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TIM--SCT CABLE TESTING PROTOCOL

Kurt H. Coonrod et al.

Kaman Sciences Corporation
6400 Uptown Blvd, NE
Albuquerque, NM 87110

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Advanced Weapons & Survivability Directorate
AIR FORCE MATERIEL COMMAND
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WILLIAM D. PRATHER, GM-14
Project Officer

FOR THE COMMANDER

DANIEL T. McGRATH
Major, USAF
Deputy Chief, EM Sources Division

WILLIAM L. BAKER, GM-15
Acting Director, Advanced Weapons and Survivability Directorate

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Kurt H. Coonrod, Karl R. Jurisson,
J. Todd Hendrickson, and Donald P. McLemore

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This document presents a standardized approach for measuring transfer impedance of shielded aircraft cables in-situ. The approach is based on the present Shielded Cable Tester (SCT) and Transfer Impedance Meter (TIM) instruments.

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1.0 INTRODUCTION

This draft document presents a standardized approach for measuring transfer impedance of shielded aircraft cables in-situ. The approach is based on the present Shielded Cable Tester (SCT) and Transfer Impedance Meter (TIM) instruments.

1.1 BACKGROUND

The SCT was the first test instrument developed to measure the shielding performance of cables "as-installed" on an aircraft. This capability is important because it provides a convenient and cost-effective method for finding shield degradations and assessing the need for repair without removing the cable. The SCT also provides a high fidelity technique for determining the life cycle behavior of shielded cables. The TIM was developed to miniaturize and package the SCT's functionality in a hand-held test instrument.

Manuals have been written for both testers describing the basic test setups and procedures for measuring cables with simple topologies (two connectors with a bundle of wires and an overbraid). Many aircraft cables, however, are very complex (with multiple branches, internal shield groupings, and multiple external ground points), and subtle errors in the test setup can invalidate the data. In addition, the detailed procedures needed to separate the performance of different shield components or to isolate a problem area can become lengthy.

Because of these complexities, specific test procedures have typically been developed on a case-by-case basis for each cable and system. Furthermore, determination of the best test setups have often required experimentation on laboratory mock-ups. This engineering work requires personnel with a solid understanding of transfer impedance coupling and familiarity with the SCT and TIM test equipment.

1.2 PURPOSE

The SCT and TIM testers are now in use on several different systems, and test techniques have been developed to handle various shielding scenarios. The purpose of this document is to collect and organize this pool of information and present a standardized approach for cable surveillance that can be used for any similar aircraft (note that new test situations requiring additional engineering development may still exist). This transfer impedance measurement protocol will allow less experienced engineers to acquire valid data and properly develop and implement detailed test procedures intended for technicians.

1.3 DOCUMENT ORGANIZATION

Some familiarity with system hardening, transfer impedance coupling, typical cable characteristics, the SCT and TIM test instruments, and strategies for cable surveillance is needed to make full use of the protocol. Basic transfer impedance concepts are presented in the next section, and references are cited for detailed treatments of complex subject material.

Section 3.0 presents the general SCT and TIM measurement techniques, and Section 4.0 contains the beginning of the "protocol." Elements that are common to most measurements are given first, and procedures for specific test situations are contained in sub-sections. The approach for identifying and isolating shielding degradations is given in Section 5.0, and troubleshooting information, including examples of mistakes which commonly occur in the test process, is outlined in Section 6.0.

2.0 BASIC TRANSFER IMPEDANCE CONCEPTS

Transfer impedance describes the voltage induced on a core wire per unit current on the shield of a cable. It is an intrinsic property of the cable alone, and is therefore independent of the loads at interface circuits and the electromagnetic geometry external to the shield. In most cases, transfer impedance is the dominant leakage mechanism for potentially damaging electromagnetic (EM) environments (electromagnetic pulse (EMP), lightning, electromagnetic Interference (EMI), and electromagnetic compatability, (EMC)).

Transfer impedance is a function of frequency, and there are a few basic physical phenomena that define the baseline frequency domain signature of a simple cable. The cable's response at low frequencies is characterized by the end-to-end d.c. resistance of the cable (R_{dc}). At mid-range frequencies the thickness of the shield becomes a factor, and penetration of electromagnetic energy into the core is attenuated as a function of frequency (the skin depth effect). The transfer impedance therefore "rolls-off" from the d.c. value. The roll-off continues with increasing frequency if the cable has a solid tubular shield. For cables with braided shields, however, energy at higher frequencies begins to penetrate effectively through the diamond shaped holes in the woven overbraid. The mutual inductance between the braid and the core wires (M_{12}) produces a core voltage that increases with frequency.

The shape of the composite transfer impedance curve depends primarily on the shield thickness and the optical coverage of the braid. Sketches of typical curves for single overbraid shields, double overbraid shields, and solid shields are shown in Figure 1. For a much more comprehensive treatment of transfer impedance theory, read Vance's Coupling to Shielded Cables Reference [1].

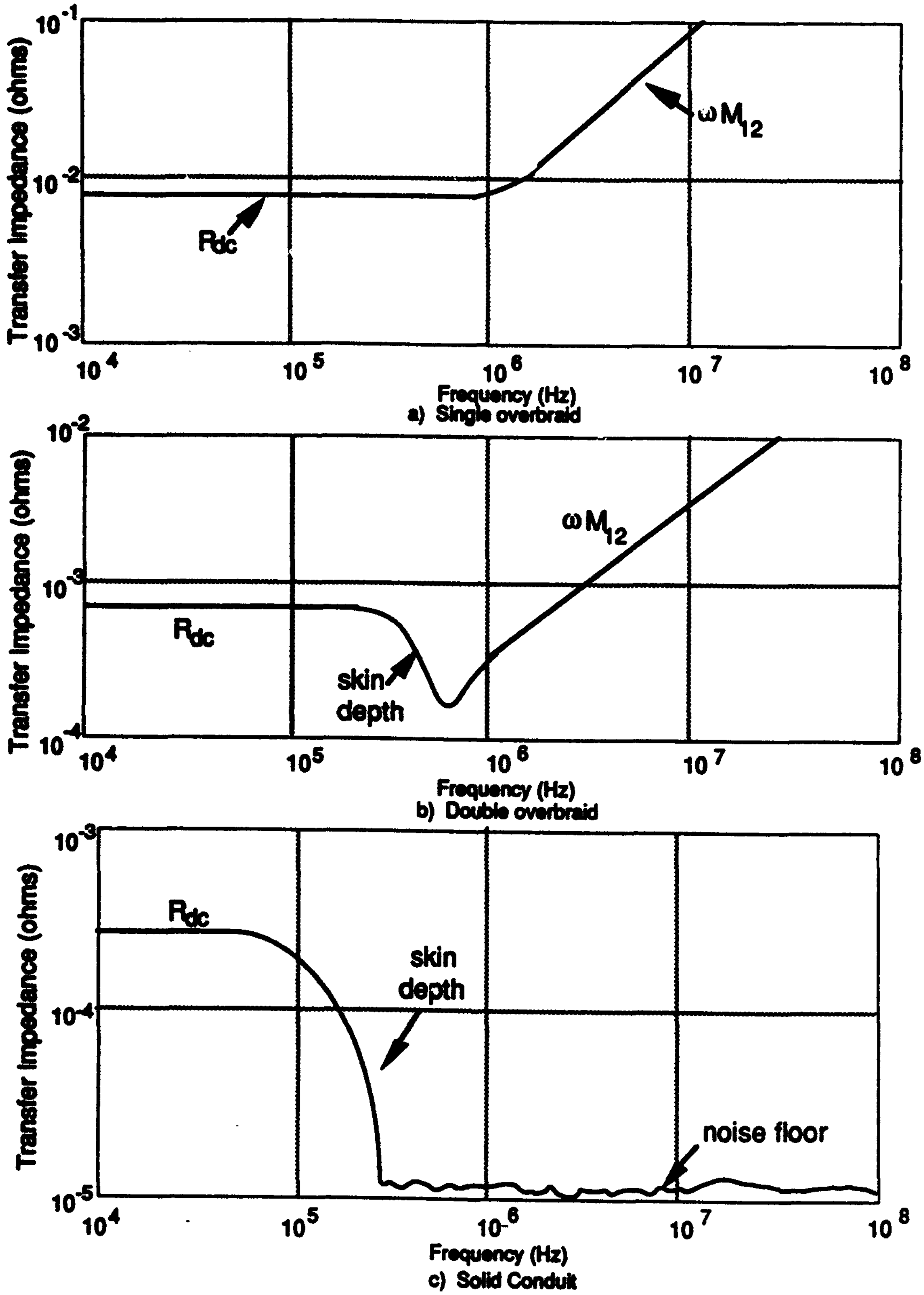

Figure 1. Typical transfer impedance curves.

3.0 THE SCT AND TIM TEST METHODOLOGY

The SCT and TIM test techniques must be thoroughly understood in order to develop test procedures for new cable configurations. A summary of each test technique is presented here. Detailed operating instructions can be found in: "Shielded Cable Tester Users' Operating Manual," Reference [2], and "Operation and Maintenance Instructions for the Transfer Impedance Meter," Reference [3]. The user should become familiar with the applicable manual prior to performing tests.

3.1 THE SCT TEST TECHNIQUE

Both the SCT and TIM measure cable transfer impedance using the same basic approach. They both induce (over a given frequency range), a current on the shield of the cable-under-test (CUT). They then measure the induced voltage on the inside of the shield by instrumenting one of the cable's core wires. The ratio of this voltage and current defines the cable transfer impedance. The basic SCT setup consists of a network analyzer, a computer to control the network analyzer, an inductive current driver, a current probe, an radio frequency (RF)-tight fixture or adapter to gain access to the inside of the cable's shielding, and instrumentation cables to interface the probes and fixture to the network analyzer (Figure 2).

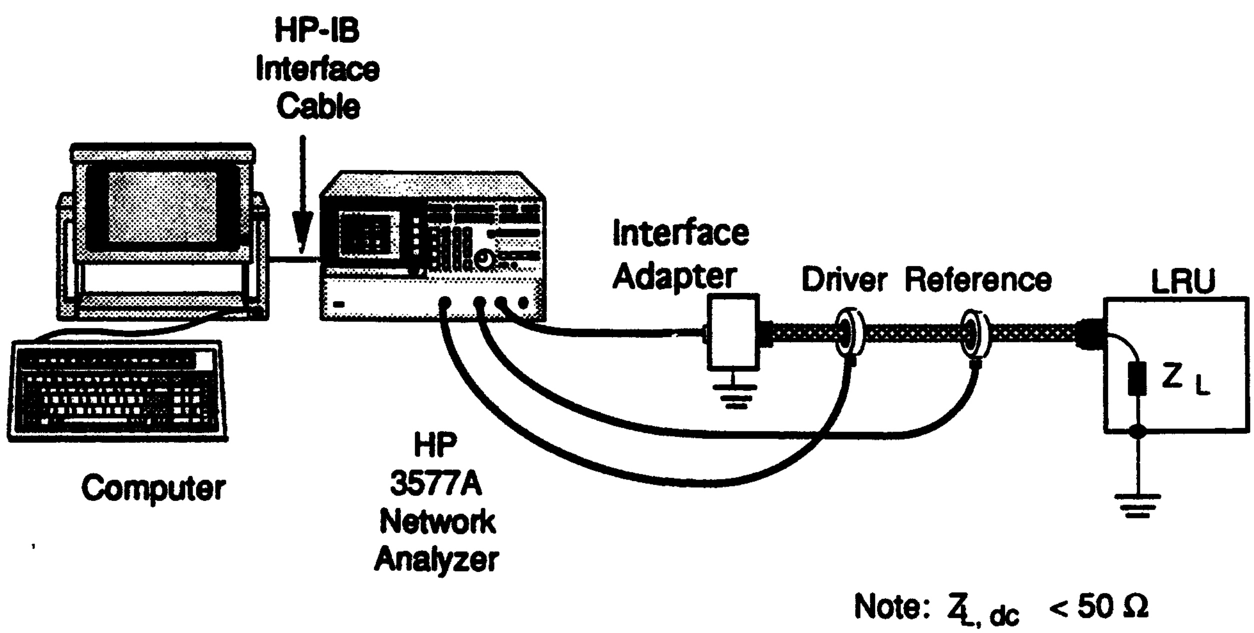

Figure 2. Shielded Cable Tester components.

Figure 3 shows a basic electrical diagram of the SCT measurement concept. Note that both ends of the tested cable must be tied to a common ground to form a continuous current loop. The SCT drives current on this loop using an inductive driver attached to the output of a network analyzer. The current coupled to the shield is measured with a current probe that is attached to the reference channel of the network analyzer. The drive current is typically swept from 1 kHz to 100 MHz, and is measured at 401 log-spaced points within this frequency range. One of the core wires in the cable is attached to the network analyzer input via an RF-tight connection. The far end of the measured core wire must be terminated in a low impedance (less than 50 Ω). The voltage induced on the core wire is measured at each frequency point.

