistance of the circuit.

If the intial voltage = V_i And the voltage under load = V_L

Then the resistance of the circuit $R_s := \frac{V_i - V_L}{V_L} \cdot 100 \cdot \Omega$

For example:

If the intial voltage $V_i := 30 \cdot \text{volt}$ And the voltage under load $V_L := 28 \cdot \text{volt}$

$R_s := \frac{V_i - V_L}{V_L} \cdot 100 \cdot \Omega$ Substituting.. $R_s := \frac{30 - 28}{28} \cdot 100 \cdot \Omega$ $R_s = 7.1\,\Omega$

To Find High Resistance Joints:

The resistance R_s is the total resistance of both the 'flow' and 'return' wires.

e.g 2.5mm^2 cable has a resistance of 8Ω per kilometer. It takes 2 wires to flow and return. therefore the resistance is 2 x 8 = 16Ω .

Most cable runs will only be a few ohms. Therefore the voltage drop when the 100Ω load is applied is unlikely to exceed one to three volts unless there are high resistance joints. Most decoders will not work reliably below 15V or 16V. If the loaded voltage measured with the probe is near or lower than this figure, there may be unreliable switching, including decoders that don't turn off, or turn on briefly then off again. The effect of multiple solenoids on simultaneously from some controllers should be considered.

If you are measuring with one probe in the moist ground, the earth resistance back to the transformer will be included.

How to Connect the Probe:

Remove the normal red and black test leads from the multimeter. Plug the probe's red and black plugs into the multimter's sockets. Plug the original black lead into the top of the probe's black plug which has a socket built into it. Use the probe as the red lead. The 100Ω load will not be connected until you press and hold down the button. Releasing the button will disconnect the load.

WARNING: Do NOT measure line (mains) 115V/240V with the load probe. It is only designed to be used with Extra Low Voltages (ELV) smaller than 48V ac.

The Tonick Capacitive Load. TW/CAP

The TW/CAP capacitive load is used for circumventing 'Solenoid Permanently On' Error Messages. Watermation TW1 or TW2 and Aquarius AQ2100 or AQ2400 controllers will not function in diagnostic or normal irrigation with what they believe is a permanently on solenoid. Their perception of this situation is the measurement of a lag in the AC current compared to the AC voltage. For further details see the Solenoid Failure section in Types of Faults. If in fact a solenoid is actually on, running the pump and looking for the water is an effective way of pinpointing the problem. However decoders can occasionally fail in a way that fools the controller into thinking a solenoid is on even though a real one is not.

The secret to circumvent this impasse is to connect a suitable capacitor across the field wiring (at the controller will do). Capacitors are an electrical component that behave almost in the opposite way to coils. They have the property that the AC current leads the AC voltage rather than lags it like coils. If a correct value capacitor is placed in parallel with the fault, the current (although altered in magnitude), is swung back to look like a plain resistance and the controller is happy again! Tonick make the TW/CAP module which will do the correction. Once the module is connected and 'tuned', the controller can be used in the normal way to detect station failure. One of these will be the failed decoder that is causing the original

How to use the Module:

Using the two crocodile clips, connect the module across the power wires of the field wiring. With the knob fully anti-clockwise the capacitance will be disconnected. Each click clockwise will increase it in roughly equal stages up to a maximum after 9clicks.

Try the controller after each click to see if the 'Solenoid Permanently On' message goes away. If it does, you can proceed with further diagnostics.

After detecting and replacing the failed decoder, remember to remove the module or at least turn the knob fully anti-clockwise to remove the capacitance.

Basic Wiring Checkout.

Step 1. Earth potentials.

Note connections, then remove field wiring from controller. Plug in transformer to mains. Check potential of transformer green socket against (a) controller's earth, (b) the moistened ground outside the building. Investigate voltages in excess of 1V AC

Step 2. Multimeter zero reading.

Connect power wires of field wiring zone to red and black terminals of transformer. Use the grey extension cable with the crocodile clips (wire colours same as transformer terminal colours). Leave signal wire (if present) open circuit. Place multimeter current clamp set to 4A AC over whole grey cable. Check it reads zero. Switch to 400mA range, check meter still reads zero, or at least less than 2 mA.

Step 3. Zone standby current.

Place clamp over just the red wire. Use the table of decoder currents below to verify that the current being taken is roughly in line with the numbers of decoders fitted on the zone. Beware that a multi-output decoder takes roughly the same current as a single. Thus counting the station numbers will not necessarily indicate the number of decoders fitted.

