NEW DEVELOPMENTS IN THE PRACTICAL APPLICATION OF LOW-ENERGY HIGH-VOLTAGE WIRE DIAGNOSTIC TECHNIQUES

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New developments in the practical application of Low-Energy High-Voltage (LEHV) techniques for detecting and locating potential defects in Electrical Wiring Interconnect Systems (EWIS) are presented and discussed.

The two LEHV techniques presented are:

1. **Fast Pulse Technique[1], which initiates a high voltage, narrow width pulse down a wire. Comparison of the return signature with and without an arc over occurring allows determination of the distance to defect.**
2. **Slow Charge Breakdown Technique[2], which slowly charges the distributed EWIS parasitic capacitance to a fixed voltage. If an arc over occurs, this distributed capacitance discharges, and analysis of the return signature allows determination of the distance to defect.**

I. Background

Astronics Advanced Electronic Systems Inc.[3] has core business focus in advanced power control and electrical distribution in aircraft systems. The company has a long history in developing and manufacturing specialized test equipment for aircraft. Interest in self-diagnostic systems and other smart electronics led to the development of the Slow Charge Breakdown Technique. This technique showed early promise in detecting and locating defects in EWIS. The Federal Aviation Administration (FAA) funded Astronics (then General Dynamics AES) to develop and validate a portable device that implements this technique [1].

Sandia National Laboratories received funding from the Department of Energy, the U.S. Navy, and the FAA in the development of a LEHV technique they call Pulsed Arrested Spark Discharge (PASD) [2], which in this report is referred to as the Fast Pulse Technique. This technique also showed early promise in detecting and locating defects in EWIS.

Astronics is now under contract with the FAA to develop a portable test set that embodies these two LEHV techniques for use as an aircraft wiring diagnostics tool.

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[1] Fast Pulse technique is also called Pulsed Arrested Spark Discharge or PASD by developers at Sandia National Laboratories. Technique patented by Sandia National Laboratories and licensed to Astronics.

[2] Slow Charge Breakdown Technique is the primary technique used in the Astronics ARCSAFE© MET tool. This technique is sometimes referred to as the MET technique in other literature. Technique patented by R. Blades and licensed to Astronics.

[3] Astronics was formerly General Dynamics and formerly Primex during parts of LEHV technique development.

II. Introduction

It is well documented that aging aircraft EWIS contains defects [3]. Industry struggles to provide cost effective solutions to assist in the growing need for diagnosing aging aircraft EWIS. This paper presents the practical implementation of two LEHV techniques that can be used to detect and locate defects so that they may be assessed and the appropriate corrective action taken. As this paper describes new types of diagnostic techniques, some background comments are appropriate:

- Presently, tools exist to detect shorting defects. Ohm meters can be used to detect the presence of these defects, while Time Domain Reflectometry (TDR) tools and their variants can be used to locate these defects. TDR works very well for controlled impedance wiring, and has varying success with uncontrolled impedance wiring.
- High Potential (HiPOT) testers can detect defects prior to becoming shorts, but has no capability to locate these defects. HiPOT testers typically dump substantial energy into the defect, causing further degradation of the defect site.
- In this paper, we allude to similarities between TDR testers, HiPOT testers, and the new LEHV techniques. However, the differences are monumental and allow the LEHV techniques to detect and locate defects prior to becoming shorts. This allows an aircraft operator to detect, locate and repair defects before they progress to where they cause an equipment failure during flight.

The LEHV test set detects defects where two conductors in close proximity have their insulation material degraded in any manner such that applying a momentary high voltage between the conductors allows a momentary breakdown (induced arc). The applied high voltage will only jump a gap of up to 1/8th of an inch. Even if the detected defect is not shorting while tested on the ground, it is at risk of shorting in flight due to thermal expansion, vibration, and/or reduced atmospheric pressure. LEHV techniques only detect defects where shorting is a high probability. It does not detect cosmetic defects where there is little risk of a short developing.

Some commonly asked questions about these techniques are:

1. Question: What can LEHV do that TDR can not?
   Answer: Locate defects prior to becoming shorts. (It can also locate shorts and opens, however TDR does have this capability).
   Answer: Locate these defects with fewer problems on uncontrolled impedance wiring.
2. Question: What can LEHV do that HiPOT can not?
   Answer: *Locate* defects; HiPOT only *detects* defects.
   Answer: Energy dissipated at the defect is much less, so further degradation does not occur.
3. Question: Can I use LEHV to find the defect when my Arc Fault Circuit Breaker Trips and I can't find a short?
   Answer: Yes, this is exactly the type of defect LEHV was intended to find.
4. Question: Can I use LEHV to find intermittent defects?
   Answer: Yes, this type of defect is often forced into a persistent type of fault while high voltage is applied.

In this paper, the LEHV techniques are introduced, the practical use of these techniques are described, and performance results are presented. The ability of the techniques to locate the position of a given defect is situation dependent, but accurate results have been obtained for both controlled and uncontrolled impedance wiring.

III. LEHV Technique Introduction

Two diagnostic techniques for identifying and locating EWIS defects have been developed that use a Low-Energy High-Voltage signal that induces an arc event at a defect location. The induced arc has an energy content of about the same order as an Electrostatic Discharge (ESD) event. Analysis of the resulting traveling waves allows determination of the distance to the defect.