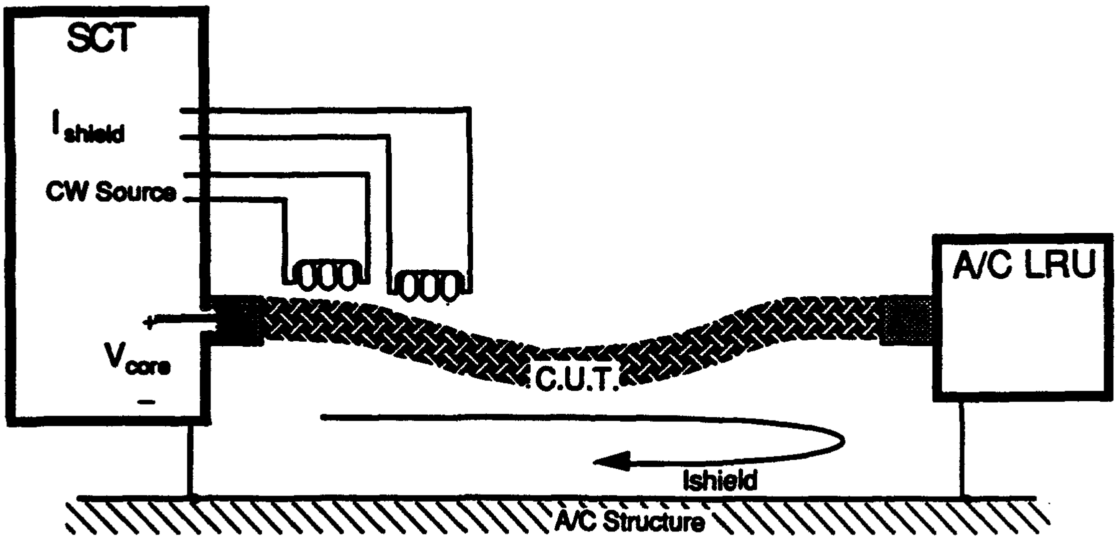

Figure 3. Electrical diagram of the SCT measurement concept.

The SCT includes computer software that controls the network analyzer (via a general purpose interface bus (GPIB) interface), and this software can be customized to guide the user step-by-step through the measurement process for a specific cable and system. The core software automatically sets up the network analyzer to compensate for the frequency characteristics of the reference probe (using a stored probe calibration). The software also automatically calculates the "raw" transfer impedance by dividing the core voltage by the shield current and stores the data on disk and provides hard copy plots. Finally, the software analyzes the raw voltage/current ratio and estimates the low frequency end-to-end resistance (R_{dc}) and the mutual inductance between core wire and the braid (M_{12}).

The most critical element of the SCT setup is the RF connection between the sense wire in the cable and the network analyzer. The current loop "return" connection is made near this joint, and if the connection is leaky the data will be contaminated. There are several different methods that can be used to make this connection. Some of these are illustrated in the examples that follow. The ideal setup for performing transfer impedance measurements is the trace wire concept (Figure 4), which is also discussed in Section 4.5.2.

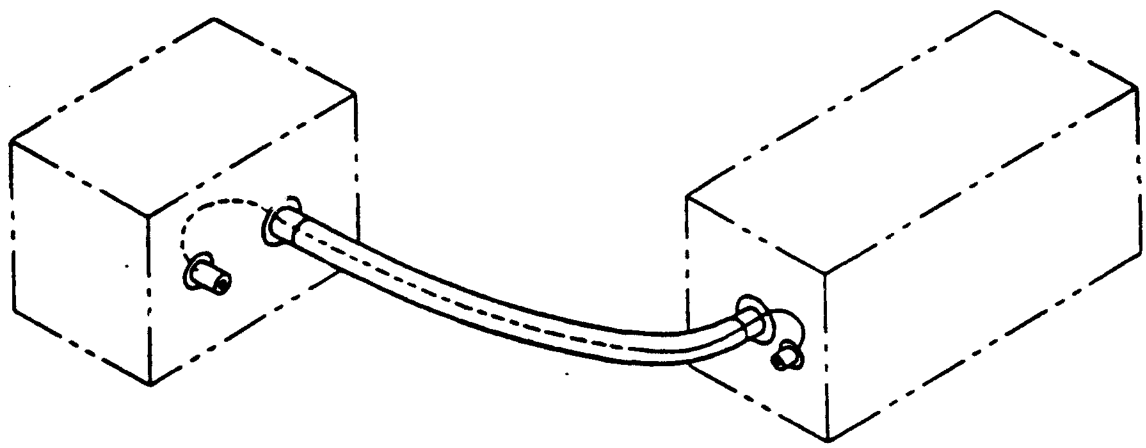

Figure 4. Trace wire concept.

The trace wire setup allows for all joints in the cable assembly, including mating connectors on both ends, to be measured at once without disconnecting either end. The voltage connection is made via an instrumentation connector located on the line replaceable unit (LRU).

This measurement technique provides data indicative of all the connector joints left undisturbed. Since the cable is left attached to the LRU, the current path at this end of the cable is already established. New systems which rely on shielded cables should employ the trace wire concept during initial design to make future testing simpler and more accurate. All other test setups require that at least one end of the cable be disconnected. This prevents the measurement from showing the exact state of the cable as it was installed or its condition after a length of time in an operational environment.

Another way to make the core-wire voltage connection is to use an interface adapter made with a cable mating connector and an instrumentation connector, as shown in Figure 5. With this setup, a ground return strap must be used to complete the current loop by attaching the adapter to aircraft ground. In this manner, all the joints in the cable connector are evaluated; however, the mating connector joints are replaced by those of the adapter. This method is preferred when there is an established test program for evaluating a set of cables. At present, this is not practical for random testing since there are hundreds of different connector configurations.

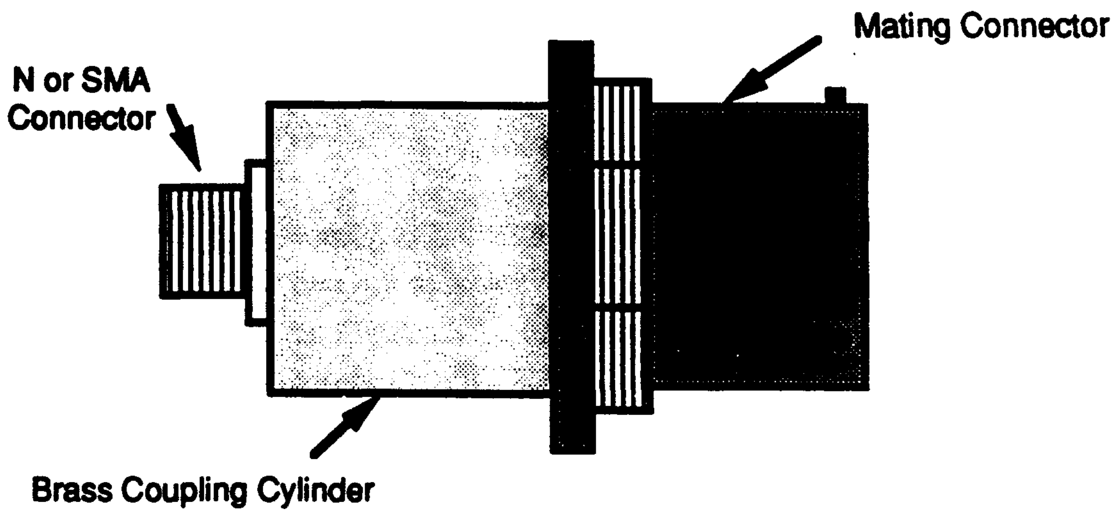

Figure 5. Connector interface adapter.

A universal adapter utilizing cable braid, known as the "sock adapter," has also been utilized, as shown in Figure 6. When this adapter is used, the braid is pulled over the connector ring and circumferentially bonded with a hose clamp to the connector backshell. The sock cannot be attached to the connector ring because this is not a RF joint on the connector. With this setup, a ground return strap is also needed. To avoid including the effects of the sock-connector joint, the ground return strap must be attached to the connector backshell beyond the point where the sock is clamped on the backshell. The disadvantage of this technique is that none of the connector joints covered by the sock adapter or the mating connector joints will be included in the measurement.

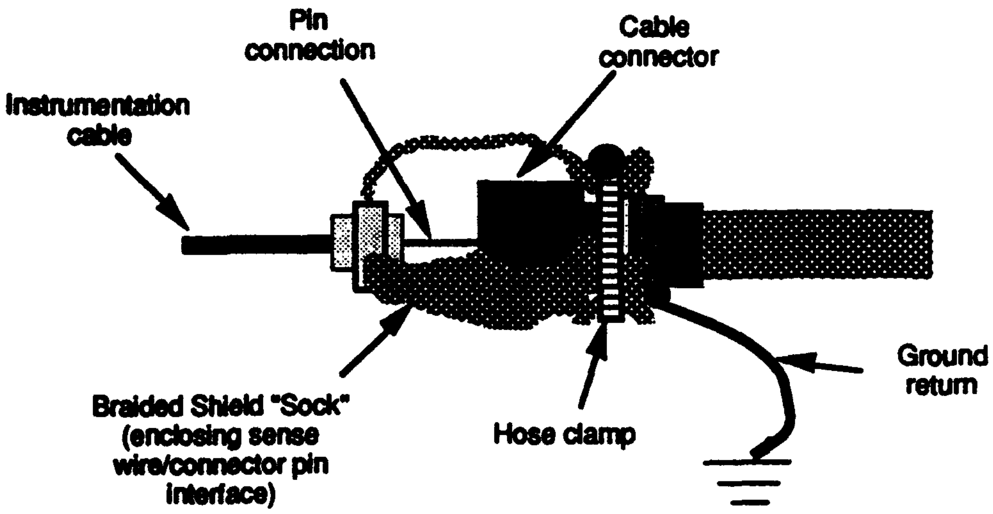

Figure 6. Sock adapter.

3.2 THE TIM TEST TECHNIQUE

The TIM works similarly to the SCT with the following notable exceptions. The TIM tests at 11 discrete frequencies in the EMP threat range and then reports the two transfer impedance parameters: R_{dc} and M_{12}. It uses dedicated electronics instead of a network analyzer and a computer. The TIM drives current directly on the shield of the cable being tested. The drive circuit impedance is set so that the shield current varies little for cables installed in a system with a good ground plane. This eliminates the need to reference the driven shield current. The TIM can also use a universal probe to attach to cables at the measurement end, as illustrated in Figure 7. This probe includes the contacts for the current drive as well as the contacts for the core-wire voltage measurement. Figure 8 shows the basic electrical diagram of the TIM measurement concept.

Since the TIM uses direct drive to couple current, one end of the CUT must be disconnected to allow the TIM to drive the current loop. (The TIM is in series with the current loop.) Note that in addition to using the universal probe for making connections to the CUT, the connector interface adapter and "sock" techniques (described in Section 3.1) can also be used for the voltage measurement with a separately attached drive circuit. The ground of the drive circuit is "zero length" connected to the measurement end of the CUT shield, and the core of the drive circuit is connected to the aircraft ground via a ground strap. The ground strap should preferably be <1 ft in length. Figure 9 shows an example of this type of setup.

