Using Time Domain Reflectometry to Diagnose and Locate Faults in Electrical Heating Cables

Abstract

Time Domain Reflectometers (TDRs) can be used to verify all sorts of cables and locate faults on them. Here, we will look at how to check underfloor heating cables.

By

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Introduction

There are several ways of making a room warm; one way that is relatively efficient is underfloor heating. If you have the resources and are building new construction, you may contemplate using a ground-source heat pump which warms and circulates water throughout the new building using pipes embedded in the floor slabs. Another solution, often more realistic for smaller renovations, is electrical heating wire. Electrical heating wires do not benefit from the super efficiency (300 to 500%) of heat-pump systems; but they have much lower cost and are ideal for smaller areas such as bathroom updates where heating load remains low, and customers want to install low-carbon heating.

Cable Types

There are three main types of electrical heating cable:

1. Simple single core wire loop, where a single core of "resistance wire" is placed into the floor. This requires a thermostat to obtain a stable temperature.
2. A two-core cable formed from resistance wire, where the two cores are shorted at far end of the cable before being placed into the floor. This requires a "thermostat" to obtain a stable temperature.
3. Two core "self-regulating" heating cable, where two "conventional" low resistance cores of copper-based wire are embedded into a partially conductive polymer. This self-regulates the heat because the carbon loaded polymer is initially a lower resistance but as it warms the molecules space out increasing resistance, lowering the heat output.

The first two types are the most common used in most buildings and are often called "constant wattage". In addition to the resistive elements that perform the heating function; the cores of all types are insulated from each other using a heat resistant polymer, often PTFE or high-temperature polyethylene before they are over braided by a ground screen or foil. The ground screen acts to ensure safety should any fault occur with the cable's insulation by providing a local route to ground ensuring safety protection devices "trip" as soon as necessary.

Single Core Cable

A “single-core” style of resistive heating cable is normally a “coaxial” construction (with a safety “ground” screen over the heating wire) and therefore relatively easy to test with Tempo’s “coaxial” TDR products as it has a coaxial construction; however, it is extremely lossy due to the increased resistance. This cable is often wound through special formers on the floor before the floor screed or special boards are installed above. Both ends of the cable are normally brought to the same connection point in a room. They must be installed with thermostatic control.

Two-Core Cable

This may be the most common type of cable to be installed as it is easier to get both ends of the loop to return to the same point in the room for termination without crossing over (hotspots can be dangerous). The far end of the cable has the two inner cores shorted; this is then safely covered by waterproof heat-shrink. This is also often available in pre-made “mats” where the cable is taped to a self-adhesive fiberglass mesh to speed up installation and to keep the wires correctly spaced. These mats come neatly rolled up and skilled technicians can place them onto the clean sub-floor in minutes before being screeded ready for tiling etc. They must be installed with thermostatic control.

Self-Regulating Two Core Cable

Increasingly used for underfloor and similar applications, but the most common use for this is thermal protection of pipelines from frost. Self-regulating cable is easy to simply wrap around and along the pipeline beneath any insulation. The surface of the tape will reach a known temperature without additional hardware (no thermostat required, but often installed with some feedback system when used for space heating for efficiency reasons). Each section of self-regulating cable automatically adjusts its output depending upon the local load; sections of floor beneath rugs may dissipate less than sections in “uncovered” floor near windows – unless the sun is shining and warming that section of floor near the window. The magic of self-regulation.

Installation Tests

It is common for most heating cable suppliers to pre-test the cable assembly, whether on a drum or formed into a mat, before shipping and to mark it with the known “resistance”. The installer then checks before laying the cable or mat that no damage has occurred and repeats this testing at each stage: once unrolled, once laid, once the screed has been installed and before final commissioning. You will also check the insulation resistance between the core(s) and ground screen.

Testing the self-regulating type of cables can be tricky as the core-to-core resistance will vary with temperature and length; however, these can still be checked for safe insulation between the “cores” and the ground screen.