Fast Pulse Technique

This technique initiates a high voltage, narrow width pulse down a test harness. Comparison of the return signature with and without an induced arc event allows determination of the distance to the defect. The following is a description of the basic algorithm employed (refer also to Figure 1):

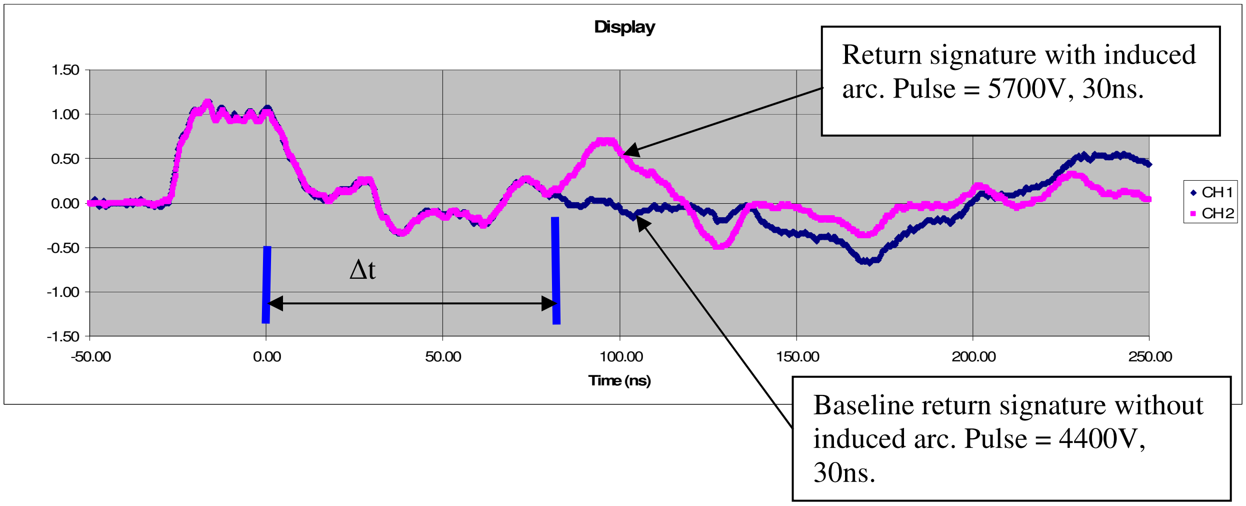
1. A baseline return signature is first captured with a pulse amplitude low enough to ensure an arc event *is not* induced at the defect. This return signature is analogous to the result obtained from traditional Time Domain Reflectometry (TDR) analysis. However, the shape of the return signature is not important, as the goal is not to match impedance features to the return signature.
2. The initiating pulse amplitude is then increased until a change is detected in the *shape* of the return signature from the baseline return signature. Up to a certain pulse amplitude, it can be expected that the characteristic impedance distribution along the harness does not vary with pulse amplitude, and hence the return signature *should be* a scaled replica of the baseline return signature.
3. When a traveling wave induces an arc breakdown at the defect, the impedance at that point starts changing, and the portion of the traveling wave that is transmitted and reflected changes as well. The return signature now departs from the baseline signature, but the departure does not occur until after a time delay equal to the time it took for the initiating pulse to travel from the test set, to the defect and cause the breakdown, and then to travel back to the test set.
4. The baseline and breakdown return signature are amplitude scaled so that the initiating pulse shape matches. By measuring the time between pulse initiation (minus pulse width) and when the signature difference first occurs, the distance to defect can be calculated using the propagation velocity of the harness.

Since the fast pulse technique looks only at the difference in return signatures to identify and locate defects, it can be successfully used with uncontrolled impedance wiring. It does not attempt to identify impedance profiles by analyzing the shape of the return signature, which is the issue that most TDR techniques need to overcome. This technique has successfully located defects past harness branches, where the slow charge technique does not work well. The technique works very well with controlled impedance co-axial and twisted pair wiring.

$$d_{fault} = \frac{\upsilon_{propogation} * \Delta t}{2}$$

$where:$

d_{fault}	Distance to fault
$\upsilon_{propogation}$	Average harness propoagation velocity
Δt	Time from initiating pulse falling edge to change in return signature



Return signature with induced arc. Pulse = 5700V, 30ns.

Baseline return signature without induced arc. Pulse = 4400V, 30ns.

Figure 1. Actual Fast Pulse Technique Capture on 50 foot, 12 conductor bundled cable, with defect at 25 feet. Note that the return signatures are amplitude scaled as described in the accompanying text.

The primary challenge with the Fast Pulse Technique is in getting the desired pulse shape to the defect to cause the arc over. At each impedance discontinuity, the signal passed can vary from twice the incident voltage to 0V, depending on the ratio of the characteristic impedances. Characteristic impedances along a harness can typically vary from 10's of ohms to 100's of ohms. There are also many opportunities for lumped parasitic capacitive and inductive loading to occur. The voltage transmitted through a characteristic impedance discontinuity is:

$$V_{Transmitted} = \frac{2 * Z_2}{Z_2 + Z_1} * V_{Incident}$$

The Fast Pulse Technique is quite successful if an initiating pulse with sufficient amplitude to induce an arc event makes its way to a defect. Sandia has proposed a wide 30 ns initiating pulse to increase the likelihood of the full amplitude of the pulse in reaching the defect location for 100 foot wire runs [2]. This increased pulse width is accompanied by a distance correcting technique that tends to consistently cause the arc over to occur at the trailing edge of the incident pulse. This technique slowly increases the initiating pulse amplitude; the assumption is that if the previous pulse didn't induce an arc, and the breakdown criteria has a pseudo volt*second relationship, and the next pulse induces an arc event, it can be assumed the defect arced at the instant the trailing edge of the pulse arrived.

Slow Charge Breakdown Technique

This technique slowly charges the test harness parasitic capacitance to a fixed voltage. If an induced arc event occurs, the distributed capacitance discharges, and analysis of the return signature allows determination of the distance to defect. There is no return signature if a breakdown does not occur. When the breakdown occurs, the voltage at the defect collapses and initiates a traveling wave that echoes back and forth between the ends of the cable and the defect location. These waves initiate at the defect and travel down the harness, reflecting at impedance boundaries. Under ideal test conditions, the traveling waves will produce a return signature at the end of the harness that is square in nature, with a period proportional to the distance to defect. The test set determines the distance to defect by detecting the time between the first and second edge of the breakdown waveform voltage at the end of the harness and using this value to determine the distance to the defect.