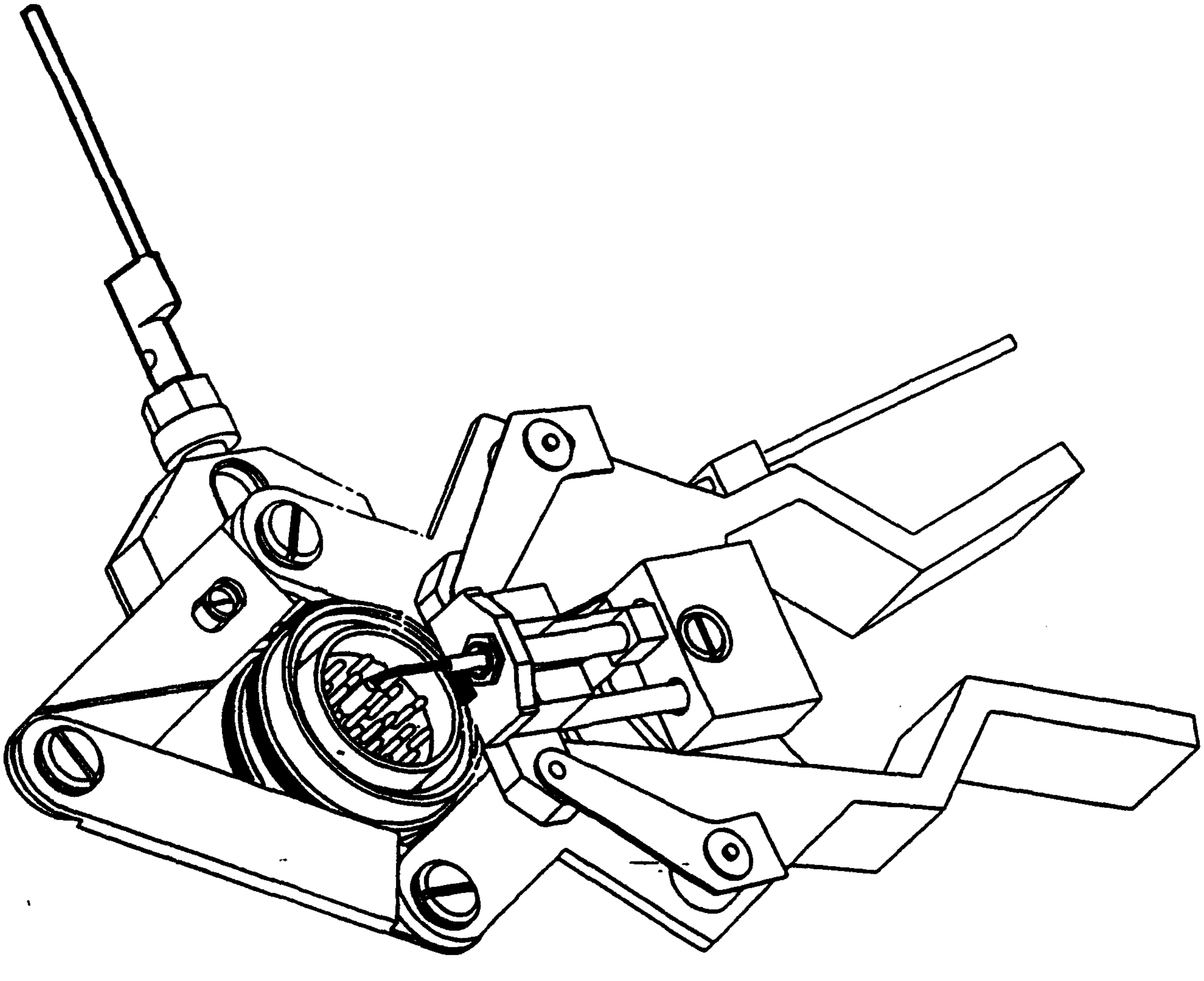

Figure 7. Universal probe used by the TIM.

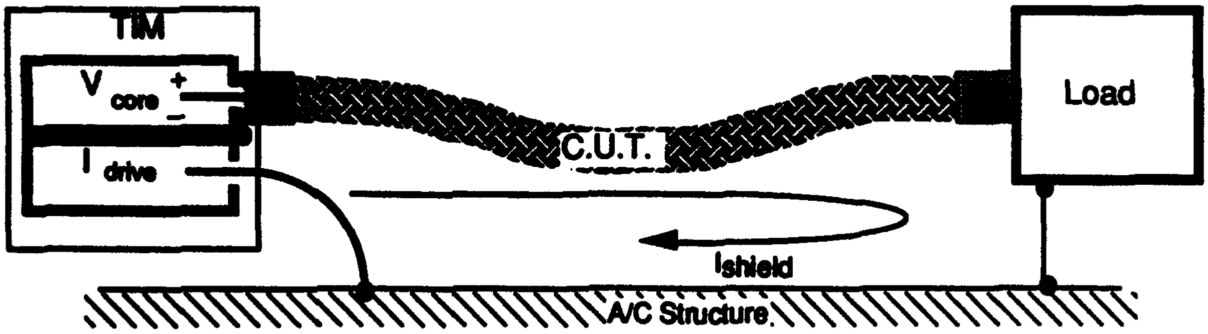

Figure 8. Electrical diagram of the TIM measurement concept.

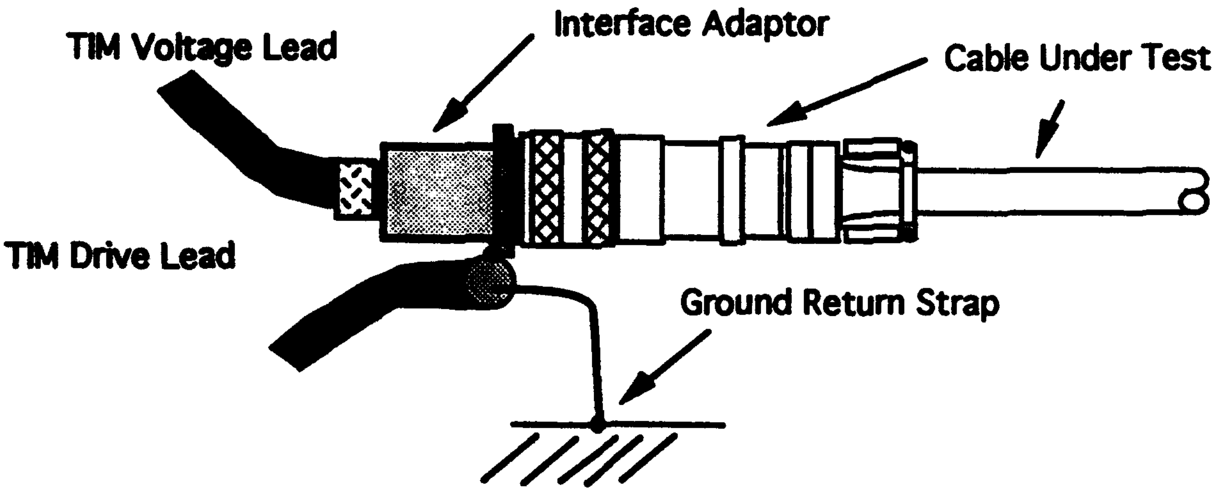

Figure 9. The TIM hookup without the universal probe.

3.3 SAMPLE IMPLEMENTATION

The most important thing to remember about both testers is that they will measure the total transfer impedance of a cable shield provided that the shield current path routes along the section(s) of the shield containing the voltage-sense core wire. This fundamental principle is the basis for proper implementation of test techniques using these testers. Figures 10 and 11 show two examples to help clarify this concept, with separate drawings for the TIM and SCT implementations.

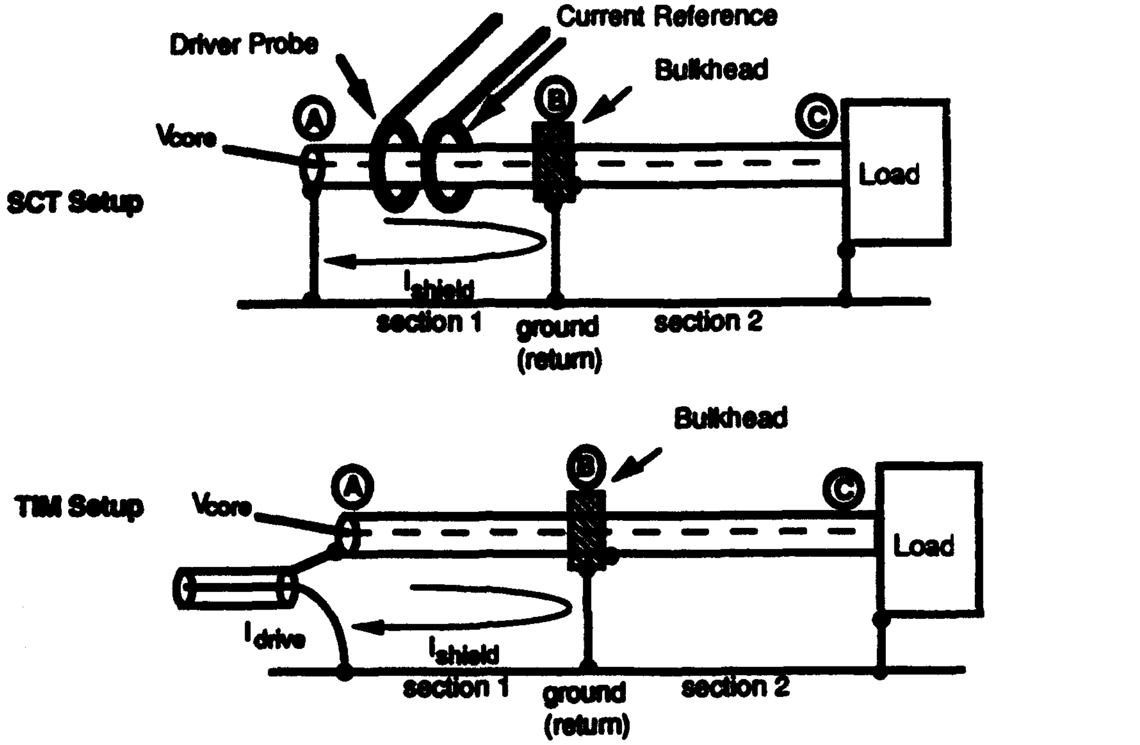

Figure 10. Transfer impedance measurement for a cable routed through a bulkhead.

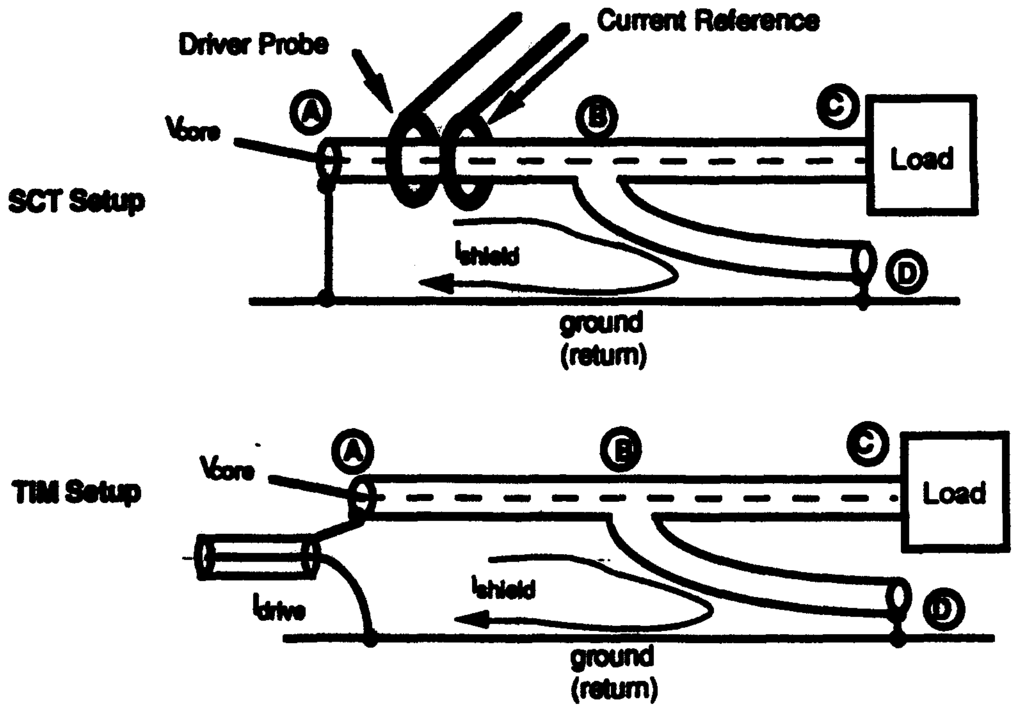

Figure 11. Transfer impedance measurement for a branched cable.

In Figure 10 a cable is routed through a bulkhead with the shield grounded at that point. Only the cable section between points A and B is measured because it is the only part of cable over which the shield current path contains the sense wire. In Figure 11, which represents a branched cable, only the cable section between points A and B is measured because there is no shield current on the section between points B and C, and there is no sense wire in the section between points B and D.

Understanding this concept also helps to avoid contamination problems from either the termination or instrumentation end of the CUT. For instance, if the load at the termination end is not a good RF seal then under no circumstances should shield current be forced over that end of the cable. If this occurs, the contribution from this poor RF connection will be included in the measurement of the cable. The current return connection must be made beyond the connector away from the poor RF seal (toward the cable braid). Also, if the shield current routes along the instrumentation cable because of a poor ground at the measurement end of the cable, the transfer impedance of the instrumentation cable will add to the total transfer impedance.

At higher frequencies, even when there is a good ground connection at the measurement end, current will exist on the instrumentation cable. For this reason, the instrumentation cable used for the voltage measurement must be extremely good. Double overbraid cable is preferred. If a highly shielded cable is tested, the "bleed back" current may contaminate the measurement. In this case, a very good instrumentation cable is required (i.e., semi-rigid RG-141).

3.4 The SCT AND TIM APPLICATIONS

While both the SCT and TIM testers can evaluate the shield quality of a cable assembly, there are particular situations in which one tester would be better suited than the other. In general, when the only users of the tester are to be technician level personal, the TIM is better suited. This was one of the main goals in developing the TIM: to make a small, lightweight, portable replacement for the SCT, easily used by technicians in the field.