TABLE OF DECODER STANDBY CURRENTS

No. of decoders in zone	1	20	40	54	72	90
	Current in mA					
Watermation TW2	16	320	640	864	1152	1440
TW/WM	7	140	280	378	504	630
TW/2W	2.9	58	119	157	209	261
TW/LS	2.9	58	119	....	....	....
Wright Rain Mk. I & II	25*	500	1000	1350	1800	2250
Robydome Mk. I & II	25*	500	1000	1350	1800	2250
Prime Primetime	25*	500	1000	1350	1800	2250
Tonick TW/WR	12	240	480	648	864	1080
Photron CIC & CIC1+	4	80	160	216	288	360
Tonick TW/CIC	4.5	90	180	243	324	405
Robydome Mk. III	7	140	280	378	504	630
Tonick TW/WR Mk. 3	7	140	280	378	504	630
Toro SC3000	3.5	70	140	189	252	315
Tonick TW/TOR	4.5	90	180	243	324	405

* Early versions of these decoders take 25mA, later ones take 12 mA. Check a decoder in a nearby box with the clamp meter on the 40mA range.

Decoder currents vary depending on the voltage applied. Near the controller they will take more,at the end of a long run, less. After a bit of practice you can judge the sort of voltage levels on a decoder from its standby current. This may save breaking into the joint to gain access with the voltmeter.

Step 4. Signal Lead Currents.

Connect the signal wire in 3 wire systems:-

Wright Rain/Primetime/Robydome	to Red
CIC	to Yellow
Toro	to Red

Place the clamp just over the signal wire. Use the 400mA range. Current should not *exceed*:-

Wright Rain/Robydome/Primetime	1.5mA per decoder
CIC	0.5mA per decoder
Toro	0.5mA per decoder

Current may be much less than this, however if they are significantly in excess of the above, it indicates a short or leakage either in the cable or within a decoder.

Reconnect the signal wire:-

Wright Rain/Primetime/Robydome	to Yellow
CIC	to Black
Toro	to Black

This puts the signal connection to the benign logic 0 position.

In this position, none of the decoders should take significant current in the signal lead.

Step 5. Earth leakage.

Reconnect the signal wire:-

Wright Rain/Primetime/Robydome	to Yellow
CIC	to Black
Toro	to Black

This puts the signal connection to the benign logic 0 position.

Connect the green earth link in turn
allow a path back to the transformer for any earth leakage in the field. Place the current clamp over the whole grey cable. If there is any earth leakage it will show on the meter as an excess over that read in step 2. Note all three readings. Experience shows that leakages less than 20mA are not intrusive to signalling performance

If the wiring system passes all the above tests, it is safe to reconnect the controller and proceed with a zone decoder test. Obviously for multi zone controllers, the electrical tests must be repeated for each zone.

If any test fails, carry out the appropriate faultfinding procedures in the next section.

IMPORTANT TIP.
In addition to the above tests, if the load probe (see page 13) is used on the furthest point from the controller the overall resistance can be calculated. By allowing 16Ω per 1000m for cable (2.5mm^2), any excess is in the joints themselves. This indicates the condition of all the joints between you and the controller and gives an important but quick overall check.

Fault Tracing Procedures.

General notes:

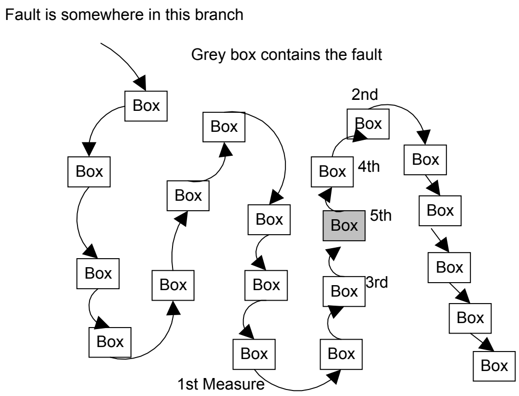
Having a clamp meter means it is hardly ever necessary to cut wires to pinpoint faults.

A knowledge of the general layout of the cabling is very helpful. i.e. the branches and general runs. If an 'As Laid' diagram is not available, the Head Greenkeeper should be able to give guidance. Do not be afraid to ask for help from the greenkeeping staff in locating cable branches, cable runs and box positions. The golf course management will not thank you for charging man-hours wandering around looking for things.

Making a general sketch on a clipboard then writing down decoder numbers found and any line currents/voltages measured will sometimes help diagnosis later over a cup of tea! Waterproof paper and pens are available if needed, just ask Tonick. The sketch, if filed, can help in subsequent visits.

Binary Search can minimise the number of measurements to pinpoint the fault. The procedure is:-

Go to roughly the halfway point. Make a measurement Decide which half of the run the fault is in. Walk to the point roughly halfway between the beginning/end of the run and where you were. Make another measurement. Decide whether the half is between you and the end, or you and the place were you were last. Repeat the procedure. For example in a run with 20 boxes, the box containing the fault can be located in a maximum of 5 measurements.



Measuring the standby currents down a run allows comparison between the number of decoders expected 'downstream' and the actual current. Most solenoids take 180-250mA so any excess current will show up much better if only a few decoders are 'downstream' rather than measuring at the transformer.