Figure 2 shows the ideal breakdown waveform seen at the test set. First, assume the harness wire is charged to some voltage V. At time (A), an arc breakdown occurs somewhere down the length of the wire. A summary of the wave events that occur is:

Time (A) - Arc occurs. Not sensed at test set until time (B)
Time (B) - Wave arrives at test set and sensed voltage reverses. Wave travels back towards defect.
Time (C) - Wave arrives back at defect.
Time (D) - Wave arrives back at test set.
Time (E) - Wave arrives back at defect.
Repeats until all of the energy in the cable dissipates.

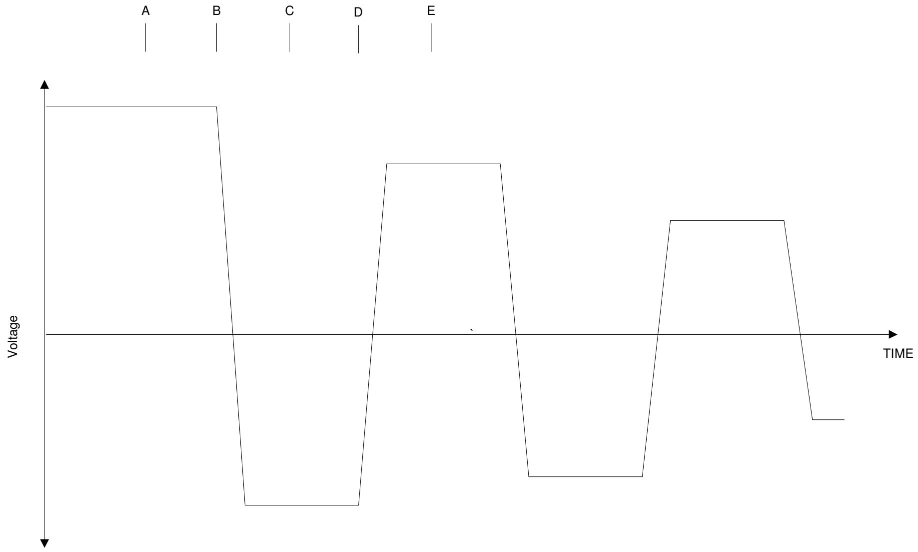


Figure 2. Idealized Breakdown Waveform Seen at the test set.

Test Set signature is AC coupled and inverted when compared to this ideal signal.

Note the waveform depicted in Figure 2 is only valid at the open ends of the harness.

- At the defect, the voltage will be much closer to 0V after the initial arc, with the voltage developed being a function of the arc impedance and defect current.
- At points midway between the defect and the test set, the wave will step from +V, then to ~0, then to –V, then to ~0, then to +V, then to ~0, etc.

If the propagation velocity of the cable is known, the distance to the defect can be determined by measuring the time between the edges at time (B) and at time (D). This is the time it takes for the wave to travel from the test set back to the defect, and then back to the test set. The total distance traveled is given by:

$$d_{total} = \upsilon_{propogation} * t_{D-B}$$

The distance from the test set to the defect is half the total distance traveled, so:

$$d_{fault} = \frac{d_{total}}{2} = \frac{\upsilon_{propogation} * t_{D-B}}{2}$$

The Slow Charge Breakdown Technique works very well with controlled impedance co-axial and twisted pair wiring. The technique has had good success with uncontrolled impedance wiring, but experiences difficulty under the following scenarios:

1. Attenuation Loss – Initial discharge edge is present and well formed, but the anticipated return echo is never received.
2. Dispersion – Initial discharge edge is present and well formed, but the subsequent echo edge is significantly rounded, which results in an uncertainty of the TDR measurement, and a significant error in the distance calculation results.
3. Branches in harness – Multiple traveling echo edges confuse the technique, as there is uncertainty which edge (if an edge is even discernable) to use for the TDR measurement.

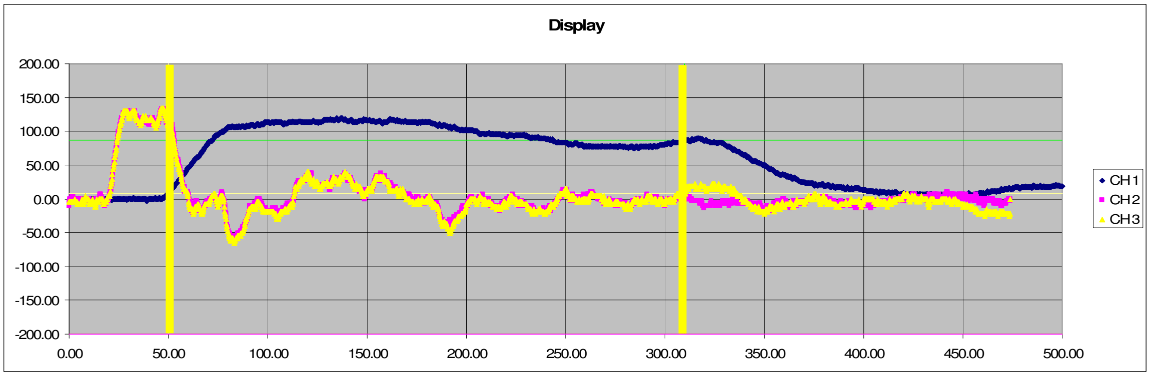
Fast Pulse and Slow Charge Breakdown Technique Together

Figure 3 shows an example of the two techniques used on the same harness. This is a harness fabricated by Sandia National Laboratories and installed in their 737 test bed aircraft. This defect is on wires 13 and 14 on their harness #570. A summary of the test results are given in Table 1. Note: These particular results favor the Slow Charge Technique, but this is likely due to the default propagation velocity factor being slightly underestimated. In general, the Fast Pulse Technique has proven to be more accurate, since the point of signature difference is more precisely identified than the beginning of the reflected edge for the Slow Charge Technique.