The SCT would be more appropriate in situations where both technician and engineer level personal would be using the tester. This would allow the technician to perform routine surveillance testing while at the same time provide the engineer with a tool that can be used for a more detailed analysis of a cable response. Because the SCT provides a full frequency response plot of cable transfer impedance, it can be used in the design and evaluation stages of new cable production and when evaluating repair procedures.

Some real-world cable flaws are visually apparent but cannot be detected with the TIM, SCT, or any known practical field measurement technique. An example has been found on heavily shielded B-52 cables. These cables contain two layers of metal overbraid, and a layer of copper foil that provides 100% optical coverage. The outer layer of braid can be pulled back from the connector backshell with no impact on the overall EM quality of the cable. Visual inspection is the most practical technique for detecting this type of flaw, and although the shield quality is not affected immediately, if not corrected additional shield layers could also eventually loosen to the point where the shielding is compromised. A detailed study of this type of flaw and the measurement requirements can be found in a companion report "Fault Detection Techniques for Complex Cable Shield Topologies."*

* To be published as PL-TR-93-1111

4.0 TEST PROCEDURE DEVELOPMENT

Once the user has become familiar with the SCT/TIM test concepts and procedures, he can begin the process of developing new test procedures. As stated earlier, the SCT and TIM testers will measure the total transfer impedance of a cable shield (providing the shield current path contains the sense wire). Therefore, the process of developing a test procedure centers on defining and controlling current paths on the test cable and selecting a proper sense wire to use for each of these paths. In the last part of this section, several examples of typical cable configurations and their test procedures are presented. It is impossible to give examples of every possible situation, but these examples can be extrapolated to new situations to help develop new procedures.

4.1 INFORMATION COLLECTION

The process of developing a test procedure for a particular cable begins with information gathering. The required information includes the following: data from previous tests on the cable which may have been obtained during qualification or verification testing; wiring diagrams showing cable branches, core-wire paths, shield topology, and LRU loads; previously used test procedures (if the cable was ever tested in-situ before); and any particular hardness concerns that may have been previously identified. Additional information obtained from personnel familiar with the system includes: how to remove power from the system being tested; the location of connectors on the cable to be tested; and the availability of 110 V power.

Cable wiring diagrams are critical. Without them, the process of developing a test procedure becomes much more complicated and could result in the inability to properly select a sense wire. The technical manuals for most systems contain complete wiring diagrams. Since this is such an important part of the test procedure development, a typical wiring diagram showing common cable topologies is given in Figure 12. This figure will be referenced throughout this section. Data from previous tests are useful in determining if the acquired data are realistic. Previously used test procedures can identify appropriate core-wires to use for sense wires. Previously identified hardness concerns can flag a particular section of the cable to monitor closely.

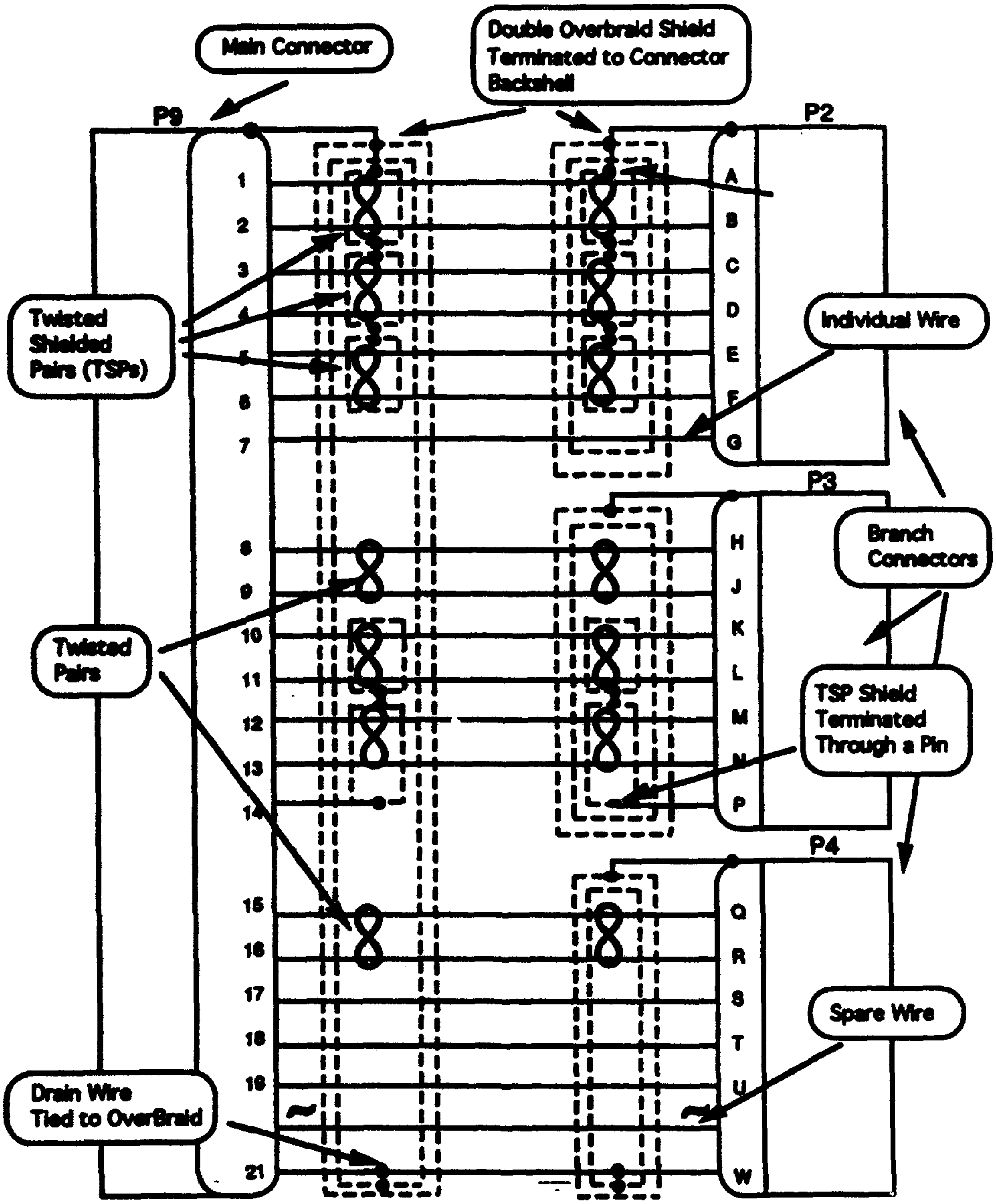

Figure 12. Example of cable wiring schematic.

4.2 SYSTEM SURVEY

The system survey is used to verify the information gathered above and to fill in missing parts. The external grounding topology of the cable must be assessed. All points where the cable shield is attached to a common ground must be located. This includes all branch connectors, bulkhead feed-throughs, and ground tie points. If this cannot be verified visually or from the wiring diagram, it must be done electrically with an ohmmeter. To do this, all obvious ground contact points should be disconnected to isolate the shield. There should now be an open circuit between the cable shield and ground; if not, there is another ground attachment point that has not been located.

4.3 MEASUREMENT PATH SELECTION

To properly evaluate a cable, it is necessary to test each unique path in that cable. A unique path is defined as the cabling between any two connectors on the cable assembly which contain core-wires common to both connectors. A single branched cable thus has only one unique path. If a wiring diagram is available, it is simple to identify all core-wire paths. If a wiring diagram is not available, it is not practical to determine all core-wire paths. In this case, measuring each part of the cable braid at least once will be sufficient. An ohmmeter should be used to find pins which route between connectors so that all cable sections (branches) can be measured.

Once the grounding topology is determined and the paths determined, it is possible to define the measurements that will be required to evaluate the entire cable assembly. Each path should be evaluated separately, treated it as if was a single branched cable. If a shield current can be driven over an entire path with one setup, then only one measurement is needed to evaluate that path (otherwise, more measurements are required).

4.4 SENSE WIRE

The TIM exploits a core-wire in the CUT as a sense probe for the voltage measurement. The wire used must meet three conditions in order to make a valid measurement. First, it must not be contained in a twisted shielded pair (TSP). If it is, the measurement will include the shielding provided by the shield of the TSP. Second, its path must run the full length of the cable or cable section being tested before terminating. Third, it must have a load at the terminating end < 50 Ω. If not, a load must be created. Creating a load is discussed in Section 4.5.

Using the sample wiring diagram given in Figure 12, an example procedure for testing this cable is as follows. This cable shield has three unique paths through which core-wires route and is tied to ground at each of the connectors, so it will require three measurements to evaluate the overall cable assembly. One measurement is of the section of cable between connectors P9 and P2. In this branch only pin 7 is valid to use since pins 1 through 6 are all part of TSPs. A second measurement would be between connectors P9 and P3. In this path, pins 8, 9, and 14 are valid. Pins 8 and 9 are good even though they are part of a twisted pair because the pair is not shielded. Pin 14 is good because, in this case, the TSP shield acts as a wire feeding through to a pin. Pins 10 through 13 are not valid sense wires since they are all inside TSP shields. The last measurement includes the section of cable between connectors P9 and P4. Pins 15, 16, 17, 18, and 19 are all valid. Pin 21 is not valid since it is tied to the outer shield at both ends.

4.5 LOADS

As stated previously, both testers require a load < 50 Ω between the sense wire and shield for acquiring a measurement. There are several ways that this can be accomplished. The following sections provide some examples.

4.5.1 Host Load

When testing a cable installed in a system, the preferred condition is to leave one end of the cable attached to its host LRU. This is valid if there is a load (in the LRU at either end of the cable) < 50 Ω on a pin that meets the trace wire conditions given in Section 3.1. A digital multimeter or the "Pin Search" function on the TIM (in conjunction with a cable wiring diagram) can be used to find such a load.

4.5.2 Trace Wire

The ideal condition for performing transfer impedance measurements on a cable installed on a system is the use of a dedicated trace wire. A trace wire is a wire in a cable whose only use is for performing transfer impedance measurements. Figure 4 in Section 3.1 shows the trace wire concept. This wire meets the three conditions given in Section 3.1. The LRU at one end (ideally both ends) of the CUT requires a trace wire routed through the connector and attached either to ground or to an sub-miniature style A connector (SMA) connector on the LRU. If the trace wire is connected to SMA connectors on both LRUs, a shorting cap must be placed on one of the SMAs for a terminating load. If the SCT is being used, the voltage connection is mated to the other SMA connector. If the TIM is being used, the connector at the "core-voltage" or "measurement" end must be disconnected to include the TIM drive circuit in the current loop. The voltage connection is then made via one of the methods described in Section 3.1.

4.5.3 Mating Connector Shorting Load

To provide a terminating load for in-situ measurements when a proper host load is not available or when measuring a cable in the lab environment, a shorting load, using a mating connector, can be utilized. Since this requires procuring the mating connector and fabricating a load, this approach is practical only if measurements are to be performed repeatedly on a particular cable type.

This connector shorting termination should be made RF-tight. This can be done by making the load with a brass cylinder threaded to mate to the back of the mating connector. An appropriate core-wire is "pinned out" and shorted with a cover soldered on the end of the brass cylinder. Figure 13 shows a typical shorted load construction.

A ground strap will also be needed to attach the shorted load to the appropriate ground return (i.e. aircraft frame). This strap should be made of flexible wire braid (preferably about 1-ft long) with two large alligator type clips at either end. Since a proper mating connector is used, the current return can be attached to this mating connector (before the brass coupling ring).

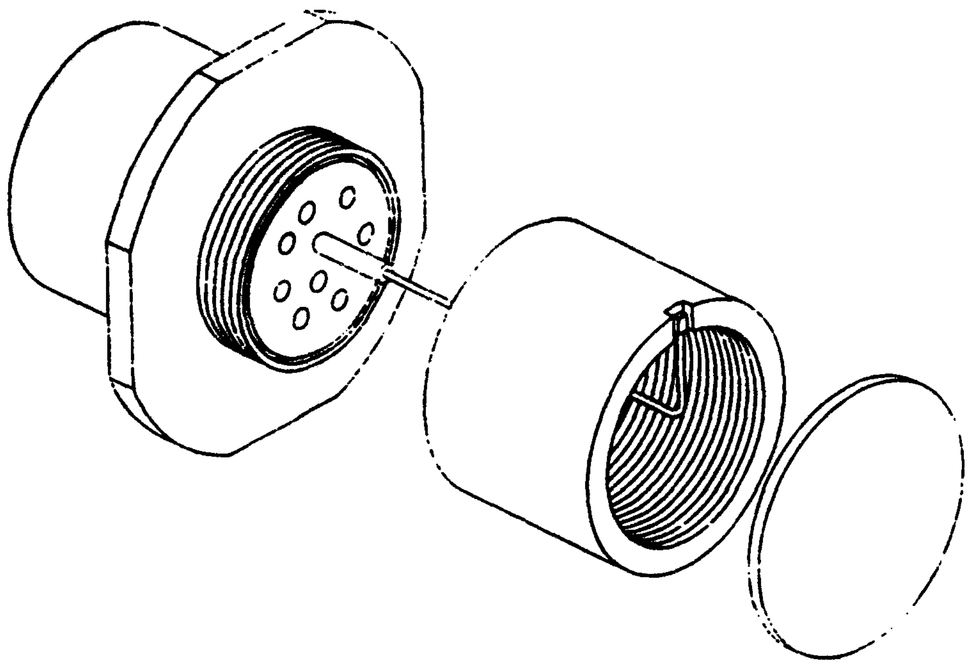

Figure 13. Typical shorted load.

