# Unraveling the Cannot Duplicate and Retest OK Problems by Utilizing Physics in Testing and Diagnoses

Louis Y. Ungar
A.T.E. Solutions, Inc.
8939 S. Sepulveda Blvd., Suite 110-779
Los Angeles, CA 90045
Phone: 310-822-5231, Email: LouisUngar@ieee.org

Larry V. Kirkland
WesTest Engineering Corp.
810 W. Shepard Ln
Farmington, Utah 84025
Ph: 801-451-9191 ext 124, Email: LarryK@westest.com

***Abstract*** *– Automatic Test Equipment (ATE) has been traditionally tasked with supporting field returns. This task includes verification of proper operation and in the alternative to diagnose and provide repair instructions. While ATE has done reasonably well to certify a unit under test as ready for issue (RFI), it has been hampered by diagnostic complications in many instances. Two such complications, Cannot Duplicates (CNDs) and Retest OKs (RTOKs) are particularly troublesome because of the ATE's limited vocabulary of Pass/Fail or Good/Bad determination. When a unit under test (UUT) is returned from the field labeled faulty, yet passes on the ATE, a RTOK, additional testing and diagnosis is required, despite the "Pass" result. Similarly, when multiple runs on an ATE provide different results, a CND, the ATE (in conjunction with the test program set –TPS) is not sufficient to unravel the conflict. In such instances, the ATE must be supplemented with various tools that characterize the physics of the circuit in order to assist in diagnoses. This paper will highlight a number of failure modes that can create CND and RTOK, and examine tools that can be used instead of or in conjunction with ATE to help diagnose and repair units that experience such phenomenon.*

***Keywords*** *– diagnoses, diagnostics, cannot duplicate, retest OK, false alarms.*

## I. INTRODUCTION

Diagnoses are complicated by testability issues in general [1-5], but the test results coming form CND and RTOK events offer an extra layer of confusion. General testability and diagnostic solutions have been published [6-10] but little is available on these two phenomenons. Moreover, the test program set (TPS) or built-in test procedures anticipate only catastrophic and stable faults that will always result in a predictable manner. It would not be feasible for TPS developers to plan for exotic failure modes that would result in CND and RTOK events. [11-14] As a result repair technicians are often left confused about test results in general and diagnostic help in particular.

Relying on the technician's judgment to diagnose root causes of failures can lead to a shotgun approach to repair. This can be quite costly when one considers the consequences.

## II. DEFINITIONS

There is a widespread confusion and perhaps disagreement of some of the terminology we use in this paper. We will use the following definitions:

**Cannot Duplicate (CND) -** An operationally observed/recorded system malfunction (for example, by BIT or on-line monitoring means) which maintenance personnel were unable to duplicate. (The CND occurs at the same level of maintenance where the malfunction was originally observed.) [15]

**Retest OK (RTOK) -** A unit under test that malfunctions in a specific manner during operational testing, but performs that specific function satisfactorily at [the next] level maintenance facility.

For example, a board in a box (line replaceable unit or LRU) is found to be faulty. When the board (shop replaceable unit or SRU) is swapped, the box (LRU) is "fixed." The suspected board (SRU), however, passes the board test and is labeled RTOK. [16]

**False Alarm (FA)** – Per MIL-STD-2165, it is a fault indicated by BIT or other monitoring circuitry where no fault exists. [1] We recommend a more pragmatic definition that centers on what is actually done as a result of a False Alarm: A call for a maintenance action when none was needed. Under this definition a real fault that went away (for whatever reason), or a fault that could not be verified at test and subsequently worked in the system, would also be considered a False Alarm. A False Alarm is a CND event, though not all CND can be categorized as a False Alarm. [2]

**Misdiagnoses or False Pull (FP)** - Diagnoses that incorrectly identified the fault. Misdiagnoses can lead to replacing the wrong replaceable unit or False Pulls. A False Pull usually results in a RTOK event. [17]

**Diagnostic Ambiguity** - The situation that arises when diagnostic is able to detect a fault, but the smallest fault group to which that fault can be isolated contains more than one repair item. In this case some good units will be delivered to the next level of assembly and when these good units pass the ATE test, they will be rendered RTOKs.

With the above definitions in mind we can better explore the subject at hand. Figure 1 illustrates CNDs and RTOKs events.