Adapter Length = 33 inches
Assumed Prop velocity factor: 0.63

Wires	**Breakdown Voltage**	**Slow Charge**		**Fast Pulse**		**Actual Distance**
		Δt	**Distance**	**Δt**	**Distance**	
13, 14	~2100 V	267 ns	82.7 ft	260 ns	80.5 ft	80+ 2.75 ft adapter length

Table 1: Aircraft Harness #570 DTF Measurements



CH 1 = Slow Charge
CH 2 = Fast Pulse, 0VDC bias, peak = 1678V, no breakdown
CH 3 = Fast Pulse, 0VDC bias, peak = 3102V, first breakdown with 178V steps

Waveforms vertically scaled, and amplitude has no physical meaning.
Waveforms shifted to align t=0 (yellow cursor) for technique timing calculation

Δt for Slow Charge Breakdown = 267ns
Δt for Fast Pulse = 260ns

Figure 3. #570, Wires 13 And 14, Slow Charge Breakdown and Fast Pulse With 0vdc Bias. Defect at 80 feet.

IV. LEHV Practical Use

Practical Implementation of LEHV

Aircraft operators desire a portable diagnostic tool that can be used by unskilled personnel. Repairs need to be made quickly, as large assets are tied up when otherwise good aircraft are grounded. Without the introduction of a new type of diagnostic tool, aircraft maintenance personnel have limited options in identifying and locating defects in aircraft wiring. It is anticipated that a test set armed with the capabilities of the introduced LEHV techniques can guide the operator to a simple repair rather than requiring the replacement of an entire aircraft harness section.

Both of the introduced LEHV techniques come with different strengths and weaknesses. However, they can be combined into a test methodology that incorporates the best results from each technique. Up to now, we have described the techniques with general regard. The following section is based on the specific implementation we chose in our LEHV test set, as it introduces several subtle and important features that are not necessarily features of the basic techniques.

The Slow Charge Technique is a good screening test, as the slow rise time of the applied signal acts a lot like a traditional HiPOT test used to screen for weak dielectric[4]. Unlike many HiPOT tests, the energy applied is much less, therefore reducing the possibility for further degradation that could otherwise occur[5][1]. When an arc is induced at a defect, the return signature is analyzed, and the distance to the defect can often be determined. The return signature has been shown to provide useful distant to defect information for many practical wiring scenarios, including instances of uncontrolled impedance wiring. This technique does not have the same level of accuracy and robustness as the Fast Pulse Technique when dealing with impedance discontinuities.

The Fast Pulse Technique has many similarities with traditional TDR, but does not demand the same requirement of identifying features by the relative shape and amplitude of the return signature. As described before, only the point in time where the signature difference begins to occur is important in locating the defect. Although it is not the better screening technique, it has more accuracy and ability in precisely locating a defect. It also has the ability to locate defects past wire branching, where the Slow Charge Technique quickly runs into difficulty.

A typical session with the LEHV Test Set might play out as follows:

- Perform a DC scan using the Slow Charge Technique to locate potential defects. Insulation resistance and wire capacitance are reported if no arc event occurs. This screening is facilitated by a custom high voltage sequencer developed for this purpose.
- A Slow Charge return signature is captured if an arc is induced at a defect. The software calculates the distance to the defect. If a distance result was not obtained, or if the operator wishes to attempt an improved solution, the Fast Pulse Technique can be used.
- In general, it is assumed the Fast Pulse Technique will be used to attempt an improved distance to defect solution. [6]

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[4] Compare the well controlled voltage applied along to the harness with this technique vs. the uncertain distribution of pulse peak voltage that can occur along the test harness with the Fast Pulse Technique. When a breakdown occurs with the Slow Charge Technique, the voltage withstand capability at the defect is well defined, and the severity of the defect can be judged.

[5] The capacitance of the test harness is measured prior to application of the high voltage stimulus. The test voltage can than be limited so that a predetermined energy limit is not exceeded.

[6] A variation on the Fast Pulse technique is to add a DC bias just prior to initializing the fast pulse. This has been shown to allow an induced arc at a lower peak pulse voltage, with some introduced degradation in accuracy. The benefit is that defects can be located on longer harness or further beyond branches than would otherwise possible.

Skill Level for Operation

One complaint of TDR type equipment is that they require too much specialized skill to use, and different users can get different results. Many manufacturers have responded by fielding devices that require little more than pressing a button and reading a distance off of a display. There are many test scenarios where accurate results can be obtained with this type of rudimentary interface. For more challenging wiring diagnostic problems (i.e. branched wiring), a skilled operator can manage an improved result if more features are available from the test set.

The Astronics LEHV Test Set is controlled by automated software, with the simplest interface requiring a start and stop command[7]. If a defect is located, the distance to the defect is automatically displayed. The test set can be used with a two wire flying lead approach, or with an optional sequencer designed to accommodate the LEHV test pulses. The sequencer allows the complete diagnostic of a complete harness with the touch of a button. Very good results have been obtained using this simple interface, even on uncontrolled impedance wiring.