4.5.4 Makeshift Load

The final option for installing a load on the CUT is to use a combination of mating pins, copper wool, and copper tape. For cables with pins on the termination end, place a small amount of copper wool in the inner connector ring on top of all the pins. Make sure to short the pin selected as the sense wire. Using a piece of copper tape (about 2 x 2 in), cover the end of the connector forcing the copper wool against the pins. For connectors that have sockets at the termination end, place a mating pin into an appropriate socket . Then, using a piece of copper tape, cover the end of the connector, making sure the copper tape shorts the inserted pin to the connector shell.

> **WARNING:** The edges of the copper tape are extremely sharp, so care must be used when handling the tape. Most importantly, when removing the copper wool and tape after a measurement, care should be taken to ensure all materials are removed from the connector.

As with the shorted connector load, a ground return strap will be needed to form a ground return. However, since the copper tape does not form a perfect RF seal, the current return should not route current over the tape (this will have a dramatic effect on the measurement). The ground return strap should be attached to the connector backshell. However, this technique excludes the joints between the backshell grounding point and the copper tape.

4.5.5 Universal Shorting Connector Set

Another shorting termination method which is currently being investigated is the use of a universal connector set. This set would be similar to the shorting connectors described in Section 4.5.3 except that there would not be a pin or socket insert in the connector, and the keying of the connector would be universal. This would allow one connector to mate to all connectors of a particular shell size and connector series.

4.5.6 Shorting Wafers

Another possible shorting termination method is to use wafer technology. A shorting wafer is a thin conductive wafer which fits over the pins in the connector and shorts the appropriate pin to ground. To implement this method, the connector is disconnected, a wafer placed inside, and then the connector re-mated. This method allows all joints in the terminating connector to be evaluated. This method requires further development.

4.6 EXAMPLE TEST PROCEDURES

This section contains examples of test procedures used in most common cable configurations. These procedures focus on establishing current paths - no detail is given concerning the voltage measurement or loads. Simple figures are shown with each example for clarifying the described setups.

4.6.1 Unbranched Cable

The most common cable configuration is the unbranched cable. Evaluation of this cable is typically simple and usually requires only a single measurement. Current can be driven over the full length of the cable in one step, as shown in Figure 14.

However, if the cable is extremely long (over 30 ft), the resulting cable resonances may be so low in frequency that they totally obscure the M_{12} measurement. If this occurs, it may be necessary to either use a resonance-resolving algorithm on the data, or measure each end of the cable separately (see Figure 22) and compare the result to the expected value (a sanity check as described in Section 6.0).

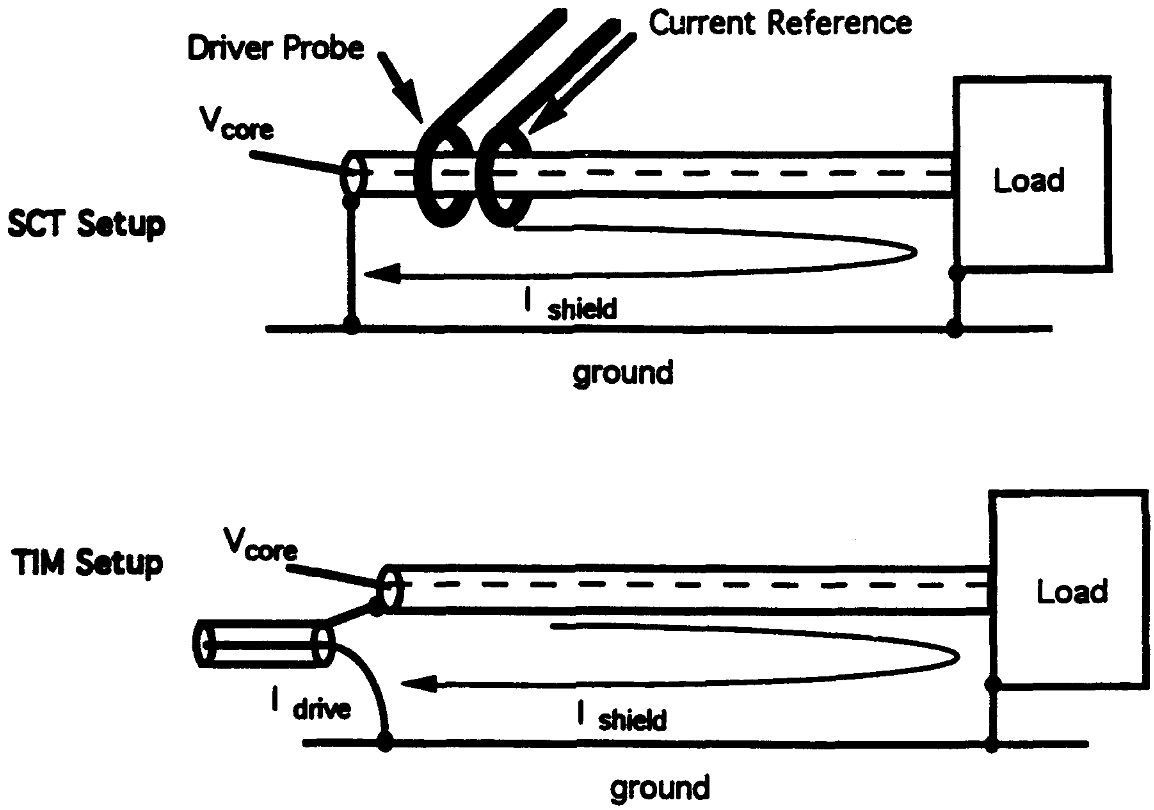

Figure 14. Test setup for unbranched cable.

4.6.2 Unbranched Cable with Bulkhead

When an unbranched cable passes through a bulkhead and it is not electrically connected to the bulkhead, the cable can be evaluated as described in Section 4.6.1. A more complicated case occurs, however, when the cable shield is grounded at the bulkhead. This case requires two measurements. The first measurement is from one end of the cable to the bulkhead, and the other measurement is from the other end of the cable to the bulkhead. To evaluate the first half of the cable, the same test as described in Section 4.6.1 for a single branch cable should be used. Figure 15 shows the setup. To evaluate the second half of the cable, the termination and measurement ends of the cable must be switched, as shown in Figure 16. If the cable is short (< 30 ft), the SCT can measure the second half of the cable simply by moving the current probes to the second part of the cable (the measurement and termination ends do not have to be switched).

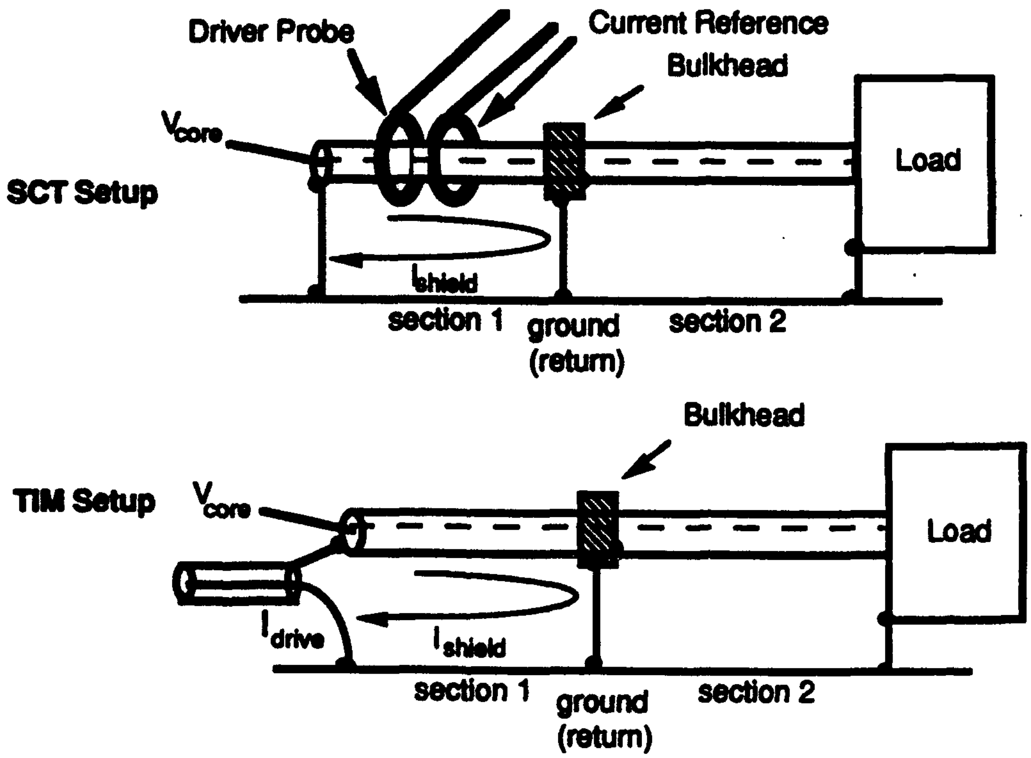

Figure 15. Test setup for a cable routed through a bulkhead (Section 1).

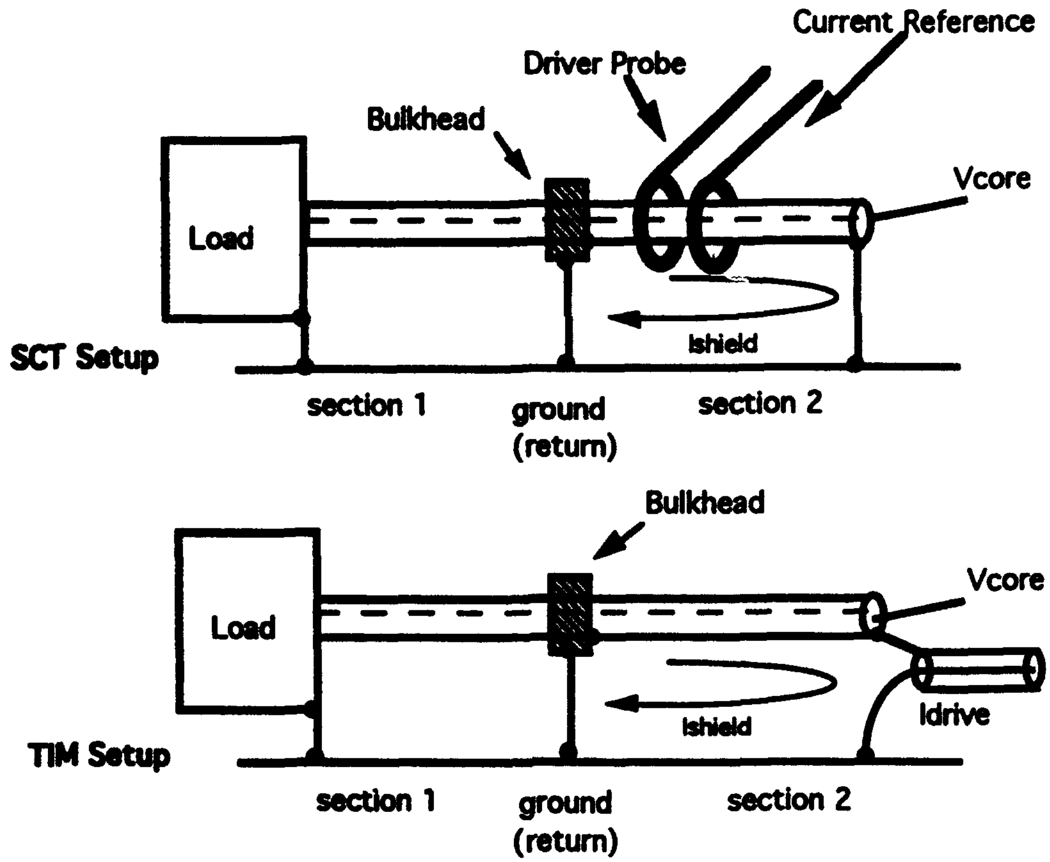

Figure 16. Test setup for a cable routed through a bulkhead (Section 2).

