AN259
Testing Single-Wires in a Harness

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Abstract: Single-wires in a harness and single-wires in other certain environments can be measured using our E20/20 or Avionics TDRs and obtain accurate distances to the wires' far end or distance to faults (DTF). However, the very nature of the harness presents some unique challenges the user to obtain relatively correct distances, understanding impedance changes over the harness' length, and trace presentations of faults.

Introduction: Step TDRs are the preferred type TDR to use on single-wires in a harness or a single-wire running through at metallic conduit or on other conductive path such as an aircraft's airframe. The reason lies in its ability to present the impedance changes in Ohms over the length of the wires and differentiate a normal or expected impedance change from that of a fault or end of the wires.

Background: TDRs work on the principle of impedance between two conductors. They also need the cable's Velocity Factor (VF), aka Velocity of Propagation (VP or VoP) or Nominal Velocity of Propagation (NVP) to obtain the cable's distance readings. Refer to AN200 "Basic Theory of TDR Operation" for more background. Coaxial cables and twisted pair cables are normally manufactured to specific standards. Their impedance and VF will be published by the manufacturer. Single-wires by themselves do not have and impedance or VF. However, when bundled in a harness, as shown in Figure 1, or running along a metal surface they adopt an impedance and VF from the contact with the other wires in the harness or metal surface they are in contact with. See Figures 2 and 3.

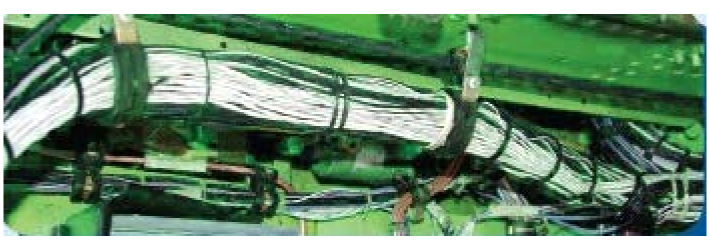

Figure 1

Figure 2

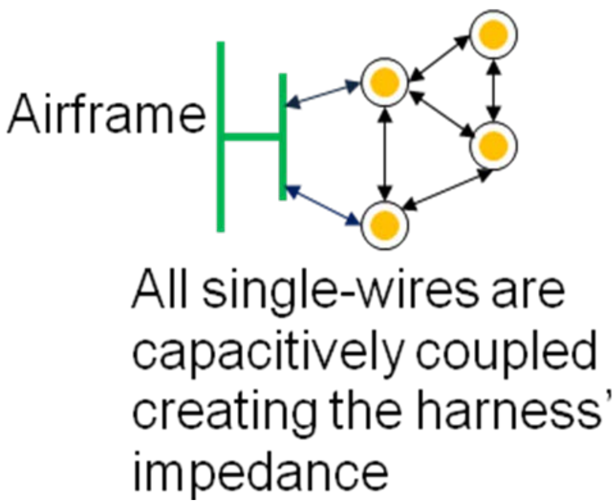

Figure 3

Testing Single Wires in a Harness

Testing single wires in a harness can be accomplished, but generally requires a good wiring diagram of the harness with pin-to-pin connection information. The reason is to find two single wires that can be treated as a pair. As explained earlier TDR's measure the characteristic impedance between two conductors separated by a dielectric material (insulation). In the case of testing a single wire it's important to locate an adjacent wire in the same harness, running a parallel length, and measure them as a pair.

The two single wires will travel the harness at varying distances from each other. Unlike twisted pair wires the wires' insulation will not be in constant contact. They will however, have other wires' insulation in contact with them and thus a dielectric path, but a variable path. This arrangement, combined with the number of wires in the harness and other factors, will cause the impedance to waver more over the length of the two single wires than if they were a twisted pair. Additionally, when the impedance varies the velocity factor also varies. Here are some general rules that affect measuring the two single wires:

Two Single Wires in a Harness Affects

Lowers Impedance & Faster VF	Raises Impedance & Slower VF
Two wires are closer together	Two wires are further apart
Large number of wires in the harness	Few wires in the harness
Tight bundling in the harness	Loose bundling in the harness
Single wires enter a larger bundle	Single wires enter a smaller bundle
Single wires merge to a larger harness	Single wires split to a smaller harness

The following are some measurement tips to use with single wires in harness:

1. Try to measure two single wires that both start at the same connector on the near end and terminate in the same connector at the far end. This should be the normal situation.

2. Compare the length of the two single wires to ensure it matches the wiring diagram's "Cut Length" for the wires or a best-as-possible measurement of the installed harness start to end. Remember, if one of the two wires is shorter than the other, the shorter wire is the electrical end of the pair.

