Automated System for Controlled Impedance Testing

by

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ABSTRACT

The need for an automated methodology for controlled impedance testing of Printed Wiring Boards (PWBs) is significant and growing. Several factors define this need and include: the volume of boards having interconnects where impedance must be controlled and thus tested, the need to test "on-board" rather than relying on coupons, and tighter tolerance requirements on controlled impedance specifications. These issues are prompting manufacturers to explore new means for meeting their testing requirements.

This paper attempts to clarify the issues surrounding production level controlled impedance testing and provide information contrasting several different methodologies.

INTRODUCTION

The speed of electronic circuits has increased by a factor of ten in the last five years for a wide range of consumer products from children's toys, which contain digital chips, to high-speed computer systems. Important examples include high-speed memory bus systems (Rambus and DDR), and communication architectures such as Firewire and USB 2.0. These examples point to a strong industry wide movement to high-speed communications in digital electronic circuits and demands the use of high speed interconnects on the Printed Wiring Boards (PWB) that provide the foundation for these circuits.

Digital signals with fast transition times act like radio signals and passive circuit components, such as traces on circuit boards, become miniature “transmission antennas”. A large number of circuit components, occupying very small areas, act like transmitting and receiving antennas and create distorted signals that interfere with the operation of the digital circuit. There are thousands of digital signals that can be corrupted causing the electronic circuit to stop working intermittently or permanently. An important technique to avoid this increasingly serious problem is to consider transmission line effects in the design of the PWB and to test PWB's to verify proper impedance control.

There are three (3) different types of test equipment that can be used to determine the impedance of a PWB trace.

An LCR meter can be used to take inductance and capacitive values directly in a typical four-wire measurement process. The disadvantage of this process is that the LCR meters operates at a frequency under 200 MHz which may not simulate operational frequencies. Additionally this method requires shorting of traces to gather all the measurement information, a procedure that is not practical in a production environment.

An alternative instrument is a Network Analyzer that has the advantage of being able to sweep a range of frequencies during the testing process. The disadvantages are an increased level of instrumentation cost and a high level of equipment sophistication.

The test method of choice for the PWB industry continues to be Time Domain Reflectometry (TDR). TDR measures the signal reflections that result from a generated signal traveling through PWB interconnects. The TDR instrument sends a fast transition pulse through the trace and compares the reflections from that unknown trace structure to those produced by a standard impedance.

TESTING CHALLENGES

The industry trend towards increased controlled impedance testing with stricter requirements has produced many challenges in a manufacturing environment. Manufacturers can meet some of these challenges with the current hand probing methodology, but it is by no means a complete solution. As the industry moves forward it has become clear that an alternative to the current test methods is necessary to meet the growing list of customer requirements.

Trends in Customer Requirements

Test Results Correlation: This is an important requirement from at least two perspectives. The buyer of printed wiring boards wants to be able to match the test results with their incoming inspection processes and large multi-facility manufacturers want to provide their customers with consistent test results across their facilities if product is to be supplied from more than one facility.

On-board Testing: An increasing number of buyers are requiring on-board testing for impedance. The concerns about poor correlation between test coupons and actual product traces is driving this requirement. It is taking the form of measurement on embedded test traces within the board (non-functional parts of the product, e.g. Rambus DRIMM boards) or taking measurements directly on product traces.

Differential Impedance: Differential signaling schemes are become more prevalent in digital designs to achieve higher noise immunity which is needed for high speed signaling. Impedance testing of differential trace pairs offers particular challenges. Typically, more probe connections are required by the test system and a more stringent calibration procedure is needed to assure accurate results. There are also variations of differential impedance measurement which may be required including true differential (two test signals, one per trace, with opposite polarities) and common mode differential (two test signals, one per trace with the same polarity).

Tighter Tolerance: The manufacturing tolerances for impedance control are tightening. In the past it was felt that a manufacturing callout for impedance tolerance of +/-10% was not problematic. The manufacturer would simply need to take some additional care in selecting material and/or controlling line widths. Today, tolerances are critical and products will not function or will become unreliable if board impedance is not tightly controlled. To that end, impedance specifications are being lowered to +/-8% or +/-5% and designs with lower impedance produce lower absolute tolerance values (e.g., 28% +/-10% results in a smaller numerical ohm tolerance of +/-2.8 ohms). Thus testing systems must be more accurate.

More Data: Measurement and test of the PWB trace impedance has been the most important tool for monitoring the high frequency properties of a board. Buyers are starting to require other measurements such as propagation delay (or signal flight time). Propagation delay can impact the ability of an assembled board to function in designs with high speed data rates and tight timing margins. Additionally, as new high frequency materials are being introduced in board fabrications, information about the dielectric (Er) properties of the manufactured board is becoming important to board designers. With a simple coupon design an accurate TDR system can measure material Er [1] and "effective Er" values can be obtained for the material surrounding a measured trace in real product [2].

Special Coupons: Board designers, now more sensitive to impedance control issues within the manufacturing process are starting to require the measurement of special test coupons. These coupons may have varying line lengths, different probe point pitches/patterns and they may have requirements for specific and additional placement of the coupons on the manufactured panel. These requirements tend to increase the cost and complexity of existing manual impedance testing processes and increase the cost of board fabrication.