The world of wiring diagnostics can get quite complex and a trained user can often improve the diagnostic results with a more sophisticated interface. The user can optionally bring up displays of the digitized return signatures, and adjust pre-placed cursors. The digitized displays are designed for ease of use. Interpretation of the return signatures is not nearly as technically involved as is required for traditional TDR diagnostics; the key features are easily identified, and when a cursor is moved to an identified feature, all distance calculations are automatically updated. Although it is helpful, a technical background is not required for successfully using these digitized displays. Even though it is often not required, some practical reasons for viewing the digitized displays are to:

1. Assess the accuracy of the automatically generated solution – at a glance the user can determine how well pronounced the signature feature is at the pre-placed cursor.
2. The human mind is significantly more adept at pattern recognition than software code. Signature irregularities that can confuse a computer algorithm are easily recognized and corrected by the user. The user corrects the distance to defect calculation by simply moving the cursor to the correct location.
3. When the defect must be found, and the automated software is not able to distinguish the distance from the return signature, it may still be possible for the user to resolve a solution(s). For some users, it might prove beneficial to be able to investigate several uncertain possibilities than to settle for having no solution at all.

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[7] Assumes default test parameters are used or have otherwise been set to the desired value. These values control attributes such as the maximum test voltage to use and propagation velocity of test harness. When using the optional sequencer, test profiles can be written and stored as is typically done for traditional wire harness testers.

Packaging for Portability and Automation

The primary goal in the development of the LEHV test set was to take the DC Scan technique (used in the pre-existing Astronics MET tool) and marry it to the fast pulse technique (Sandia's PASD technique) in a portable, automated test set.

We were successful at incorporating Sandia's laboratory setup[8] into an automated test set, shown in Figure 4. This test set consisted of a custom high voltage pulse generator, a return signature digitizer, along with other circuitry to implement the Slow Charge Technique, resistance measurement, and capacitance measurement functions. Full automation and control is provided through a wireless RS232 link with a personal computer (PC). Software was written for a PC that automates the performance of the test, digitization of the return signature, analysis of the return signature, and display of the test results. Significant effort was placed in developing an automated high voltage sequencing function. This sequencer provides tremendous advantage in timely fault identification in multi-conductor harnesses. Attempting to test a single wire against all other wires using a simple two wire tester is a formidable task.

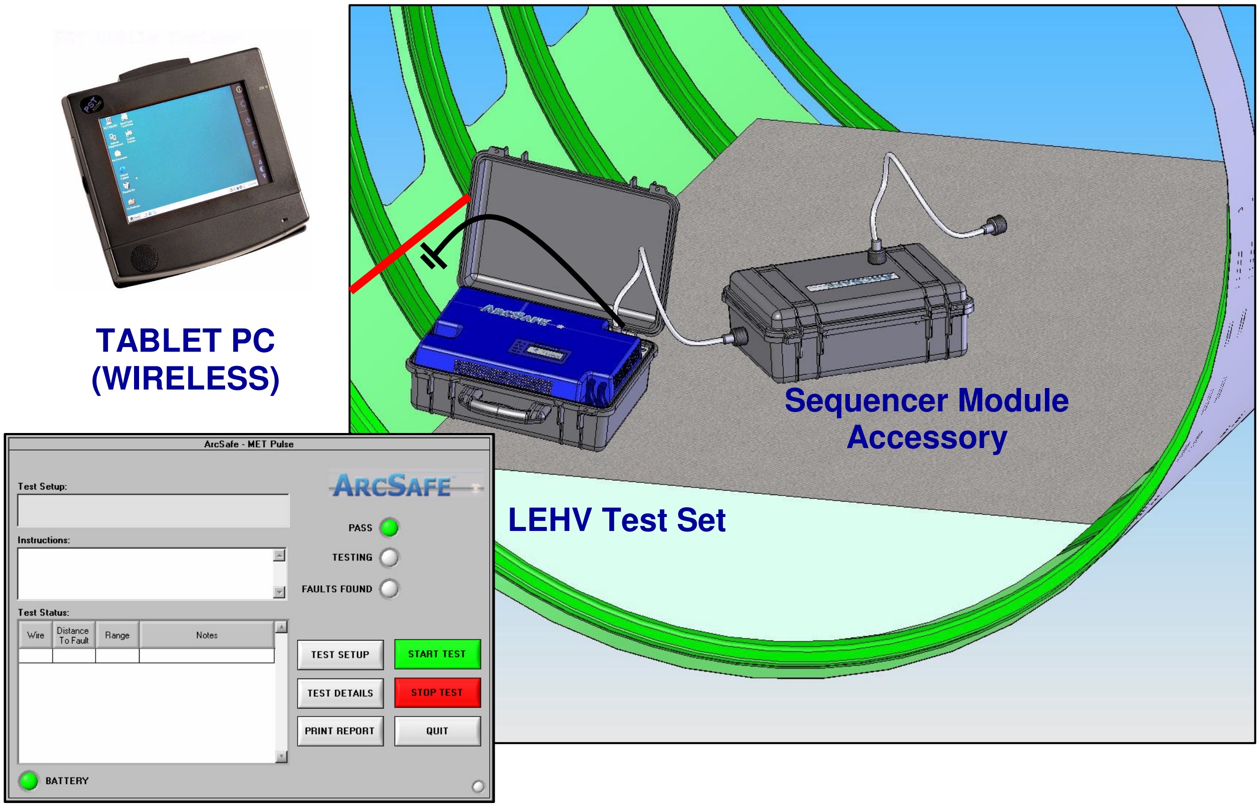

Figure 4. LEHV Test Set and Software Control Panel

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[8] Sandia used their laboratory set up to explore the technique and its variations. The implementation consisted of a rack mount high voltage supply and oscilloscope, and a pulse generator submersed in oil for high voltage insulation. The return signatures captured by the oscilloscope were copied to a floppy, and manually manipulated and analyzed.

V. LEHV Performance Results

For both LEHV techniques, performance on controlled impedance wiring is very precise, and is not presented in this paper. The investigation performed at Astronics has focused on performance on uncontrolled impedance wiring, including branched wiring.