4.6.3 Branched Cables

A multi-branched cable poses the most complicated cable configuration. Some cables can have as many as 10 branches or more. The process illustrated is for a cable with only two branches, but it can be extrapolated to a cable with many branches. To evaluate each identified path, the shield connections must be configured to drive current only on that section of the cable. Figures 17 and 18 show the test setups for measuring the two branches of an example cable.

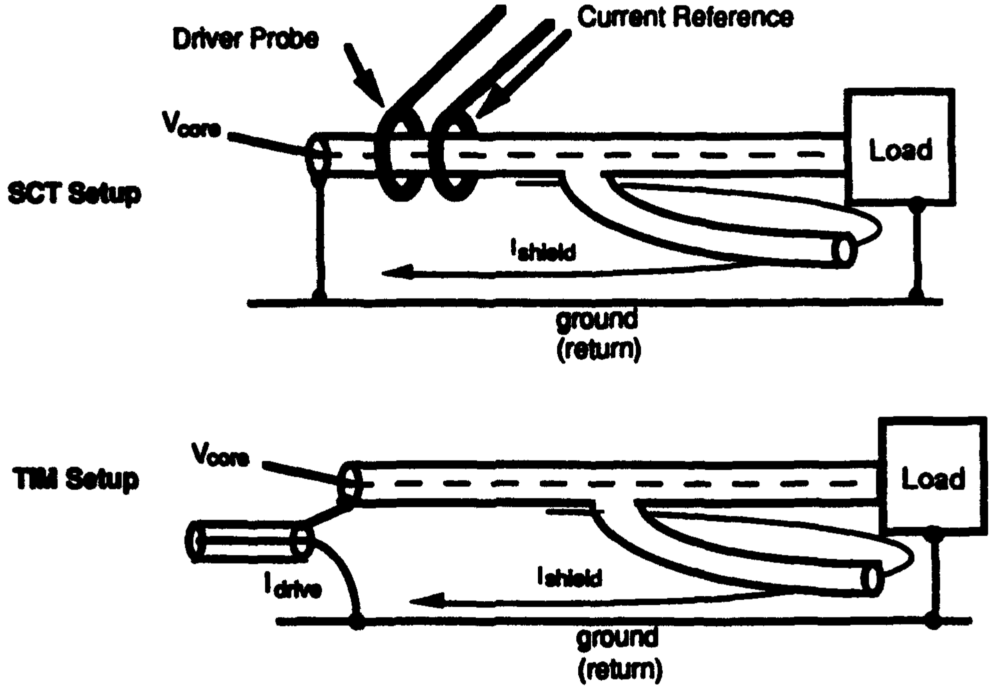

Figure 17. Test setup for branched cables (branch 1).

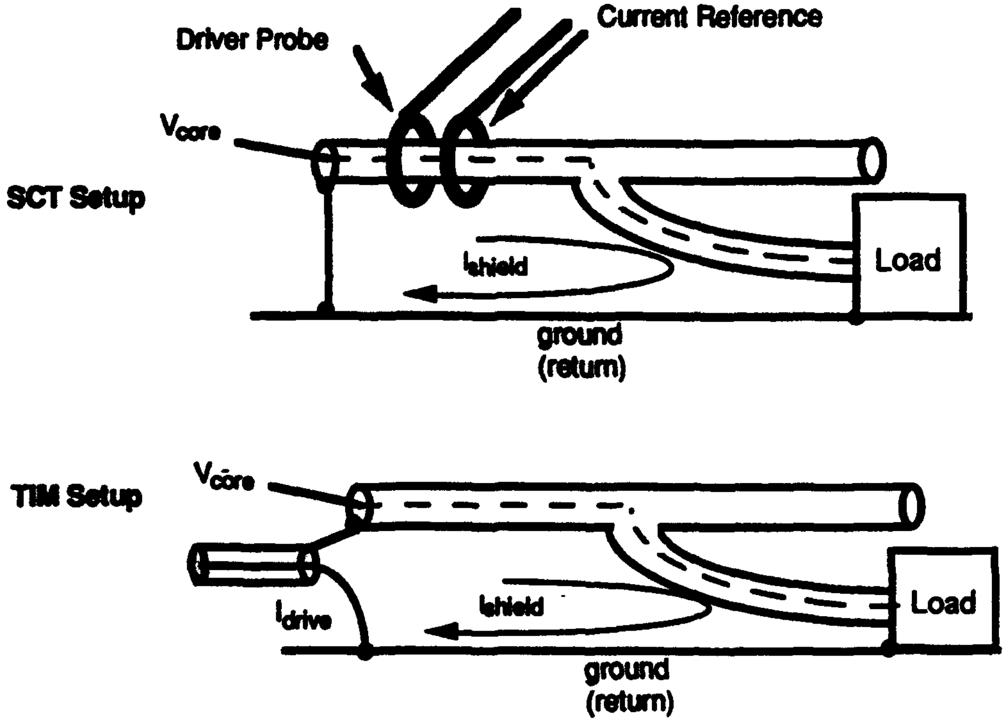

Figure 18. Test setup for a branched cable (branch 2).

With branched cables it is possible to evaluate a cable while the other branches remain connected. This can be done by treating the cable similarly to a single branched cable with a bulkhead. The current will "split" where the branches come together, but the full current can be driven on specific parts of the cable. There will be some contribution to the transfer impedance from the split current flowing over other sections of the cable if they contain the wire being used for the voltage measurement. If this approach is used, then the same procedure must be used each time the cable is evaluated.

This approach also requires one more measurement to evaluate the entire cable. Figures 19 through 21 show this approach and also how the "split" current can affect the measurement. Note that if the far end connector has a fault, the alternate test setup will give a false low reading because only half of the referenced current flows over the fault (a significant fault will still be detected, but not properly quantified). For this reason, each branch must be evaluated separately, and the data must be compared to verify the location and magnitude of a fault. The primary test setup (Figures 17 and 18) provides a more clear-cut evaluation and is therefore preferred.

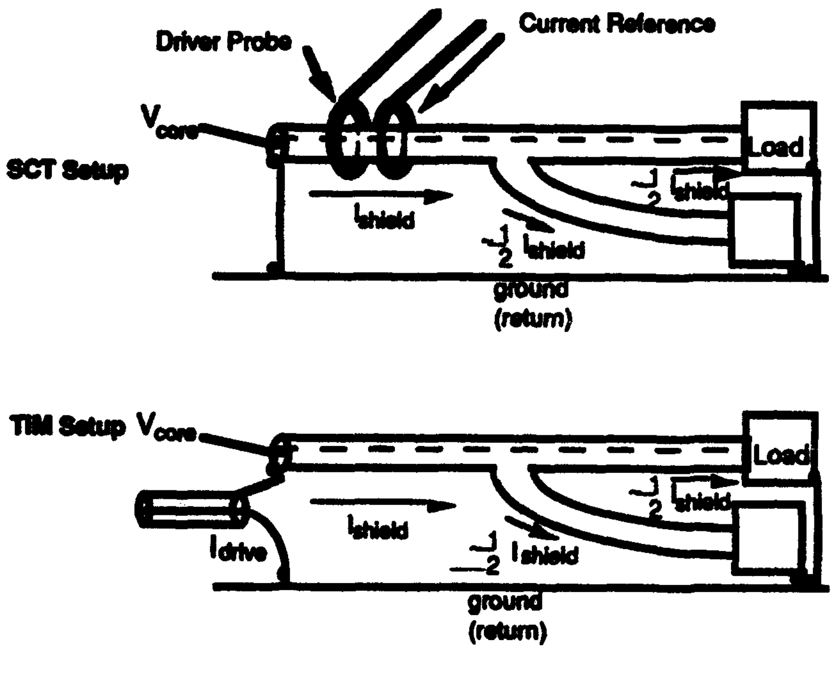

Figure 19. Alternate test setup for a branched cable (common branch).

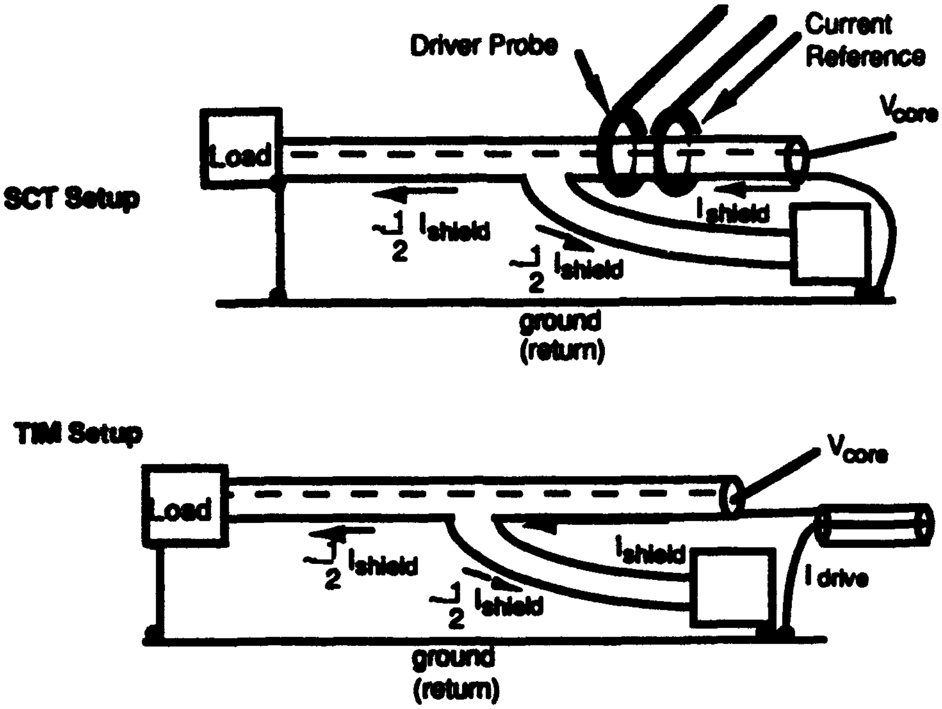

Figure 20. Alternate test setup for branched cable (branch 1).

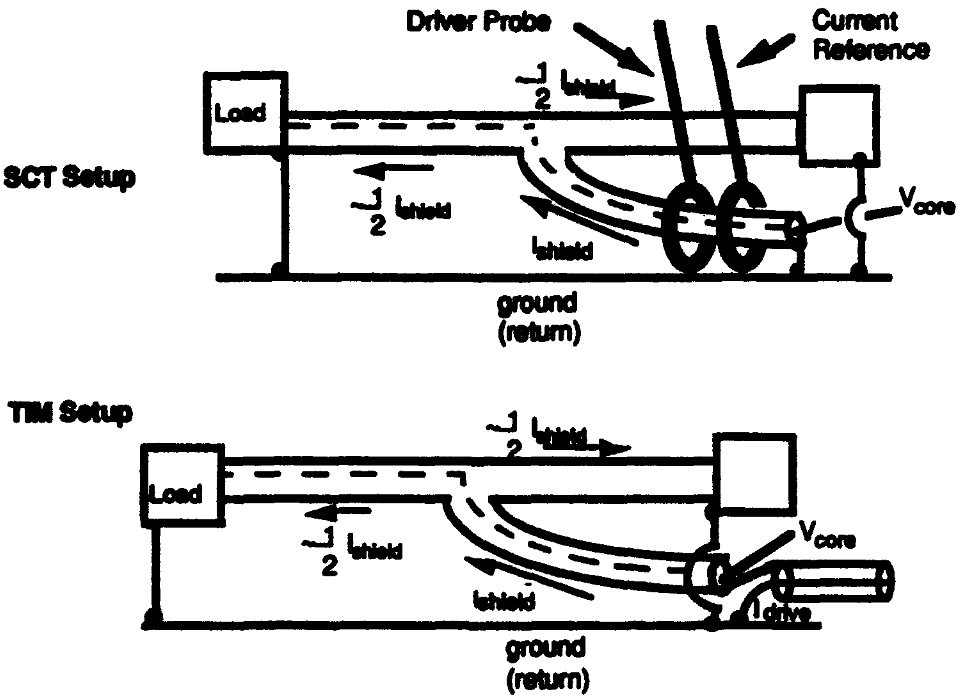

Figure 21. Alternate test setup for branched cable (branch 2).

5.0 FAULT ISOLATION TECHNIQUES

Fault isolation is a subjective process which will vary from situation to situation and will be implemented differently by different people. This section presents a general approach to be used when working with a single branched cable, but enough of an explanation of the process is given so that the user can adapt these procedures to other cable configurations.