Earth leakage faults should be cleared first. The presence of this type of fault will impede the diagnosis of other faults. Also it may happen that a 'short circuit' and earth leakage are both from the same severed cable end!

Fault Tracing Short Circuits.

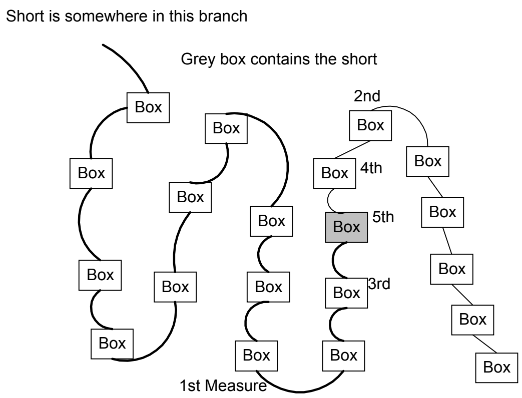
Make the transformer connections in the same configuration as was used to detect the short circuit fault in the Basic Wiring Checkout section.

Ascertain the whereabouts of major branches of the cable run. Go to the junctions and determine which branch the short is in. Don't be afraid to enlist the help of greenkeeping staff in locating these.

Having identified the branch, do a 'binary search' along the run to pinpoint the short. Be aware that decoders do take standby currents so a rough knowledge of the number 'downstream' will prevent chasing a phantom current drain.

Do remember to make a rough sketch of the cables and decoder locations. Write down the current readings on it as you go.

In the figure below, the thick connecting lines indicate higher than normal currents measured. Once you are past the short, the currents will either fall to near zero (if the voltage is cut off downstream) or go back to normal. Refer to the table of decoder standby currents in the Basic Wiring Checkout section.



To measure the short circuit currents, place the current clamp over <u>one</u> of the power wires. On the other hand, if the short is between the signal and a power wire, place the current clamp over <u>just</u> the signal wire.

If the joints are made so that the individual wires in the main cable are not accessible individually, the main cable will have to be split. Remember it is the currents in the main cable you are trying to measure, not those in the decoders attached.

To split a main cable: Run a Stanley knife carefully down a 3" to 4" length of the main outer. Tease out the wires inside. Measure the currents *on all conductors* and make a note of them. To make good, push the wires back into the outer, apply liberal quantities of Evostick and bind the slit with Self Amalgamating Tape. Ensure there is a good overlap between the start and finish of the binding and the undamaged outer of the main cable. This repair technique has been used successfully on towed marine seismic cables, a far more severe environment!

Once the area of the short is found, the exact cause can be identified. Check for warm decoders or joints, especially if the short is several amps. Place the current clamp over individual wires to see which ones are carrying the current. Do not forget that a current flowing 'out' from the transformer must 'return' down another conductor, so more than one wire will be involved.

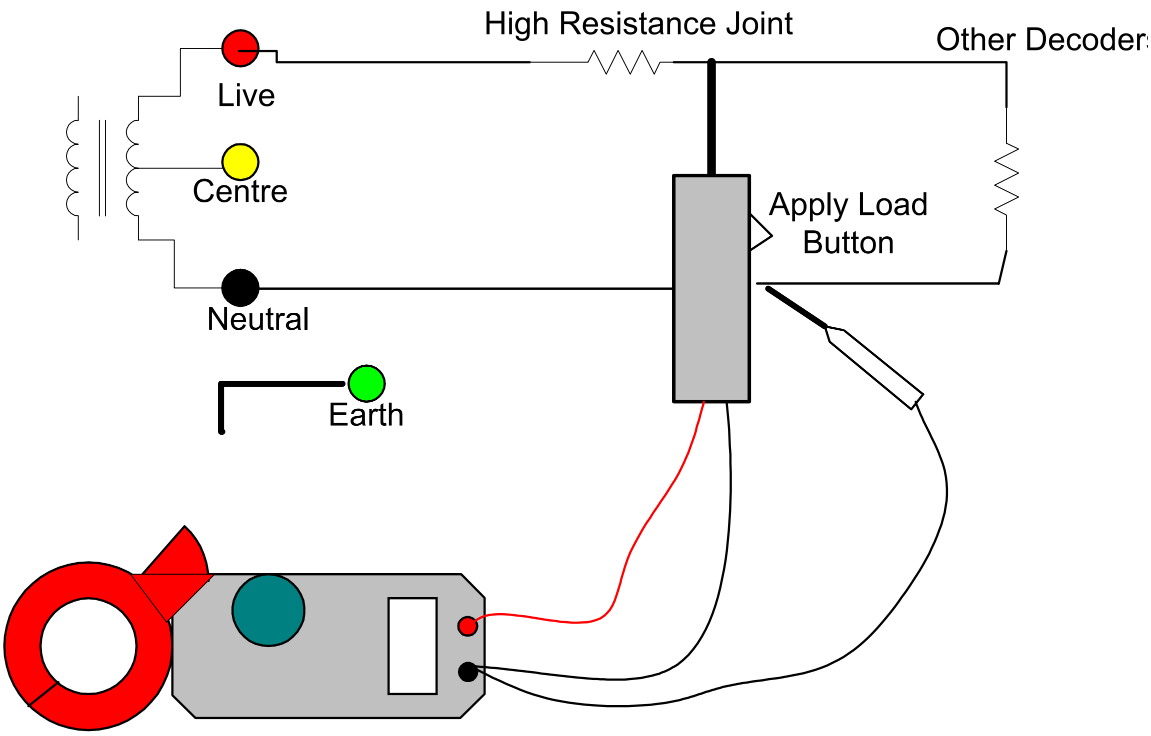
Fault Tracing High Resistance Joints:

High resistance joints can be identified by connecting the transformer then measuring the voltage down the cable at each joint with the load probe and multimeter. When the 'apply load' button is pressed on the probe the voltage will drop. A voltage drop exceeding about 3 or 4 volts indicates a high resistance in one of the joints. As you travel back towards the transformer, you will eventually pass the bad joint and the voltage drops under load will go back to normal.

In a 2 wire system, just measure between the two joints in the box. An excessive voltage drop will tell you that one or other side is high resiatance, but not which side.

In a 3 wire system, with the signal line connected to the yellow centre tap of the transformer, measure from each side of the power to the signal wire. A high volt drop on one copasred to the other will indicate that power line has the bad joint. If both drops are roughtly equal, it must be on the signal wire.

As before the binary search technique can be used to reduce the number of measurements made. See the general notes section in Fault Tracing Procedures



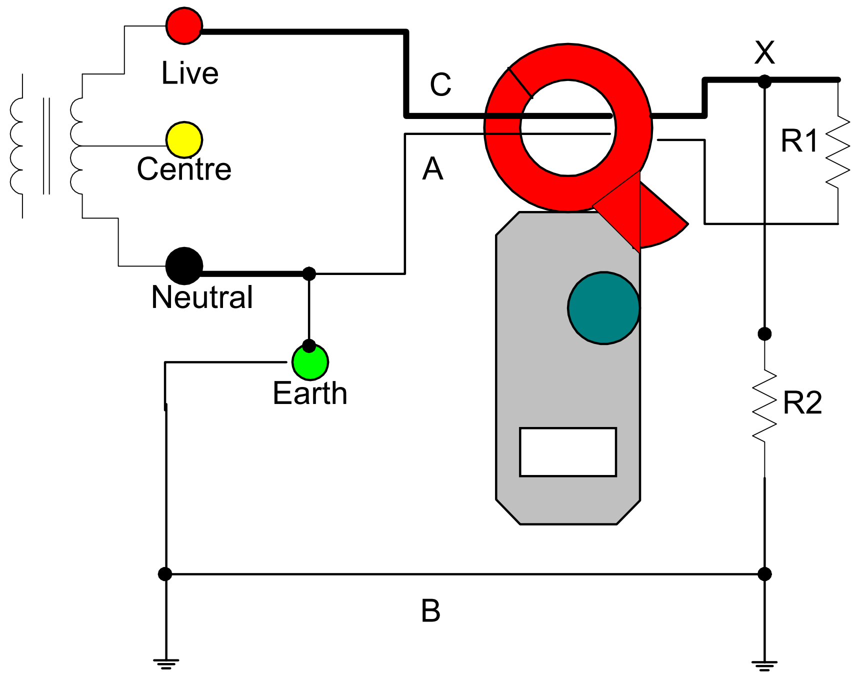
Fault Tracing Open Circuits.

Open circuits are just an extreme case of high resistance joints! The techniques in the previous section apply. As before the binary search technique can be used to reduce the number of measurements made. See the general notes section in Fault Tracing Procedures

Fault Tracing Leakage to Earth.