Controlled impedance wiring is achieved when care is taken to ensure a uniform ratio of unit inductance to unit capacitance along a length of the conductor. Due to cost and weight, controlled impedance wiring is only installed when signal integrity requires it, and the bulk of aircraft wiring is of the uncontrolled impedance variety. It is recognized that the LEHV techniques will not successfully locate defects on all types of aircraft wiring harnesses. However, the LEHV techniques can locate defects on a variety of uncontrolled impedance wiring.

LEHV technique performance is a strong function of the harness under test. Distance to defect accuracy can range from within inches to undetermined when considering the entire range of possible wiring configurations. However, accuracies within a couple of feet for a 100 foot distance to defect are often achieved on uncontrolled impedance wiring. This paper takes the following approach to presenting performance results:

1. Present baseline data on an uncontrolled impedance aircraft harness configuration where response is good, and quantify the significant features of this harness. This baseline harness was constructed using Boeing wiring specification D6-54446, and should be representative of a typical aircraft wiring harness.
2. Comment on several gross features of this harness and discuss the relative impact on the distance to defect accuracy.

Table 2 provides a summary of the baseline performance of the LEHV techniques on a 12 conductor, 50 foot harness, with a defect located at 25 feet. Figure 5 shows the typical test set up for the testing presented in this paper.

In Sandia’s reporting on the accuracy of the Fast Pulse Technique (PASD in their reports), the propagation velocity was adjusted for each harness [2]. This was accomplished by timing the transit time of the initiated pulse against the open terminated end of the harness and dividing by twice the known length of the harness. The reported accuracy was on the order of inches, and is an indication of how accurate the technique can be. However, the accuracy of the distance to defect calculation will vary directly with the accuracy of the propagation velocity value used in the calculation. We recognize that in general a user might not have access to such technical information as the propagation velocity of test harness, and might have only limited knowledge of a length of the harness. Also, under some scenarios, the initiated pulse reflection against the open end of the harness may not discernable.

In calculating the results for this paper, we assumed a single default propagation velocity of 0.63 of the speed of light[9], and used it for all of our distance to defect calculations. Using a default value is more representative of how the test set will be used in practice, even though it reduces the reported accuracy of the techniques. This default propagation velocity is in the ballpark of what is commonly encountered in uncontrolled impedance aircraft wiring. If a user has a more accurate estimation for his particular harnesses, this value can easily be entered into the test software set up screen. When applicable, the LEHV test set software includes an algorithm to assist the user in improving the propagation velocity estimation using a technique similar to what Sandia used in their investigations.

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[9] It should also be noted that this was the propagation velocity of the baseline test harness. To extrapolate the presented result accuracy to other harness configurations, the operator should consider how well the actual harness propagation velocity matches the estimated value used in the distance to defect calculation.

Voltage Required for Gap Breakdown (V)
(As sensed at the Test Set, Peak Value Reported for Pulses)

	Defect Gap		
MODE	**0.01”**	**0.03”**	**0.05”**
Slow Charge	2498	3235	4984
Fast Pulse	2900	5546	8690
Fast Pulse on DC Bias	(Pulse / DC) 2059 / 2274	(Pulse / DC) 2817 / 2876	(Pulse / DC) 4415 / 4448

Average Reported Distance to Fault (feet)

	Defect Gap Length		
MODE	**0.01”**	**0.03”**	**0.05”**
Slow Charge	26.3	26.1	27.4
Fast Pulse	24.1	25.2	24.7
Fast Pulse on DC Bias	22.5	25.1	23.3

Standard Deviation of Reported Distance to Fault for Seven Runs at each Gap Setting (feet)

	Defect Gap Length		
MODE	**0.01”**	**0.03”**	**0.05”**
Slow Charge	1.4	1.3	1.4
Fast Pulse	1.1	1.5	0.8
Fast Pulse on DC Bias	1.8	1.2	0.8

Notes:

1. Propagation velocity factor used was constant for all calculations: 0.63.
2. Sample size: 7 data points
3. Breakdown voltages indicated are those obtained during testing, but in general depend on atmospheric pressure, humidity, etc.

Table 2. Summary of LEHV Technique Baseline Performance on 12 Conductor, 50 Foot Harness with ETFE type insulation, with a Defect at 25 Feet.

All of the harnesses evaluated were secured 3” from the ground plane. The harness bundles were built in accordance with Boeing Spec D6-54446. Defect types used in the testing have chafed insulation which is typical in wire damage. The arc length was adjusted with feeler gauges to the desired length. The fixture used to hold the gap in place during testing is shown.

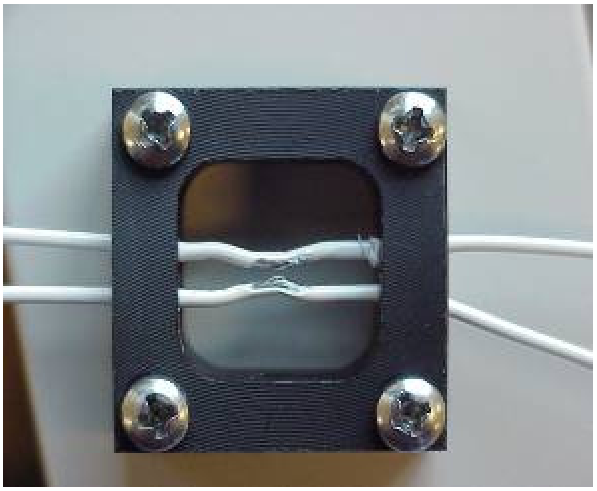

Figure 5. Typical Test Set Up for the Testing Presented in this Paper

Impact of the variation of several gross features on the baseline harness performance:

1. Proximity to ground plane – The effect of the ground plane on performance was evaluated with a 12 conductor, 50ft harness. Initially data was collected with the harness located 3” off of the ground plane, then the test was repeated with the harness 0” off of the ground plane. No significant difference in performance was observed. In general, it is expected that a ground plane can affect the performance results, as this plane provides an additional transmission line structure for the induced waves to travel along. However, the tight bundling of the test harness (as is standard practice in aircraft wiring) mitigated the tendency of the induced waves to couple between itself and the ground plane

2. Connectors and terminal blocks - All three modes were able to detect faults located beyond three 41 pin circular connectors at distances of 25 ft, 75 ft, and 110 ft. See Figure 6 for a diagram of the test set up. Presence of connectors did not have a significant effect on the accuracy of the distance to defect calculation. Additional testing using a terminal block in place of a connector had no perceivable impact on accuracy. This testing also shows the immunity of the LEHV techniques to localized characteristic impedance variation. However, when the harness was manipulated so that large, untypical loops were formed between the conducted paths of the induced pulse, the technique effectiveness could be severely impacted.