The simplest and quickest way to locate a fault is by physically manipulating the cable while re-acquiring SCT data. Since many faults are unstable, the response of the fault will deflect the SCT sweep if the section of the cable containing the fault is moved. Most faults occur at the ends of cable branches - either in the connector or at the junction where the cable braid mates to the connector. Faults also occur at junctions in branched cables where the cable branches come together. The person performing the test(s) should simply try to rotate connector joints by hand and flex the braid at the junction points - if the measured value changes greatly, an unstable fault has been located. Many times a loose connector joint will be found by doing this.

By performing this physical manipulation of the cable the fault may temporarily be "fixed," resulting in a lower transfer impedance response.

> **CAUTION:** This is not a permanent fix. The cable will most likely return in a short period of time to the original faulted condition. Either the joints have been tightened, corrosion has been "worn through," or contact surfaces have realigned to provide a better reading. Proper repair procedures should be followed to fix the fault.

If the fault is not located by this simple method and the test reading still fails the pass/fail criteria, the fault can be located by utilizing the following technique.

Since the testers only measure the transfer impedance of the cable braid where there is current routed over the shield of the sense-wire, faults can be isolated by restricting the current to specific sections of the cable. This is done by simply moving the ground contact points on the cable shield. If the sense wire routes through the same section of cable, the measurement is the transfer impedance of this specific section of cable.

Because most faults occur at the ends of a cable, this is the first place to look. First, test the connector end where the voltage measurement is being acquired. With the testers still configured for a normal measurement, disconnect the ground from the aircraft and attach a pointed probe tip (such as a scribe) to the end of the ground return strap on the SCT or the red lead of the TIM (Figure 22). On the SCT, place the drive and reference probes on the ground return strap. Now touch the point on the ground return to the metal farthest back on the connector, as shown in Figure 23, and take a measurement.

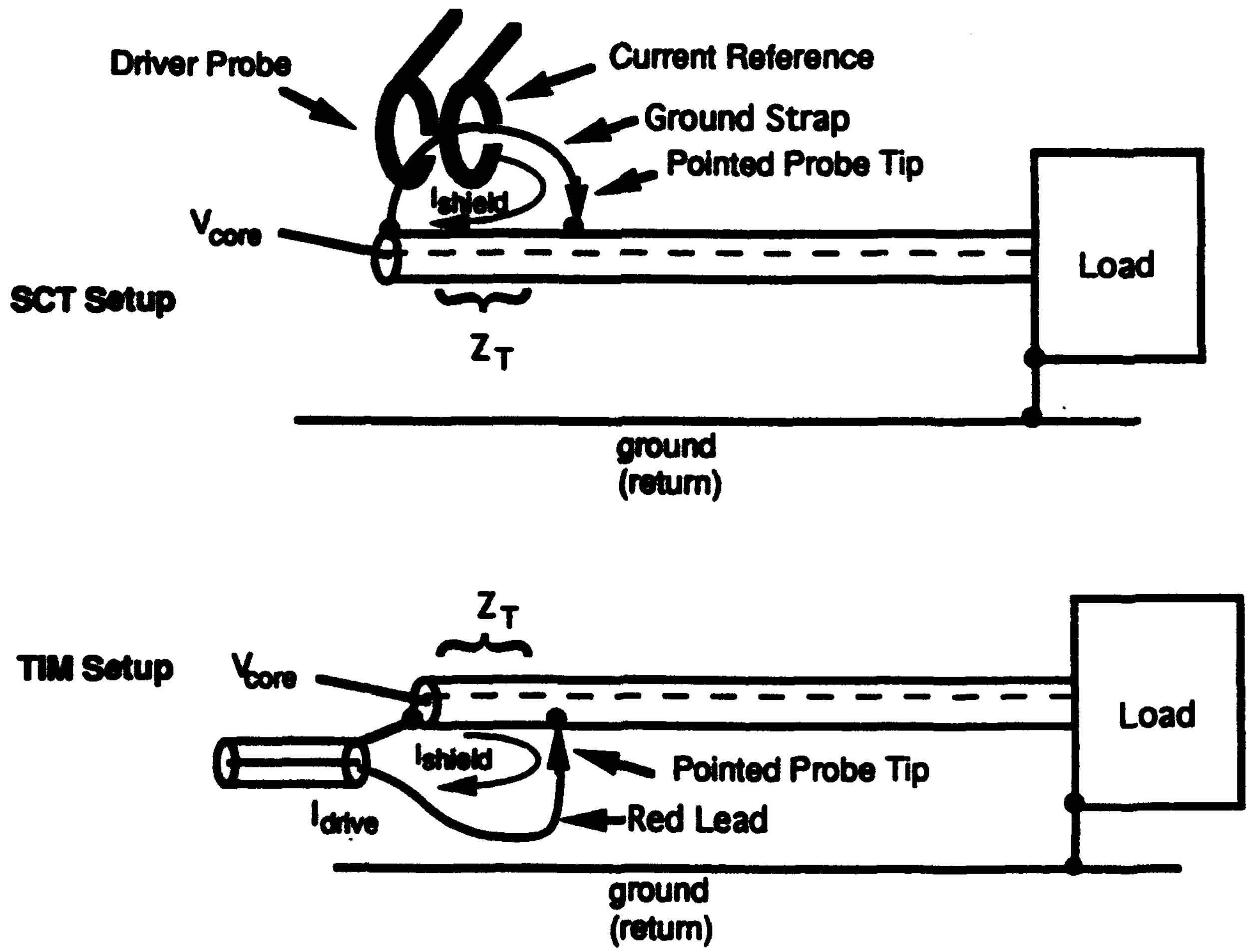

Figure 22. Test setup to locate fault.

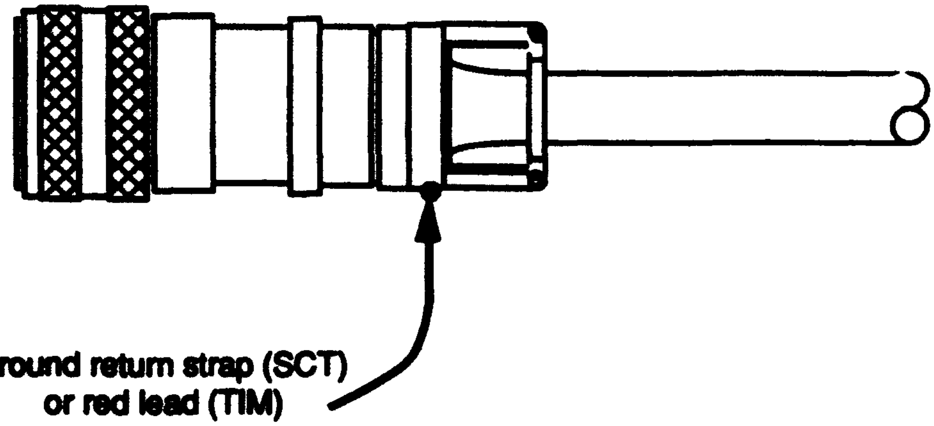

Figure 23. Ground return placement to locate fault(s).

This reading should be well below the pass/fail criteria, in the range of a few milliohms and a couple hundred picohenries. If it is not well below the pass/fail criteria, a joint in the connector is probably the cause of the high reading. By moving the ground return to different joints on the connector, the bad joint can be identified. If the fault is not in the connector, the joint where the braid attaches can be checked by touching the ground point to the cable braid behind the connector and then taking a measurement. Sometimes this requires poking through the dielectric sleeving on the cable. Since this may be considered destructive, the determination on whether this is allowable must be done on a case by case basis. If it is allowed, care must be taken not to penetrate the overbraid to avoid damaging the core-wiring.

If the fault is not found at this end of the cable, it is most likely at the far end. A similar procedure to that used at the near end of the cable can then be used at the far end to isolate the fault. First, reattach the ground return at the near end to the aircraft frame, shown in Figure 24. Now disconnect the ground attachment at the far end from the cable and attach the pointed probe. By touching the probe to different points of the connector and braid, the fault can be isolated.

If the far end was attached to a host load, it will be necessary to switch the measurement and termination ends of the cable, and then retest as if measuring the near end again.

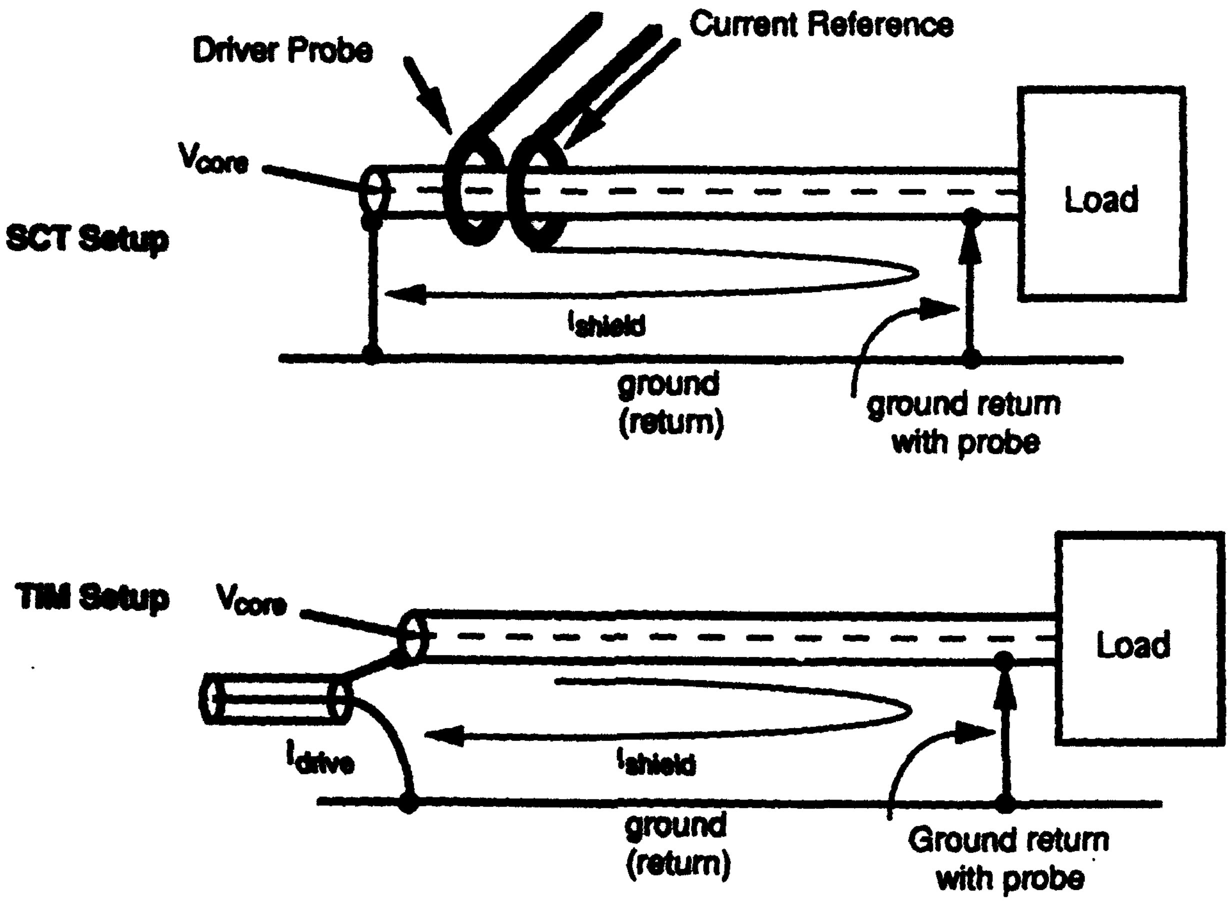

Figure 24. Test setup to locate fault with host load attached.

Now touch the point of the ground return to the cable braid just behind the connector and re-acquire data. If the measured value is above the pass/fail criteria, the fault is in the braid somewhere; otherwise, it is in the connector or the braid/connector joint. To isolate the fault further, move the ground contact point and retest. If the fault is in the braid but cannot be isolated to a single location, the braid characteristics are not sufficient to meet the pass/fail criteria. In other words, the cable was improperly designed/constructed or the pass/fail criteria was incorrectly derived.

6.0 DATA VERIFICATION/TROUBLE SHOOTING

Once a measurement has been acquired, a quick quality check should be made to filter out any obviously invalid data. Both the SCT and TIM will return error messages for most gross mistakes in the setup. The user manuals provide a trouble shooting guide for each error message. It is impossible for the testers to detect if a subtle mistakes has been made in a test measurement. The most common of these mistake is to drive current where the operator believes he is not.

The best data quality check is comparison to the expected. If data have been previously acquired on a cable, they can be used for comparison; otherwise a rough estimate for the response can be made using the following guidelines (assuming a cable about 3/4-in diameter): a single overbraid cable will contribute about 6 mΩ/m for R_{dc} and 1.5 nH/m for M_{12}; a double overbraid cable contributes about 3 mΩ/m to the R_{dc} and 60 pH/m for M_{12}; and un-faulted connectors designed for EMP protection add about 2 mΩ each to R_{dc}.