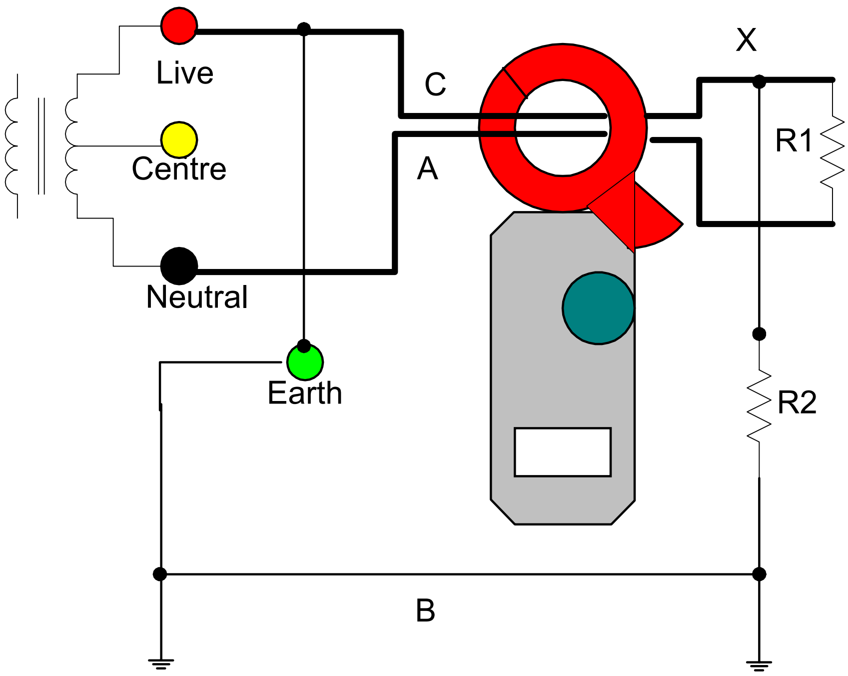
Earth leakage must be repaired first as it can interfere with the diagnosis of other faults.

In the diagram below point X represents a leakage point to earth through some value of resistance R2. R1 is representative of a quantity of decoders. Current flows 'out' of the transformer through C and splits at X to flow 'back' through A and C. The resistors R1 and R2 are effectively in parallel and see almost all the transformers voltage. The clamp meter will read the difference between the currents in A and C which is equal to that flowing in B.



Contrast the previous diagram with that below. In this case the transformer is earthed on the same side as the leakage fault X. R2 instead of seeing the whole transformer voltage now only sees a small volt drop along the cable C. Therefore the current flowing in R2 is small and so the clamp meter reads almost zero.

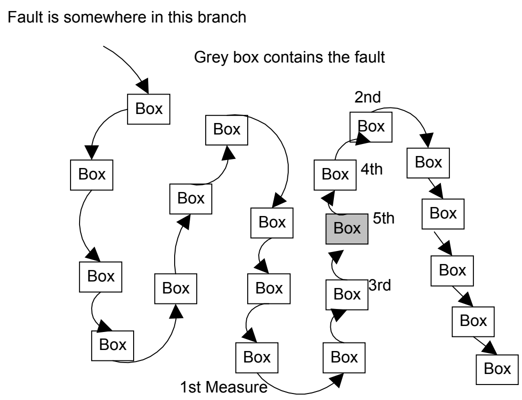
Rule: *In a single earth leakage fault*, the side of the transformer that is earthed that produces the lowest current in the clamp meter is the side the fault is on.



To locate the leakage point(s).

Place the clamp meter over whole whole grey cable. Connect the green earth link to the terminal on the transformer that produces the greatest reading on AC mA. Go out on the course placing the clamp meter round the whole main cable. When the leakage reading drops significantly you are past the leakage fault, i.e. it is between you and the controller.

The binary search technique can be used to minimise the number of measurements made to pinpoint the fault.
In the diagram below the clamp meter will read much lower when past the greyed box.



PHANTOM EARTH LEAKAGE (broken loops).

When placed over the whole field cable, the current clamp will measure the current imbalance among the conductors, that is a non zero current. This is caused by some current flowing through the ground back to the transformer (one side of which will be deliberately earthed). However, another reason is cable loops.

Field cables are sometimes looped and connected back to themselves to lower their resistance, which means less voltage drop when solenoids are on. Like a mains wiring 'ring main' the currents for the decoder/solenoid can flow in both sides of the loop. If however one wire in one side of the loop is broken or has a high resistance joint, the current in it will favour the good side of the loop. We then have a situation where the total currents when measured in a cable are not equal and opposite. This will show up as a phantom leakage current which can be quite large.

The **symptoms** are as follows:
The 'leakage current' stays substantially the same if the earth connection is removed from the transformer.
The 'leakage current is ususally larger than the one measured at the transformer usind step 5 in 'Basic Wiring Checkout'.

Resolving the problem:
Break the loop (or loops). After breaking, the good half will have nearly full volts on it, the bad substantially less. If in doubt use the load probe.

Any other tests are best done with loop(s) broken as binary search doesn't work on loops.
When finally rejoining the loop(s), check the resistance and loaded voltage with the load probe.

Fault Tracing Decoders.

Failed decoders that are taking a higher than normal standby (quiescent) current can be isolated using the current clamp multimeter, or detecting warmth with the fingers or lips. The Tonick YF-8060 multimeter can easily measure to one half a milliamp (1/2 mA) and can be used to check a decoder's standby current which is often a reliable indication of its goodness. (A table of typical decoder standby currents is given in the Basic Wiring Checkout Section.)

Other than a high standby current, the best way to detect station failure is with the controller. The suspect decoder can then be cut out and tested using the appropriate Tonick decoder tester.