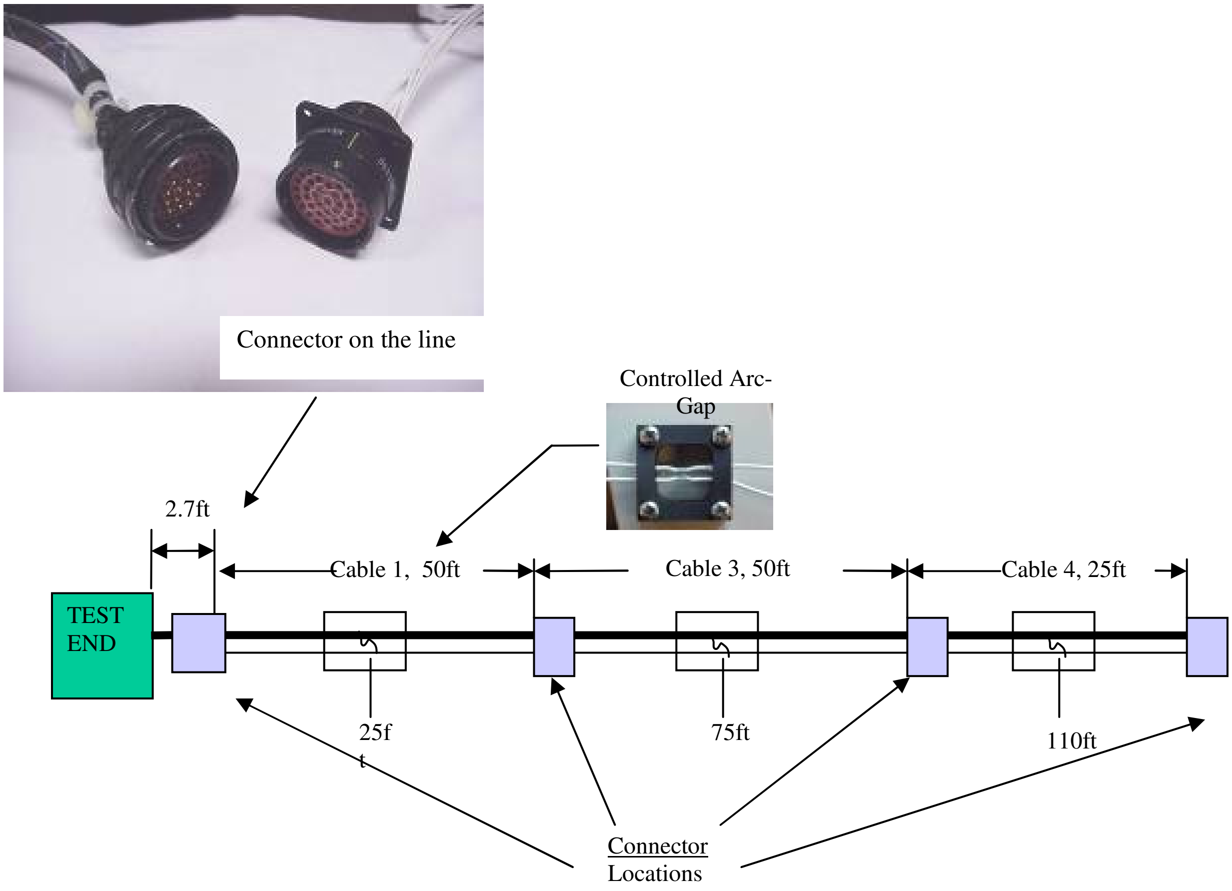

Figure 6. Multiple Connector Test Set Up

3. Branching – Branching presents a significant challenge to any TDR based technique. However, accurate results can be obtained with the LEHV techniques on some branched harnesses, as described below. The Slow Charge technique can work on branched harnesses, but the distance to defect result is not accurate if a branch lies between the test set and the defect. The Fast Pulse Technique can locate defects past a branch, but the success of applying a pulse with a high enough peak to induce an arc at the defect is greatly reduced since the pulse energy decreases at each branch location. As a representative example, a branched harness was assembled, and the ability of each technique to locate the defects was assessed. The harness configuration is represented in Figure 7.
    a) With the Slow Charge Technique, the presence of all defects was detected but the distance to defect measurements were only successful the 25ft, 59ft and 61ft defect locations. Multiple reflections from the branches cause deterioration of the return pulse edge and caused uncertainty in the distance calculation.
    b) With the Fast Pulse Technique, distance measurements were successfully performed at the 25ft and 59ft defect locations. With this particular complex harness configuration, the 12-15kV pulse amplitude was not sufficient to induce an arc at a defect past a branch in the harness. When the technique is not successful, it is because the initiated pulse was not successful at inducing an arc, not that the incorrect results were obtained.
    c) By applying a DC bias prior to initiating the fast pulse, three additional defects were detected at the 61ft, 75ft, and 80ft defect locations. Return signatures from the 91ft and 110ft defect locations were not detected due to significant attenuation of the pulse at the branches. Differences from the 75ft and 80ft defect locations between the breakdown and baseline waveforms were often too low in amplitude to be detected. Although these particular defects were not detected on every attempt, once they occurred they were identified and located.. At the 61ft defect location, the standard deviation increased to 2.3ft, at 75ft it was 2.0ft, and at 80ft standard deviation was the highest at 5.2ft.