If no errors were detected by the SCT and TIM, and the acquired data do not correspond with the estimated values, there may be a problem with the setup. If the measured value is much higher than expected, it is possible that current is either being driven over a poor connection where the voltage measurement is being taken or over a makeshift load at the termination end. A quick check of the test setup can determine if this has occurred. If the setup appears fine and there is still a high reading, there is probably a fault in the cable. If the measured value is much smaller than expected, either the sense wire is shorted before the end of the cable or the current loop is shorted out before the end of the cable. A short in the core-wire is most likely to occur at the connection between the instrumentation cable and the CUT. Shorts in the current usually occur due to connectors touching a ground return. As stated before, both the SCT and TIM display error messages flagging obvious setup problems. When using the SCT, specific problems are identified by looking at raw data traces. Figures 25 through 28 show typical SCT responses for certain setup mistakes.

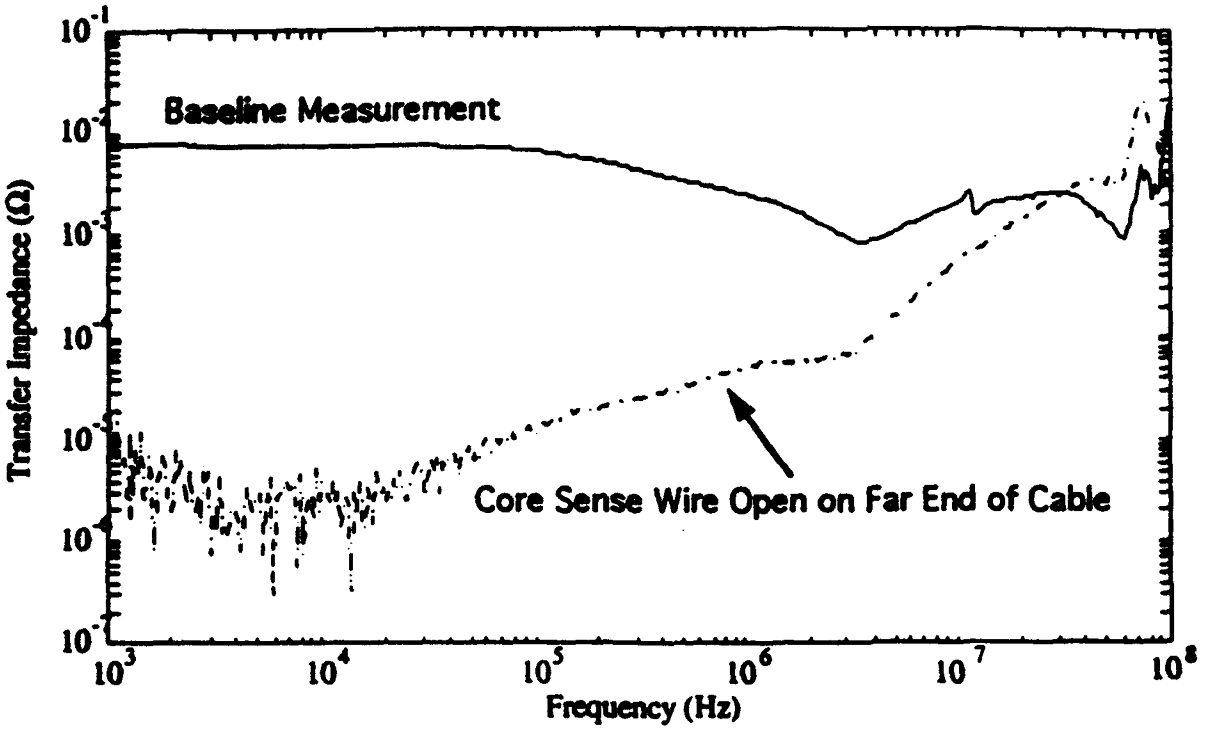

Figure 25. The SCT response when sense wire is not terminated.

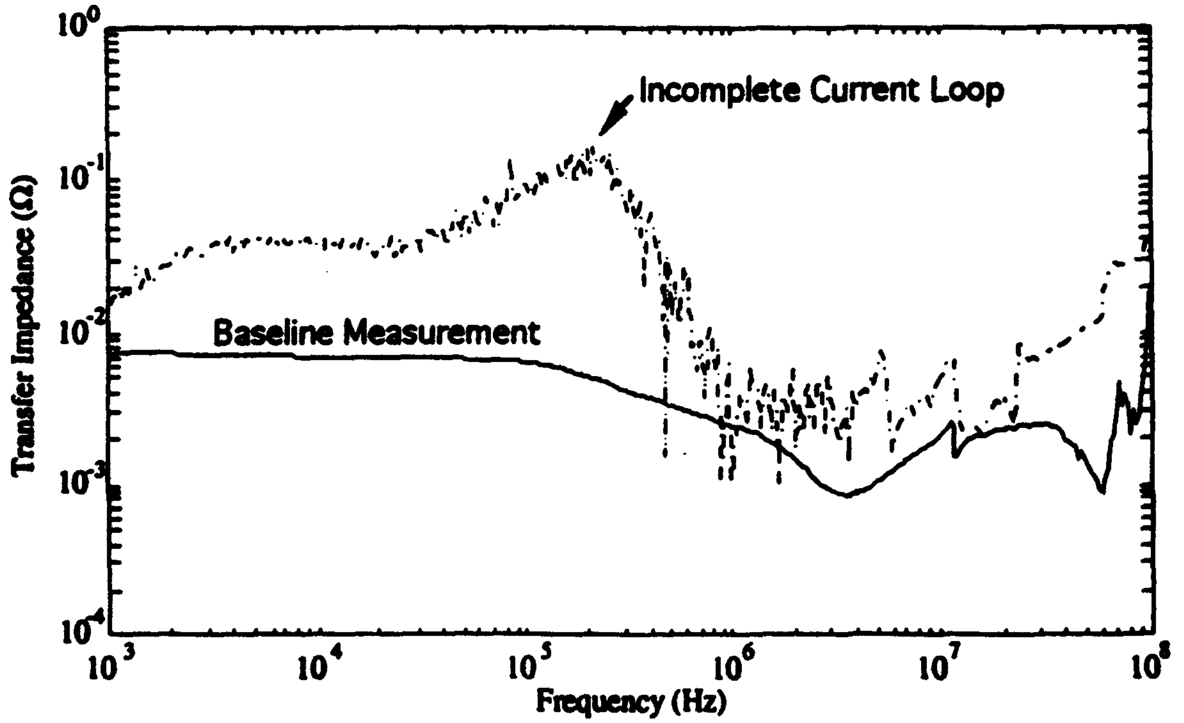

Figure 26. The SCT response for open current loop, termination end disconnected.

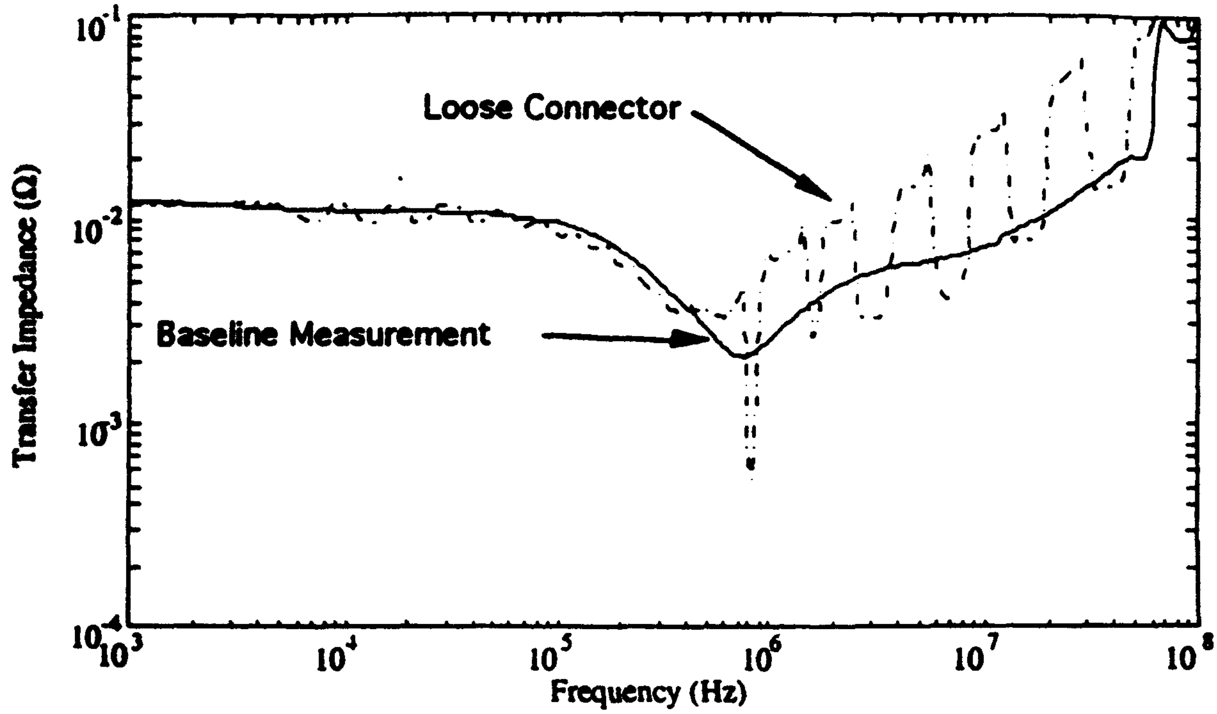

Figure 27. The SCT response for loose connector connection.

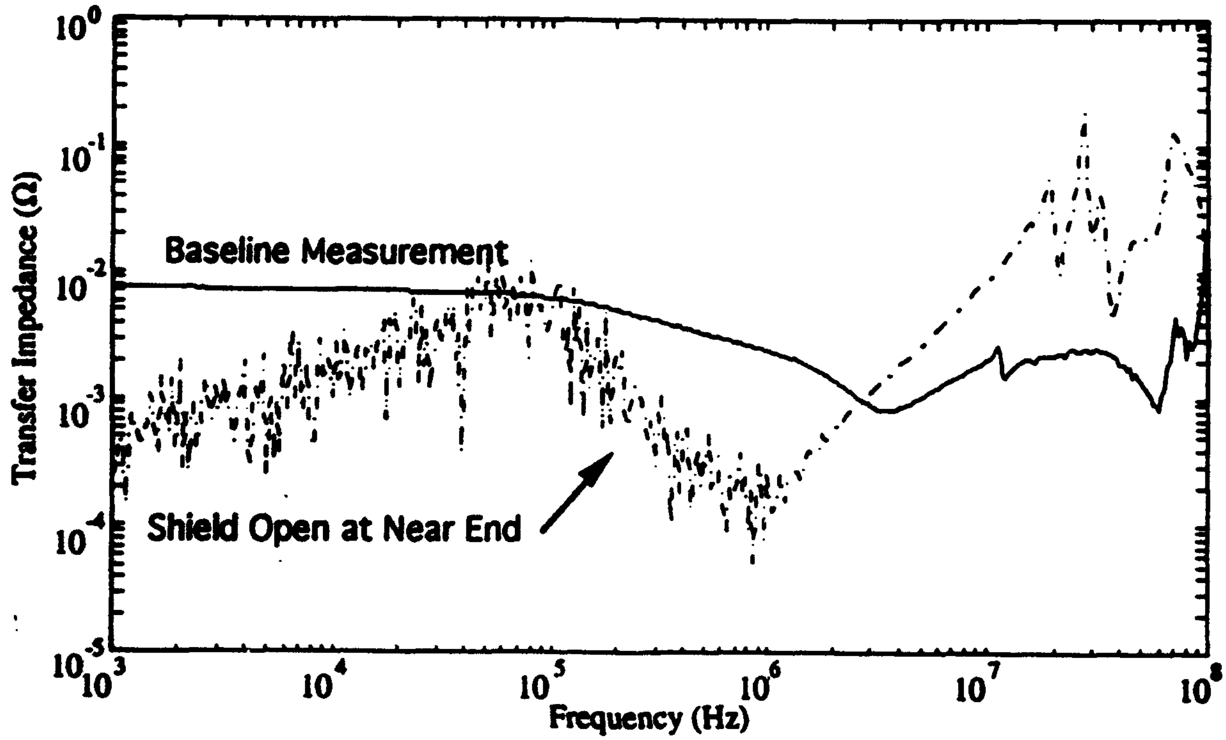

Figure 28. The SCT response for open current loop, measurement end disconnected.

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[2] Hendrickson, J.T., "Shielded Cable Tester Users' Operating Manual," TRW, Albuquerque, NM, April 1988.

[3] Coonrod, K. H. and Hendrickson, J. T., "Operation and Maintenance Instructions Transfer Impedance Meter," TRW, Albuquerque, NM, October 1992.