When a built-in test (BIT) fails or an operator reports a failure, some independent test is run off line to verify the failure. If the failure cannot be verified (i.e. duplicated) a No Fault Found (NFF) situation is recorded and this event is considered to be a CND.

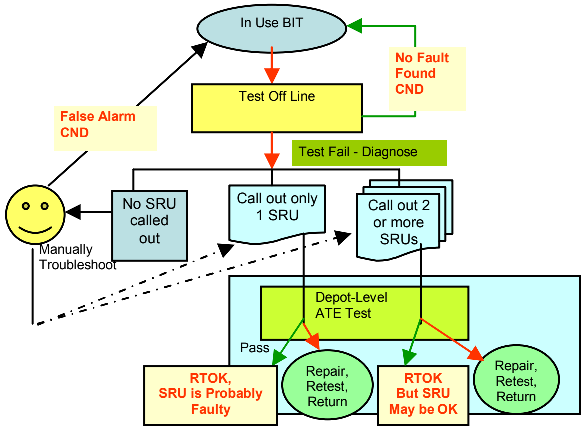


Fig. 1. CND and RTOK events in the Field and in Depot-Level ATE Test

The Off Line test of the system provides diagnostics if the test fails. Generally, it will diagnose the system (LRU) to an ambiguity group consisting of some number of SRUs that are suspected of being the root cause of the failure. The suspected SRUs are swapped and the LRU generally goes back into operation, while the SRUs removed go to a Depot Level ATE for test and repair.

The exception case, when the test fails but either no SRU or groups of SRUs can be isolated as the root cause, a manual troubleshooting takes place, resulting in a technician deciding what and how many SRUs to swap. Often, the technician runs the test several times and may not be able to repeat failures. This could be called a False Alarm, which is a CND event and the LRU could be put back in operation without replacing any of its SRUs.

If the diagnosis is precise, there will be only one SRU called out and that SRU and sent to the Depot Level ATE tester. If this SRU passes the first time a RTOK can be recorded. Sending the SRU back to the field would be futile. Evidently something is wrong with the SRU, even if it PASSes the Depot Level ATE test, but without a FAIL, the test program set (TPS) does not perform diagnoses. Clearly, there is a need to unravel such an RTOK.

In a less precise case of diagnosis, more than one SRU is called out, even if there really is only a single failure and therefore only one of the SRUs called out is truly faulty. The Depot Level ATE should pass those SRUs that were part of the ambiguity group (but not really faulty). These SRUs are also RTOKs, though they are more likely to be good then in the case where only a single SRU was called out.

While it may be practical to label SRUs that were removed as the sole cause of the LRU failure, it is not easy to keep together SRUs that were removed from the same LRU. So any SRU that passes the Depot Level ATE test the first time should be treated as an RTOK and should undergo extensive diagnoses.

Now we will examine the symptoms and causes of CNDs and RTOKs.

## III. TYPICAL CND AND RTOK SCENARIOS

A CND is simply an intermittent failure that doesn't appear on all subsequent running of the same test. In its simplest form it fails a test and passes it the next time the same set of tests are run. In a more complicated situation not all fail results are from the same test and therefore diagnoses are different each time a test fails. So a CND even at the LRU level may require a great deal of time and expertise from the technician and little, if any help is available from the ATE or BIT.

We can also have a complicated RTOK scenario where the RTOK is a result of the combined effect of more than one SRU interacting in a manner that creates a failure, while each SRU alone is OK. While such exotic cases exist, most CND and RTOK scenarios result from simple failures, as we discuss below.

### *A. Causes of CND and RTOK*

Almost any failure can exhibit itself as a CND or RTOK at one time or another. There are a number of failure types, however, that are more likely to result in CND and RTOK situations. They include the following:

- Weak circuits
- Speed related failures
- Lack of circuit robustness
- Intermittent failures
- Environmentally induced failures
- Handling errors
- Operator errors

Let us explore each of these in more detail

CND and RTOK Caused by Weak Circuits

Weak circuits relate to a problem in which an IC chip may have insufficient driving current to function properly. The chip with the insufficient driving current to function properly may not be detectable by specific ATE due to testing hardware limitations. Failures of these types might be detectable with IR or other types of unique testing equipment.

CND and RTOK Caused by Speed Related Failures

Tests run on ATE for the most part are designed to find catastrophic faults, such as stuck-at-0, 1, shorts or opens. Speed related failures, however, do not conform to the same fail indication – at least not always. A circuit running at a lower than expected speed may not be detected as faulty by the ATE. Speed related failures may be sequence and data dependent. Running the ATE test once may catch this fault, but running it a second time may have a different result either because the fault is not apparent, or because the fault does not occur with this set of data. Either way, the result is a CND.