Sometimes the difficulties with branching can be overcome by attaching the test set to a different connector, so that the defect is now between this new connector and the branch.

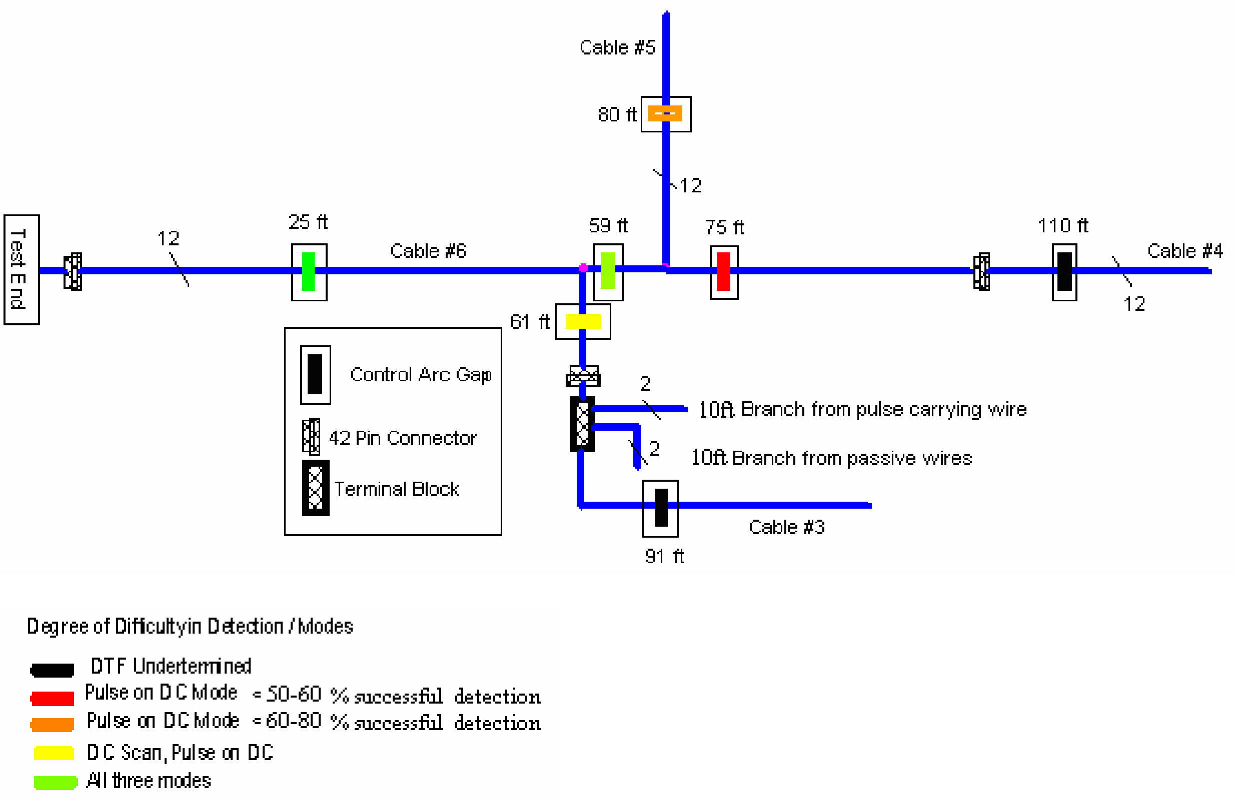

Figure 7. Performance of LEHV techniques on a Branched Harness

VI. Conclusions

Astronics continues to mature its LEHV technique based portable test set platform. This test set is targeted specifically at satisfying the aircraft industry's need to diagnose the EWIS in its aging aircraft fleet. Its ability to locate arc defects provides the aircraft maintenance community with an ability that did not previously exist.

The test set detects defects where two conductors in close proximity have their insulation material degraded in any manner such that applying a momentary high voltage between the conductors allows a momentary breakdown (induced arc). The applied high voltage will only jump a gap of up to 1/8th of an inch. Even if the detected defect isn't shorting while tested on the ground, it is at risk of shorting in flight due to thermal expansion, vibration, and/or reduced atmospheric pressure. LEHV techniques only detect defects where shorting is a high probability. It does not detect cosmetic defects where there is little risk of a short developing.

In this paper, the LEHV techniques were introduced, the practical use of these techniques were described, and performance results were presented. A summary of the LEHV test set attributes are:

- Excellent accuracy for controlled impedance wiring.
- Accuracies within a couple of feet for a 100 foot distance to defect are often achieved on uncontrolled impedance wiring.
- Accuracies can be improved to within inches if a more accurate propagation velocity is determined. Before attempting to improve the accuracy, the user should consider with what precision the distance to defect can be converted into a physical location on the aircraft.
- Connectors, terminal blocks, and ground planes have not had a significant impact on technique accuracy.
- Successful fault diagnosis can be achieved on branched harnesses. Other systems have tremendous difficulty with this task. Best use of the test set (i.e. testing from multiple termination points) will help with more complex harness diagnostics.
- Only techniques suitable for locating Arc Fault Circuit Interrupter (AFCI) trip fault locations
- Sequencing function provides tremendous advantage in timely fault identification
- Slow Charge Technique provides wire health monitoring (insulation resistance, capacitance measurement, breakdown voltage, etc.)
- Open/Short diagnosis.

VII. References

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[3] The Intrusive Inspection Working Group, C. Smith, Chairman, "Transport Aircraft Intrusive Inspection Report", December 29, 2000.