3. When the pin numbers are located for both ends of the single wires, measure the pair open at the far end, then short the two pins at the far end. The short should appear on the trace at the same distance as the open to ensure:
   A. The TDR is measuring the two single wires you desire.
   B. To be sure the wires at the far end are making good connection at that connector's pins.

The following are some examples of single wires in a harness and the type of traces you can expect.

Figure 4 is an example of impedance (Z) variations over the length of two single wires in the harness. Cursor 2 marks the end of the test leads (50 Ohm coax with a short twisted pair to connectors lead at the end). Between Cursors 1 and 2, 19ft 4 in (5.9m) are the two single wires being measured as a pair with an open at the far end. At about 9 feet (2.7m) the impedance rises slightly for the remainder of the run. This could indicate either the wires separated more at that point in the harness and never came closer over the last 10ft (3m), or that section of the harness contains less total wires.

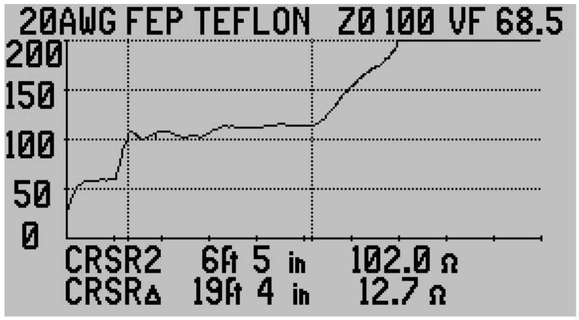

Figure 4

Figures 5 and 6 are examples of more wide variations in the two single wire's impedance. The same test lead is marked (CRSR2) as used in Figure 3-44 and the far end of the single wires is open as marked by Cursor 1. These are also good examples of measuring two single wires in vehicles would look like. The harnesses in vehicles tend to be looser and cause wider variations in the impedance.

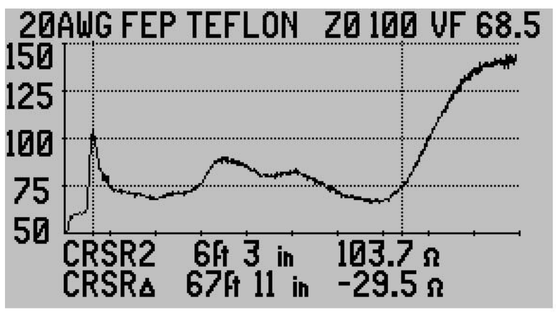

Figure 5

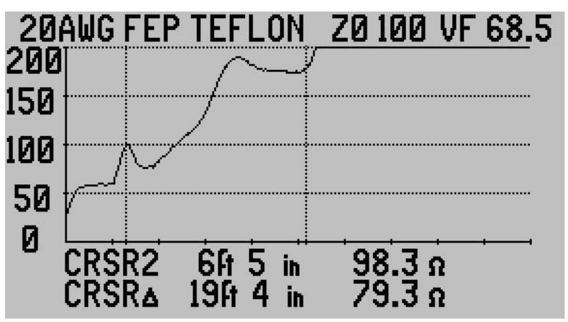

Figure 6

Figure 7 is an example of two single-wires terminating in equipment at the far end. Note the slower upward trend and flattened trace at the end. In some cases the trace will roll off slowly down or be flat at about 100 Ohms as the TDR's signal is absorbed by an impedance matching device in the equipment. This emphasizes the importance of understanding the wires' distance to end connector and the wires' destination. In this case, the end was marked based on the known distance of two other wires in the same harness.

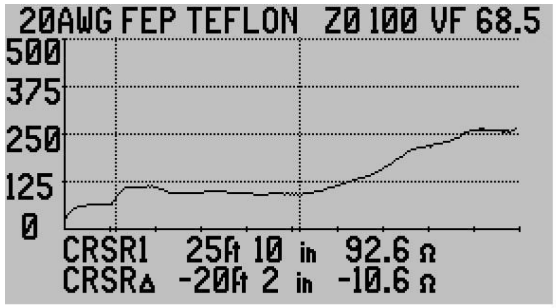

Figure 7

Figure 7 also has some other interesting features in its trace. Starting at the left note the slight rise then flat trace until the cursor is reached. This is the TDR's 50 Ohm coax test lead. Next the impedance rises to almost 125 Ohms for a short distance then drops again. This short section has less wires in the harness, hence the higher impedance. Finally, the last section of cable's trace up to the next cursor (Cursor 1) shows small impedance variations as the two wires selected for this test move closer and further apart from each other in the harness. The closer they are the lower the impedance between the conductors.