CND and RTOK Caused by Lack of Robustness

One of the causes of CND may actually be traced back to the design or even the design specification. Low signal to noise ratios can fail when spurious signals, glitches, race conditions and other signal integrity issues surface. These signals serve to “fail” the test, but are nearly impossible to repeat. In fact, sometimes a subsequent failure will exhibit itself differently, indicating a different or multiple sources for the fault.

CND and RTOK Caused by Intermittent failures

Intermittent failures are results of a number of complex signal behaviors and they can result in glitches and other random phenomenon. They can be studied using standard methods by stressing circuits with temperature, supply voltage and extra loading. Detection of intermittent failures using standard techniques is often insufficient and has the potential of reducing chip life and can even cause weakness in the chip. Experiments show that new testing techniques utilizing physics as a means of test/diagnosis can actually detect intermittent failures without causing any damage to the chip or surrounding circuits.

CND and RTOK Caused by Environmentally Induced Failures

Harsh environments can create failures in some systems that are otherwise pretty robust. Extreme heat or extreme cold environments will change the behavior of the circuit, as will higher altitude, vibration and electromagnetic interference. Any of these conditions can create a failure detected and maybe even diagnosed by BIT, but this failure will likely not be repeatable in more benign environments, resulting in CNDs. If the diagnosis is in response to an environmentally induced failure, it is unlikely that the removed subsystem will fail in the next level of repair, resulting in a RTOK. The best way to test for these failures is to change the environment during test, using heat sources, liquid nitrogen for freezing and using vibration chambers for the test.

CND and RTOK Caused by Handling Error

There are a number of ways that units can be handled or administered that will appear as a CND or an RTOK. One example may be that the operator in some way is creating a fault by shorting pins, loosening cables, running incorrect tests, removing the wrong parts, mislabeling, etc. No matter how innocent the cause, the net result is that units that are not faulty are called out to be faulty. Then on retest, these causes disappear, resulting in a different test result, which we may view as a CND or RTOK.

CND and RTOK Caused by Operator Error

One of the most common causes of False Alarms is the incorrect operation of the unit. When a system is not performing to expectation, it is considered faulty and is returned to maintenance. When an operator is not familiar with all the operating modes of the system, he or she can often mistake the unexpected behavior for a faulty unit. As systems get more complex and more embedded monitoring takes place, it is not uncommon for an incorrect operation to result in what appears to be a failure. In some cases this is purposely designed in order to create a fail-safe mechanism. Nonetheless, the operator may view this as a system failure and return the unit to maintenance. What probably happens next is that the unit is tested and the test passes, rendering a CND condition. While this is in fact a False Alarm, it is not really possible to distinguish between a False Alarm and a CND.

## IV. UNRAVELING CND AND RTOK

A defective circuit is like a sickness that needs to be identified and classified before it can be treated. One type of analysis is appropriate to determine that we feel weak and achy, and a completely different type of analysis, intelligence and insight is needed to find the root cause of our ailment. Often, the former can be achieved simply (anyone can figure out that he/she is ill), the later requires diagnostic insight that doctors train many years to accomplish. In doing so, doctors do not simply rely on the patient’s determination, but rather on external diagnostic equipment, such as thermometers, X-rays, Laser Scanners, MRI, robotic nanotechnology cameras, etc.

The dual of this problem is also disconcerting. We can have someone ridden with a disease without feeling ill at all. Circuits can be defective and pass tests – even quite comprehensive tests. CND conditions are just such phenomenon. The test passes, indicating that *no fault was found*, but that is different than *no fault exists*. So, simply stated, our task is to find faults on UUTs that pass tests!

Having classified the causes of CND and RTOK we notice that they are not exotic, rare or unlikely scenarios. In fact, fraction of false alarm, the percentage of fault detections that are not due to the existence of faults, can be as high as 70% in many operations. [11]

It is essential, therefore, that we go beyond the normal diagnostic capabilities of the ATE to hunt for root causes of failures that may be subtle and elusive to ATE test and diagnoses.

When we suspect that a CND or RTOK is due to a lack of fault coverage by the tester (ATE or BIT), we need to utilize tools capable of finding the root cause of the problem.