Likely Faults

During installation it is possible that the cable can become damaged by mechanical impact or excessive movement or stretching. Therefore, it is important to check and re-check throughout the process, until the cable is secured beneath a screed or other mechanical protection.

- Damage by crushing underfoot
- Damage by excessive bending (work hardening of the conductors)
- Damage by bending at too small a radius
- Damage to insulation by a tool

Types of Faults

Crushing or bending too tightly could cause the inner cores to short or the inner core to short to the protective ground screen or both.

Excessive bending or overworking the cable can cause both opens and shorts in conductors.

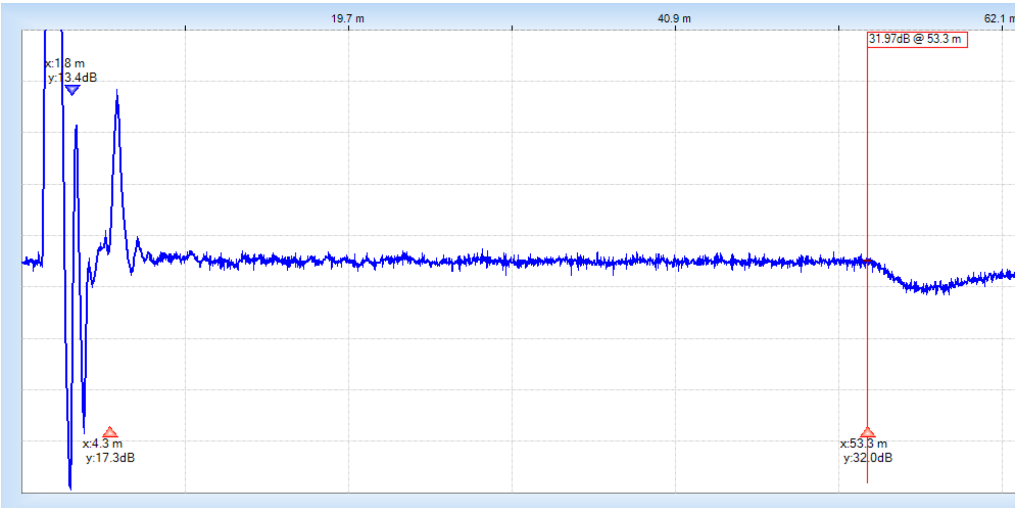
Nicks by mechanical impact of a trowel, float or simply by dropping a tool could also cause breaks but may often go un-noticed until corrosion sets into the screen sometime later; this may never cause a functional problem but could result in a less safe installation as the ground screen is incomplete or high resistance.

Time Domain Reflectometry

Time Domain Reflectometry, TDR, is a technique where a very fast rising pulse or step of electrical power is fed into a cable while recording any reflected energy received. Please see our introduction to TDR training if you are not familiar with the technique. As with all TDR testing the most critical thing to note is the “speed” or “velocity of propagation” (VoP) of the cable being tested. This VoP clearly relates time between “launch” and any “reflection” to distance and is critical to understanding your cable. Ideally installers will take a reference trace at the time of installation, noting the transition from the “cold tail” to the heater cable and the known “end-of-cable” distance.