Two particular points:

Watermation TW2 decoders if cross wired (i.e. red to neutral, black to live) will always turn on irrespective of the controller station number being transmitted.

Tonick TW/WR decoders compatible with Primetime, Wright Rain and Robydome will fail to respond to controller signals if there is more than about 2V AC difference between yellow and the two browns. e.g. if yellow to one brown is 12V AC and yellow to the other brown is 10V AC, the Tonick decoder will not respond. This effect is caused by high reistance joints. The original decoders are more tolerant of this condition than the Tonick so may still function. Sadly however, high resistance joints just get progressively worse, so all types of decoders will eventually cease to function .

Circumventing 'Solenoid Permanently On' Error Messages.

Some controllers will not function in diagnostic or normal irrigation with what they believe is a permanently on solenoid. Their perception of this situation is the measurement of a lag in the AC current compared to the AC voltage. For further details see the Solenoid Failure section in Types of Faults. If in fact a solenoid is actually on, running the pump and looking for the water is an effective way of pinpointing the problem. However decoders can occasionally fail in a way that fools the controller into thinking a solenoid is on even though a real one is not.

The secret to circumvent this impasse is to connect a suitable capacitor across the field wiring (at the controller will do). Capacitors are an electrical component that behave almost in the opposite way to coils. They have the property that the AC current leads the AC voltage rather than lags it like coils. If a correct value capacitor is placed in parallel with a coil, the current (although altered in magnitude), is swung back to look like a plain resistance and the controller is happy again! (This little trick is called power factor correction and has been around for years.) Tonick make a little module with crocodile clips which will do the correction. Once the module is fitted, the controller can be used in the normal way to detect station failure. One of these will be the failed decoder that is causing the original problem. Don't forget to remove the capacitor after replacing the decoder!

Decoder Tester.

Should an individual decoder be suspected of malfunction, it can be cut out and tested on the Tonick 2 or 3 wire decoder tester. Using either mains or vehicle battery power, the tester will cycle through all possible decoder station numbers looking for a response. If found, the tester will display that number and a green pass light. If no response a red fail light will illuminate. The setting of switches on the older decoders can be checked for water damage or vandalism without trying to laboriously interpret them. The tester can also be used to encode a station number into a replacement Tonick decoder.

With the decoder disconnected, the resistance of the solenoid coil can be checked using the multimeter.

Fault Tracing Solenoids.

As said previously, a failed solenoid is indistinguishable from a failed decoder as far as the controller is concerned.

With the controller set to energise the solenoid (diagnostics or manual, as appropriate) it is sometimes possible to probe the voltage output connections of the decoder with a voltmeter. If the 24-30V AC is measured, it is most likely an open circuit coil.

A short circuit coil, although rare, will cause an excessive current to flow *only when the decoder is activated*. The best way to isolate this problem is to place the current clamp meter over one of the field wiring power conductors at the controller and observe the current as each decoder is turned on.

Mapping Golf Course Wiring.

The transformer and clamp meter can be used most successfully to map out the sequence that boxes are wired. This is most useful where the wiring information is lost or forgotten. Although the actual path of the wires between boxes cannot be mapped using this technique, the order in which boxes are connected can be of great assistance in general faultfinding.

Procedure:

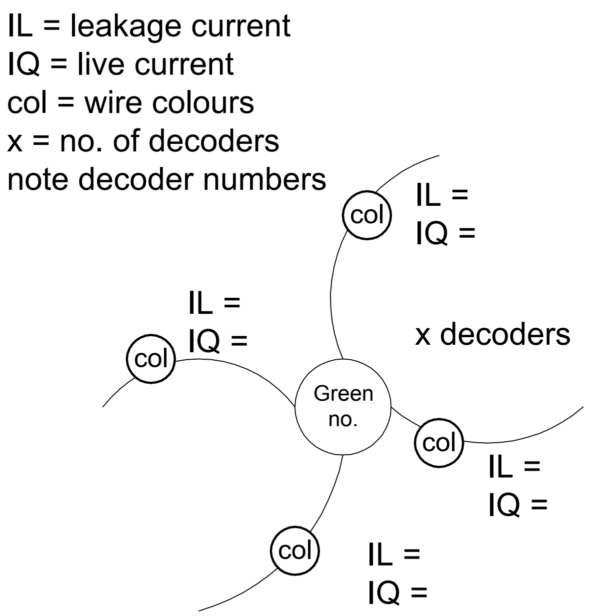
Connect the transformer red terminal to the live field power wire, the black to the neutral and the yellow to the signal (in 3 wire systems). Place the transformer's green jumper lead into the yellow terminal and one of the green terminals (earthed centre tap).

Visit each box in turn. Mark it's approximate geographical position on a sketch map. Write down the following information next to each box on the sketch.