The identified causes and solutions are related to life cycle changes, availability performance factors, test technologies, and understanding the physics of actual failures.

Our mandate is to discover and pursue technologies to improve the quality of a test and reduce test development cost and time and reduce life cycle costs. We need to do things better, more cost efficiently and improve the quality of a test.

### A. Physics to the Rescue

Over-testing, miss-testing, or under-testing is a result of standard stimulus and response. Things like timing, signal strength, duplicating the operating environment, loading, fan-out, and properly interconnecting the UUT are some factors associated with standard testing.

We need to "make" the board fail the ATE test using whatever technique we can, without of course injecting a fault of our own. Some of the methods we can use include margining power, changing temperature, creating a noisy environment, random vibrations, etc.

Considering the actual physics of the circuit can assist in this endeavor. Physics is the most fundamental science. It involves understandings of the basic principles by which all things in the universe exist and operate. It is the natural basis of all the technology disciplines such as electronics, engineering and computer science and, of course, test and diagnosis. We have to be sure we are creating an environment that will "flush out" the fault, while

We do not inject a faulty condition that did not exist in the actual system. In other words, the environment we create should not be one that would be outside the proper operating limits of the system. We need to look beyond the capabilities of an ATE to interpret the physics of the circuit under these conditions. For example, thermal signatures can provide diagnostic information. X-ray inspection can highlight shorts or coupling buried within the layers of multiplayer printed circuit boards. Optical inspection equipment can readily find distortions of shape and often even markings on chips. None of these tools are included in today's ATEs and a diagnostic technician cannot make cost effective diagnoses without them.

### B. Diagnostics is the key

While two different boards can both PASS all the ATE tests, their physical characteristics will likely be different. The physics behind those characteristics can help us diagnose the root causes behind the CND and help us repair even those boards that escaped the ATE tests.

Utilizing thermal imaging, x-ray, optical inspections and other tools of physics for test has been attempted many times in various efforts. Larry V. Kirkland has personal experiences in this area in his 43 years of test and diagnoses working for the US Air Force depot.

While test professionals have used these tools, none of the tools could replace the ATE. The reason is that ATE tests the functionality rather than the physical behavior of the circuit. To simply take a thermal picture of a circuit and compare it to that of a known good circuit is not a confident way to determine that the circuit is working properly. Clearly, many circuits with totally different thermal profiles can work properly. In fact, circuits, using parts from a variety of vendors can all work properly. Thermally, they would probably have completely different profiles. Similar analyses and results can be found with x-ray and optical inspection. That is why none of these tools have succeeded in replacing the ATE.

The tools, however, can be used to find some failures missed by ATE. The processes can serve as faultfinders, though not necessarily as testers. What is the difference? Locating the fault is a diagnostic process that is often beyond the capabilities of the ATE. Knowing that a fault exists (as determined by the ATE), however, these tools of physics can assist in locating and characterizing the failures. Integrating the ATE with such diagnostic tools can cut down on maintenance technician time and error-prone shot gunning.

### Infrared Imaging

The use of infrared thermography or thermal imaging to find electrical faults is a well-documented practice in many types of tests. [18]

In one experiment conducted by a thermal imaging company, an ATE manufacturer and a test consultant, circuit boards were subjected to an injected fault and the ATE was simple used to loop around the tests. [19] The setup is shown in Figure 2.

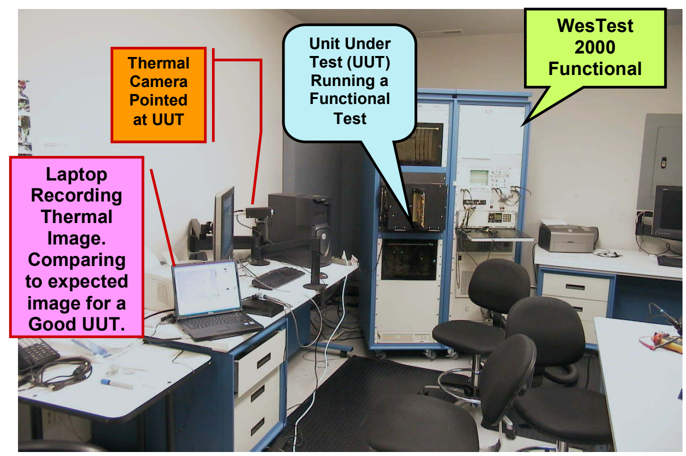


Fig. 2 Set up showing a thermal imaging integrated with an ATE running the test of a UUT.