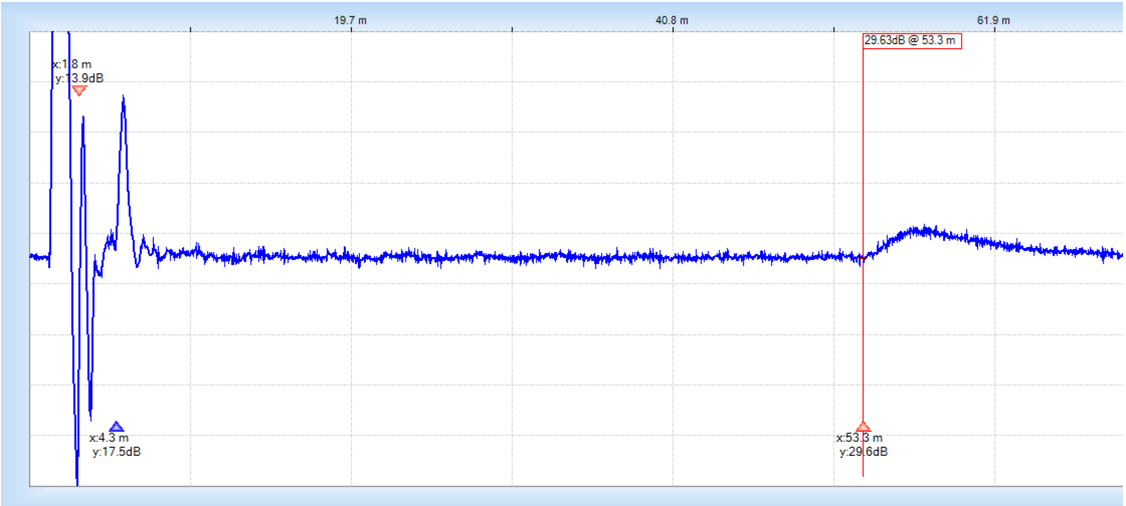
It might seem excessive to use a high-end tester such as a TDR to check underfloor heating cables; but when you consider the cost of repairing or replacing the floor should something fail, it makes a lot of sense to test.

Underfloor heating cables are often only tens to the low hundreds of metres long depending upon room size and are therefore ideal candidates for the use of modern highly precise and high-resolution testers that can pin-point trouble to within a few centimetres or inches.



In this trace for example, the transition from the TDR’s own patch cable to the “cold tail” is at 1.8m. The end of the “cold tail” where it joins the heating cable is the high impedance at 4.3m and the end of cable is at 53.3m; shown here as a “below the line” “short” event where the end of cable link is found. This is an example of a 4.0m^2 pre-made dual core plus screen “mat”.

Should the cable become “open” at some point…



Now it is easy to identify where along the cable a break has occurred from the trace. In this case, I've simply removed the shorting link from the end of a two-core heating cable, so you can see the end-of-cable event has changed from a "short" to an "open" (above the line event). Similarly, should a "short" be found earlier along the cable than expected then you would suspect damage, perhaps by crushing at that point.

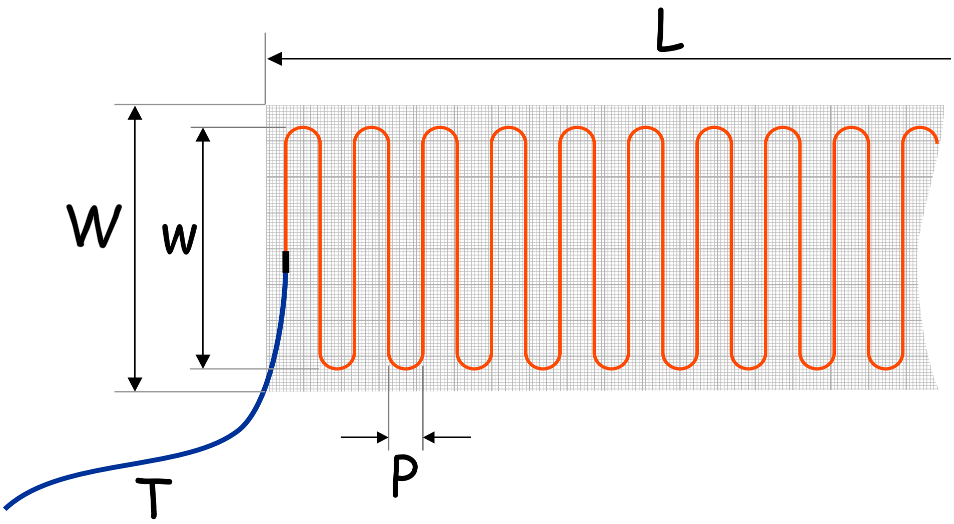
How to Characterise Your Heating Cable

All cables are formed from two or more conductors held in close proximity in a standard pattern along their length. Provided the geometry of the cable is largely constant and the materials used also don't change significantly along the length of the cable then the "impedance" and "speed" (velocity of propagation, VoP) will also be uniform and predictable. However, without getting into some very complex measurements of the geometry and deep knowledge of the materials used, particularly the insulation, of the cable, we have to "measure" the VoP.