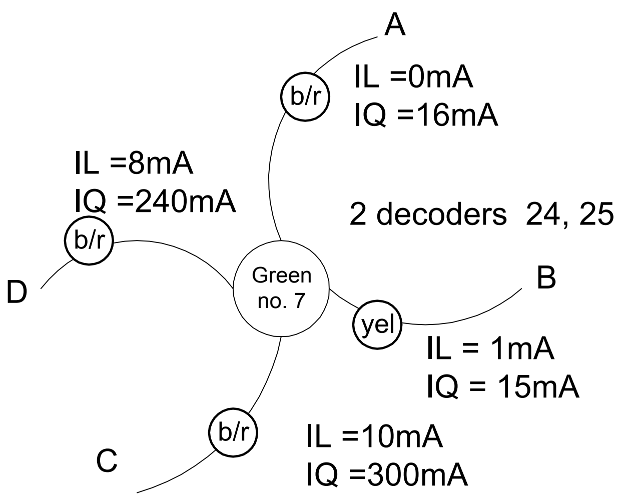
Note the current in each live wire. Place the clamp meter round just that wire. Try and be consistent in the way you put the clamp around the wire (see page 10).

Note the leakage in each of the main cables. Remember the leakage is measured by placing the clamp meter around the whole main cable.

Go back to the mess and make a nice cup of tea! Copy the sketch map onto one sheet of paper with each of the boxes looking something like this:



From your field sketches fill in the currents measured and decoder numbers. Obviously only draw in the number of main cables you find in each box.

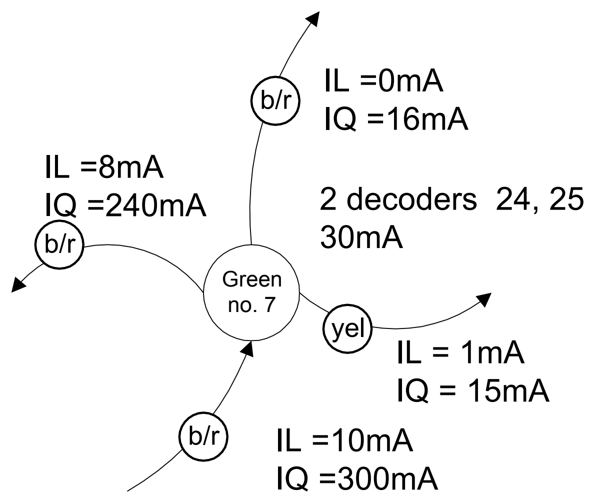


In this example 'b/r' is a black/red pair with no sheath; 'yel' has a yellow sheath.

From the table of decoder standby currents we know that the decoders on this course take roughly 15mA each.

The incoming cable (C) is the one with the highest IQ. The cables (A, B) with 15 or 16 mA must power only one decoder and are therefor spurs, probably to a Tee or Approach. The cable (D) with 240mA on it is the main outgoing field cable. It probably has around 240 / 15 = 16 decoders further on down it.

Draw arrow heads on the wires to remind yourself which way they go.