The thermal camera took a picture of a known-good UUT, which it stored in its memory. Then, with the fault injected, it took a picture of the faulty board and created the image of Figure 3 as the "difference" in the thermal characteristics of a known-good UUT and one with a fault in it. It is not only clear from Figure 3 that a fault exists, but the location of the fault is also clearly delineated.

The basic concept is that faulty connections and components in an energized circuit operating will heat up before they fail.

The thermographer scans all the devices in the circuit from one end to the other, paying particular attention to each point of connection. This approach requires mapping out the physical location of each run throughout the circuit and directly imaging each device. This procedure is well worth the effort if a UUT has a CND problem.

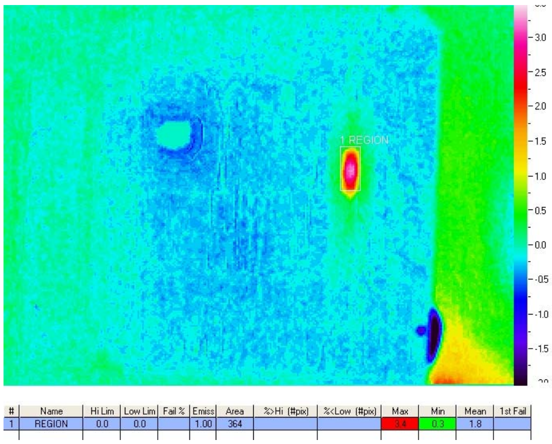


Fig. 3 Thermal picture highlighting the difference between a good and a faulty UUT. Fault location clearly shown.

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The hotter a target, the more energy it emits in the infrared portion of the electromagnetic spectrum. For electrical components such as resistors or transformers, which normally produce heat as a byproduct of their operation, warm IR signatures may be perfectly normal. However, for the preponderance of components the production of excessive heat or the lack of heat where expected can indicate a problem. Also, a low temperature could indicate an open circuit. See Table 1 for an example of general guidelines.

Table 1. Guidelines for problem evaluation based on temperature.

| Feasible defect | Variances |
|---|---|
| Nominal or borderline | Variances slightly above or below ambient |
| Possible | Variances more than slightly above or below ambient |
| Likely | Variances moderately above or below ambient |
| Probable | Variances significantly above or below ambient |
| Definite | Variances excessively above or below ambient |

Beyond making good common sense, accurate temperature readings are vital if you want to track and trend temperature changes over time. Such studies are the foundation of predictive maintenance practice, which is to project the time to failure of electronic devices. A sequence of temperature measurements taken over time can reveal the rate of increase in temperature. This knowledge enables the inspector to predict when the target will reach a state that could compromise component reliability and to recommend faulty components see Table 2.

Table 2. Some Advantages of IR thermography

| |
|---|
| ➢ Measures temperature of components |
| ➢ Inspection |
| ➢ Nondestructive testing |
| ➢ Detects incipient problems |
| ➢ Documents problems for corrective action |
| ➢ Produces diagnostics images |
| ➢ Validates repair work |
| ➢ Maximizes equipment life |
| ➢ Makes timely repairs |
| ➢ Reduces costs in CND and component replacement and/or repair |

An important consideration is that changes in ambient temperature can affect a camera's measurement accuracy. Better IR cameras have internal ambient temperature compensation systems including sensors and feedback circuits that automatically adjust for ambient variations.

IR thermography can also be used to facilitate predictive maintenance; it can aid in the determination of when an incipient failure will occur. Thermographs taken over known intervals of time enable trending of the rate at which the condition or performance of a circuit or component is declining, on the basis of increasing temperature. By projection, the moment of failure can be predicted, often with enough accuracy to order replacement parts and to plan necessary repairs during planned downtime to minimize disruption of ongoing operations.

### X-ray

Automated X-Ray inspection is non-evasive. X-Ray imaging is not trapped by heat sinks and high density (high joint count) double-sided boards. When X-Ray is integrated with in-circuit test, X-ray equipment can increase fault coverage and can find route mean causes of some classes of CND and RTOK.

### Other Technologies

Other technologies are available in the test/diagnosis world to fault isolate CND and RTOK problems. Test technology is an evolving hardware and software environment so we need to be alert and open minded to new test techniques and how they can be used to fix our testing deficiencies. It is the authors' intent to suggest there are many other viable technologies which can augment our ATE and make sure our UUTs are truly ready for issue.