For a "simple", shielded, single core cable or a double core cable on a drum this can be straightforward; you know the pre-made length and can connect this to the TDR and set the cursor at the end of the cable. Then, not forgetting to take any TDR connection cable AND the "cold-tail" length into consideration (you can normally see a small "event" at each change of cable type), adjust the VoP on the TDR until the end-of-cable event is at the distance you expect.

Serpentine Routing

Now an arithmetic exercise is needed to find the overall cable length when heating cable is supplied as a rolled-up mat...



Most mats are sold by total area to cover. Tip: Never buy more than you need as you cannot make them smaller, and the heating wires must never overlap or local overheating may occur. Here, we define the following:

- W = mat width
- w = loop width
- T = cold-tail length
- P = loop pitch
- L = A/W (length of the mat)

If you're not sure of the loop pitch, it's best measured over several loops, e.g. 8. In my case this was 64 cm, therefore each loop has a pitch of 8 cm.

The borders around the sides of the mat in my case were 2.5cm so "w" the loop width was 45cm. So how long is each wire "loop"?

$$Loop\ length = 2 \times (w - P) + P \times \pi$$

In this example each "loop" is approximately 99.1 cm

The total number of "loops":

$$N = \left(L \div (2 \times P)\right) - ½$$

Subtract half to allow for the borders either end.

So, there are 49.5 "loops" and a total cable length of roughly 49.1m.

Remember to make allowance for the "cold tail" length and any test cable you have between the TDR and the cold-tail too. This is how we derived the approximate velocity of propagation for the sample of cable that was being test, as 0.55c.

If a fault is found later then the above formulae can be used in reverse to help identify which "loop" of the mat has the fault; then by reference to "as installed" photographs it may be possible to expose the faulty section of cable and replace or repair it.

Practical Considerations

Ideally take TDR traces of the mat or cable BEFORE installation along with photographs of the room layout before screed or other material is used to cover the heating wire. Place copies of these with the customer's hand-over document pack. These will be a valuable resource should further work be needed in the room or if a fault is identified with the cable in the future. These are particularly important if using loose cable rather than pre-made mats as the relationship between distance along the cable and room position will vary from installation to installation.

Conclusions

Within the normal limitations of TDR techniques, this is another tool that can be used to help diagnose trouble and even find it enabling pin-point repair should this ever be needed.

Single shielded wire loops are straightforward to test as these are essentially very lossy coaxial cables; disconnect both ends and test.

Two-wire shielded "constant wattage" cables can be checked by pulsing towards the shorted end and checking for anomalies.

Two-wire "self-regulating" cables appear as very lossy wire pairs; so, any significant variation in the performance of the parallel heating material will show as a variation in the trace.

Disclaimers

Every cable type is different: If you install heating cables from different manufacturers you should characterise each type and keep a note of their VoP figures. Check these regularly to ensure the manufacturer has made no changes between batches.

Remember to make allowance for the TDR test lead length and the "cold-tail" of any system which will have different VoP characteristics to the heating cable itself.

Never use TDRs on "live" cables.

Background

Tempo Communications have been supplying our TDR testers to the world's leading manufacturers of electrical heating cables for several years.

Tempo Communications Inc. are a US based private enterprise with several decades of history producing many innovative, precise, and reliable products. Many of these products, like the TDRs have application in fields not commonly associated with our main customer base in the communication industries. Many products are applicable to many types of cables. Whether that be a simple pair tracing set or highly advanced time-domain reflectometer.

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