Measuring a Single-Wire to the Airframe

Figure 8 is an example of measuring one wire in the harness to the chassis or airframe to which the harness is attached. In figure 8 the impedance trace lowered, but in some cases the impedance will rise over the length of the harness. This will depend on the amount of contact the harness has to the chassis or airframe.

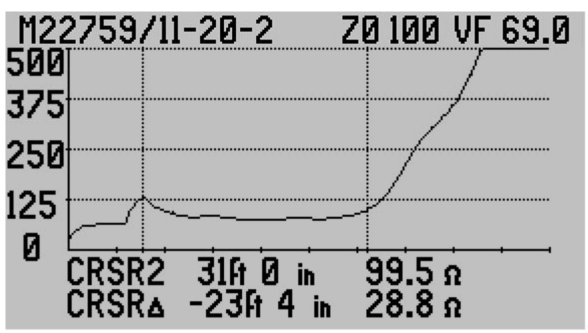

Figure 8

Figure 9 shows the same wire with the far end shorted to the airframe. Note the trace's rapid drop to 0 Ohms at the short

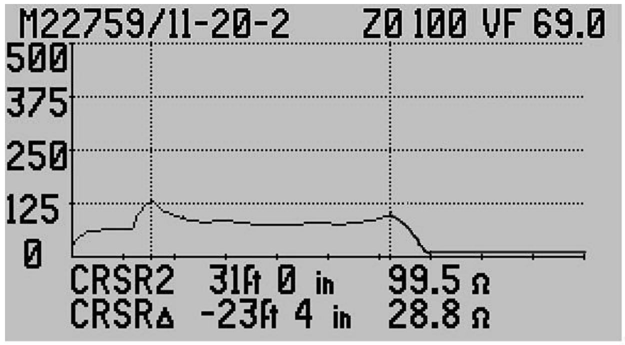

Figure 9

This testing method can also be used to test a coax cable's shield for shorting to the airframe. Simply connect one test lead to the coax cable's shield and the other to the airframe. In some cases that short in intentional for grounding the shield. So the TDR can show a ground is in-tact. However, other cases can be where the cable's insulation has chaffed away creating an unwanted ground.

Testing Single-Wires in Conduit or on Metal Surface

When a single insulated wire is running through a conduit or is in contact with any metal surface it can also be measured and tested for faults. Use the same methods discussed previously for testing a single-wire to the airframe. Connect the test leads between the wire and the conduit or metal surface. The impedance reading will depend on the wire's insulation composition and thickness. Thicker insulation will have a higher impedance. Other factors will involve the closeness of contact between the wire's insulation and the conduit or metal surface.

Single-Wires and Velocity Factor

Variations in impedance can also create variations in Velocity Factor (VF). Since VF is used to determine the distance to faults (DTF) and distance to end of a wire it is important to find the correct VF to use during testing. AEA Technology's Avionics TDRs and E20/20 TDRs all have capability to measure VF. However, you must have a physical measurement (aka Jacket Length) of the cable from a drawing, tape measure, or good estimate so the TDR can compute the correct VF. Here are some tips to help with that measurement:

1. If you can't measure the entire cable end-to-end, look for a connector between the TDR connection point down the cable you can open and measure that section of cable. Once the VF is computed by the TDR, use that VF for the remainder of the entire cable. Distance measurements between the TDR and the connector you measured to will be accurate, but those beyond may have some error. However, this is better than no VF information.

2. If there is a fault on the cable, short or complete open, that prohibits using the TDR VF measuring capability try the following:
    A. Set the VF in the TDR to your best estimate based on similar cables.
    B. Access one end of the cable and measure the distance to the fault.
    C. Now physically measure the distance from that end of the cable to the indicated fault and mark the cable with a piece of tape
    D. Go to the opposite end of the cable and do the same.
    E. If the two tapes are separated the fault is half way between them.

    Why does this method work? If the VF you chose to use is too slow for the cable's actual VF, the each tape markers will be closer to the end from which you measured. So the fault will appear closer to the TDR than physical distance. If the VF you chose to use is too fast for the cable's actual VF. The tapes will be crossed or closer to the opposite end of the cable.

Conclusion

AEA Technology's Avionics TDRs and E20/20 TDRs can present accurate impedance traces to help understand single-wires impedance changes as they travel in a harness. Additionally our Avionics TDRs have a cable list with several types of single-wires listed and a nominal VF for those wires when they are used in a harness. This provides a good starting point for obtaining accurate DTF and distance to end of the wires. Our E20/20 TDRs and Avionic TDRs both have features for measuring two single-wires or a single-wire to airframe, conduit, or metal chassis to compute VF.