## V. CONCLUSIONS

It is important to know that test technology is not limited in its extent and growth. New hardware and software techniques are continually evolving and we must stay current with the technologies that could offer better, smarter, less expensive and faster solutions to our testing problems. We must always consider the potential for CND and RTOK when creating an overall test/diagnosis plan for a system. Failure to plan ahead is always costly and causes more headaches, additional costs and problems during the life-cycle of a system.

Physics is somewhat abstract and difficult to grasp, however it is a reality. Physics can perceive real world occurrences of circuit failures by getting down to the root mean cause of a failure. In actuality the physics by which our world functions is the most important function that we can employ in detecting circuit weaknesses and failures.

The ATE as a PASS/FAIL mechanism with its "diagnose on FAIL" limitation is unable to completely unravel CND and RTOK that muddy the waters of maintenance facilities. They constitute a huge problem and may well be featured in the majority of UUTs entering a maintenance facility. We need to invent and invest in new techniques to deal with these complications and then integrate these diagnostic tools into the functional ATEs we use.

## ACKNOWLEDGMENT

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## REFERENCES

[1] Department of Defense, "Testability Program for Electronic Systems and Equipment", MIL-HDBK-2165, 31 July 1995

[2] W. R. Simpson, J. H. Bailey, K. B. Barto, E. Esker, "Prediction and Analysis of Testability Attributes: Organizational-Level Testability Prediction", RADC-TR-85-268, Rome Air Development Center, Griffis AFB, N.Y., Feb. 1986

[3] United Kingdom Ministry of Defence Standard 00-13/Issue 3, 17 June 1994.

[4] Institute of Electrical and Electronics Engineers "Test Access Port and Boundary-Scan Architecture", Standard 1149.1, IEEE 2001.

[5] Surface Mount Technology Association, "SMTA Testability Guidelines 101C," SMTA, 2002.

[6] L. Y. Ungar, "Design for Diagnosability Guidelines", *Proc. AUTOTESTCON 2007*, September 2007.

[7] L. Y. Ungar, "An Economics Model of Supportability through Design for Testability", *Proc. AUTOTESTCON 2006*, 2006.

[8] L. Y. Ungar, and R. Parameswaran, "Knowledge Base to Manage the Grading and Selection of Testability Guidelines", *Proc. AUTOTESTCON 2005*, 2005.

[9] A.T.E. Solutions, Inc., "The Testability Director, Version 3.2", Software, A.T.E. Solutions, Inc. 2003, [Online] Available http://www.ATESolutionsInc.com/OurProducts/TestabilityDirector/

[10] A. Misra, "DTOOL: A Diagnosability Analysis Tool for the Multigraph Architecture", Vanderbuilt University, October, 1995, [Online] Available www.isis.vanderbilt.edu/research/fdir/dtoolman/dtoolman.html

[11] L. Y. Ungar, "An Economics Model of Supportability through Design for Testability", *Proc. AUTOTESTCON 2006*, 2006.

[12] L.Y. Ungar, and T. Ambler, "Economics of Built-In Self Test", *IEEE Design & Test of Computers*, September – October, 2001.

[13] L. Y. Ungar, A. P. Ambler, B. Bassat, "Economics of Diagnosis", *Proc AUTOTESTCON 1997*, 1997.

[14] C. Dislis, J.H. Dick, I. D. Dear, *Test Economics and Design for Testability for Electronic Circuits and Systems*, Ellis Horwood, Chichester, England, 1995

[15] "Definition of Terms for Test, Measurement and Diagnostics," Department of Defense, MIL-STD-1309D, 12 February 1992

[16] Jones, James V., "Integrated Logistics Support Handbook", TAB Books Inc., 1987, pp 66-67.

[17] Test Definitions, by A.T.E. Solutions, Inc. [online], Available www.BestTest.com/BestTestDirectory/TestDefinitions/

[18] Xavier P. V. Maldague, Theory and Practice of Infrared Technology for Nondestructive Testing, Wiley-Interscience, April 2001.

[19] Previously unpublished report of an experiment involving, OptoTherm, WesTest and A.T.E. Solutions, Inc. on August 25, 2005. Of 10 faults injected in 5 different boards, all faults were successfully identified and locations on the boards exactly pinpointed. Faults injected were groundings and shorting pins to VCC.