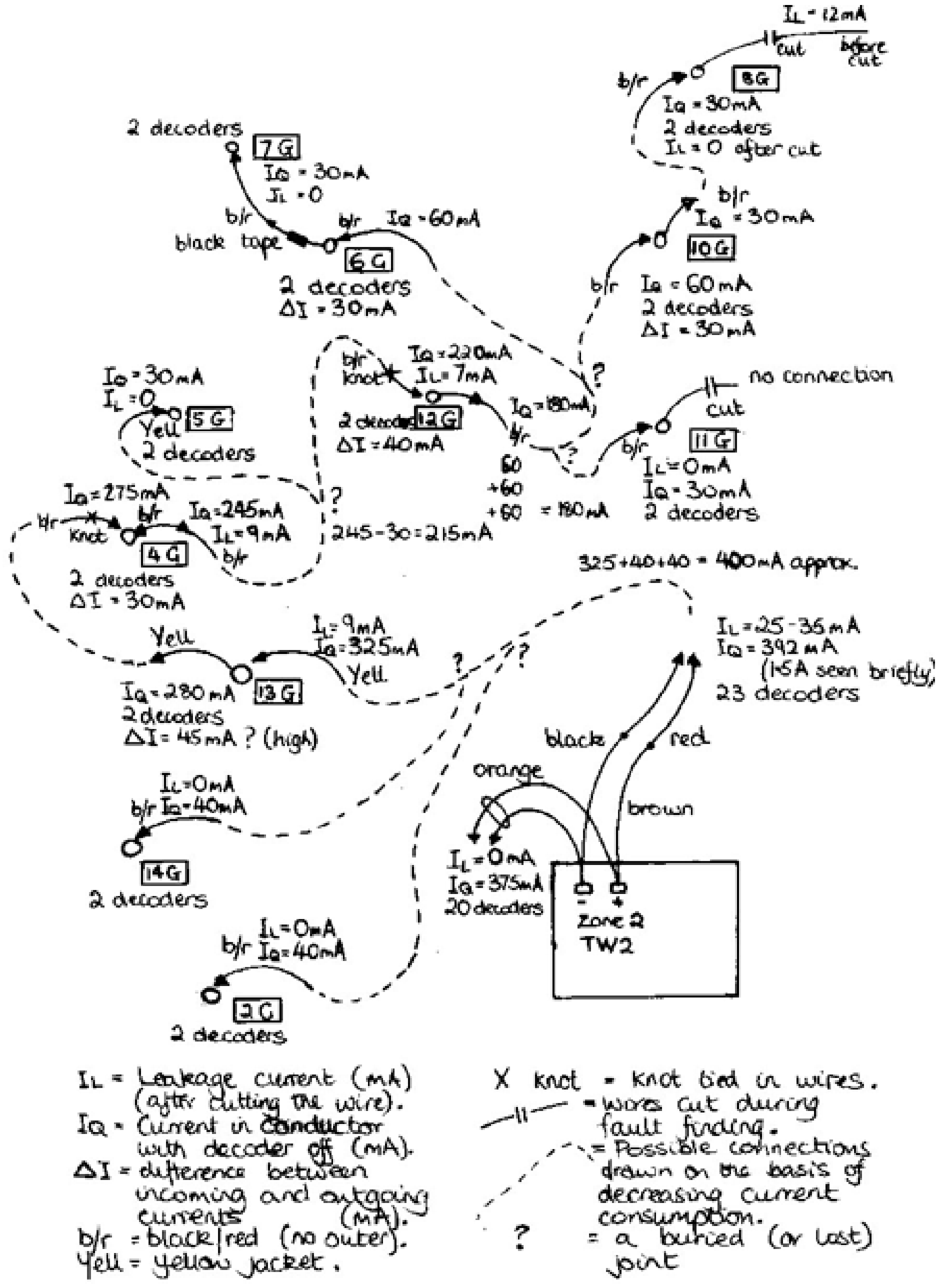


Having filled in the detail it is now necessary to join the boxes in the diagram. In the above example you would be looking for another box not too far away that has an incoming main feed of approximately 240mA and a leakage of about 8mA. Thus most of the boxes can be joined quite easily in an order of descending IQ.

The only slight problem is when there are buried or lost cable joins. In this case, there will not be a box with an incoming IQ of 240mA but something less. The amount will however be a rough multiple of (in this case) 15mA. Say it was 195mA. The difference is 240 - 195 = 45mA. 45 / 15 = 3. So there is probably a buried spur between the 240mA and 195mA boxes which has around 3 decoders on it.

Using this kind of thinking it is possible to identify the cabling order on most, if not all of the boxes. Obviously keeping this kind of information safely for the next visit makes faultfinding 'a breeze' next time!

On the following page is a reproduction of a field map drawn on a golf course. The picture illustrates the information recorded as described in this section. Note that the currents do not always add up exactly and that decoder standby currents do vary.



IL = 12mA
cut
before cut
b/r
8G
IQ = 30mA
2 decoders
IL = 0 after cut
2 decoders
7G
IQ = 30mA
IL = 0
b/r
black tape
b/r IQ = 60mA
6G
2 decoders
ΔI = 30mA
b/r
IQ = 30mA
10G
b/r
IQ = 60mA
2 decoders
ΔI = 30mA
b/r knot
IQ = 220mA
IL = 7mA
2 decoders
12G
ΔI = 40mA
IQ = 180mA
b/r
60
+60
+60 = 180mA
no connection
cut
b/r
11G
IL = 0mA
IQ = 30mA
2 decoders
IQ = 30mA
IL = 0
5G
Yell
2 decoders
IQ = 275mA
b/r
knot
b/r
IQ = 245mA
IL = 9mA
b/r
4G
2 decoders
ΔI = 30mA
245-30 = 215mA
325+40+40 = 400mA approx.
IL = 25-36mA
IQ = 392mA
(1.5A seen briefly)
23 decoders
Yell
IL = 9mA
IQ = 325mA
Yell
IQ = 280mA
13G
2 decoders
ΔI = 45mA ? (high)
black
red
orange
brown
IL = 0mA
b/r IQ = 40mA
14G
2 decoders
IL = 0mA
IQ = 375mA
20 decoders
Zone 2
TW2
IL = 0mA
b/r IQ = 40mA
2G
2 decoders
IL = Leakage current (mA) (after cutting the wire).
IQ = Current in conductor with decoder off (mA).
ΔI = difference between incoming and outgoing currents (mA).
b/r = black/red (no outer).
Yell = yellow jacket.
X knot = knot tied in wires.
= wires cut during fault finding.
= Possible connections drawn on the basis of decreasing current consumption.
? = a buried (or lost) joint

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