Test at Various Frequencies: The increased focus on impedance control has created a new test trend of matching the TDR test frequency to the operational signal frequency that the PWB will experience once assembled. This requirement forces a reduction in measurement resolution and accuracy of the TDR test process but more closely simulates the operational parameters. USB 2.0 is a good example with a test frequency requirement equivalent to a TDR risetime of 400 psec for differential tests. [3] The production testing equipment must not only have programmability of the testing frequency but must also have the bandwidth to meet the all specified test frequency requirements.

Multiple Impedance Levels: New digital designs with mixed high-speed device technologies require more impedance levels on a board. It is not uncommon to see impedances of 28, 53, 75, 110 ohms together on one board. This requires the production measurement system to be flexible and accurate on a range of impedance values.

Quantity of Test: Typical PWB controlled impedance test specifications require testing on one trace per board signal layer (on representative traces on test coupons) and a sampling program of 1% to 10% of product manufactured. With multiple impedance levels on each layer, test point counts per layer are increasing. With the concern about impedance variations over a product, the number of coupons and the number of traces tested per panel will increase and with the concern over the need for tighter tolerance control, the number of products tested may increase to 100%.

Via Effects: As board designers understand more about interconnect vias and how they affect the high frequency properties of their signals, there will be a greater demand for manufacturer control over these structures. This will require higher resolution impedance test equipment to be able to discern the variations the manufacturing process has on these trace components.

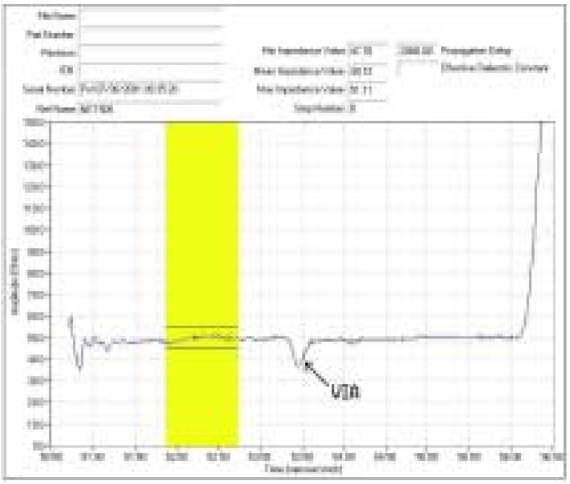


Figure 1 - TDR Waveform Capture

Trends in Manufacturer's Requirements

Accuracy & Repeatability: The accuracy and repeatability of impedance testing is extremely important to the manufacturing operations. The repeatability of the process affects the reliability of the test data, credibility of the process, and the ability to use testing for process correction. There are many factors that can adversely affect the repeatability of the current manual test methodology. These include:

- Operator to operator consistency
- Probe force variability
- Probe angle variability
- Probe placement accuracy
- Unidentified faults in probe and other measurement system components causing inaccurate test readings (i.e., static damage to TDR instrument, cable bends and cracks, loose cables, worn probes, cracks in probe, etc.)
- Consistencies in test location (one end via or the other of a trace)
- Consistencies of the measurement zone (where the average impedance is being taken along the length of the trace)
- Diligence in following calibration procedures
- Correlation of equipment (TDR instrument and probes) from test station to test station
- Use of varying calibration procedures to accommodate varying impedance levels
- Operator interactions with the device under test (DUT) (i.e., touching board or trace during test, leaving DUT on table when testing bottom microstrips).
- Proper temperature and humidity control

Standardization: The need to standardize on testing procedures is critical to ensure a repeatable test process. IPC is making ongoing contributions to this process through their work on standard documents like IPC-2141 "Controlled Impedance Circuit Boards and High Speed Logic Design" and IPC TM-650 "Test Methods Manual". The National Institute for Standard Technology (NIST) is also contributing in part to the production of the current impedance standard, a calibrated airline, as well as their research into other impedance standards.

Figure 2 - Calibration Airline

Health problems: The current manual procedure for hand probing of coupons and panels for impedance testing is inherently a very repetitive task which can produce injuries to operators.

Operator Retention: Because of the tedious nature of hand probe testing, operators often do not stay long in the production test area. This creates a burden of frequent retraining and errors due to the new operator learning curve.

Skill Level of Operator: The use of manual probing techniques with TDR instrumentation requires a certain level of operator expertise. Operators need to make constant decisions on what measurement zone to use, which end of the trace to test, what probes to use, what calibration settings are appropriate, when to calibrate, and where to probe when special panels or coupon testing is required. This level of expertise increases the cost and reduces the availability of qualified operators.

Cost: The cost of applying manual labor to impedance testing is high. The cost of acquiring and maintaining individual test stations is also high. As the volume of testing continues to increase, the magnitude of this overhead cost will increase and adversely affect the bottom line.

In Process Testing: The need for in process checks of impedance is critical. As a higher percentage of boards require impedance tests, the potential for rejection at final test is greater and more costly. In-process testing is only successful if the checks do not add significant time to the manufacturing process and if the process can be adjusted for the observed variations.

Maintaining Equipment: All TDR instrumentation is static sensitive and requires installation in special environments and special operator handling. Probes are also subject to excessive wear due to the repetitive nature of their use and direct operator involvement. Poorly maintained equipment will result in poor test quality.

AUTOMATED TESTING SOLUTIONS

The challenges of production level testing of PWBs are extensive as discussed above. However it is possible to meet most of these challenges and overcome the limitations present with current manual test techniques by utilizing an Automated Test Solutions

Figure 3 – Automated Impedance System

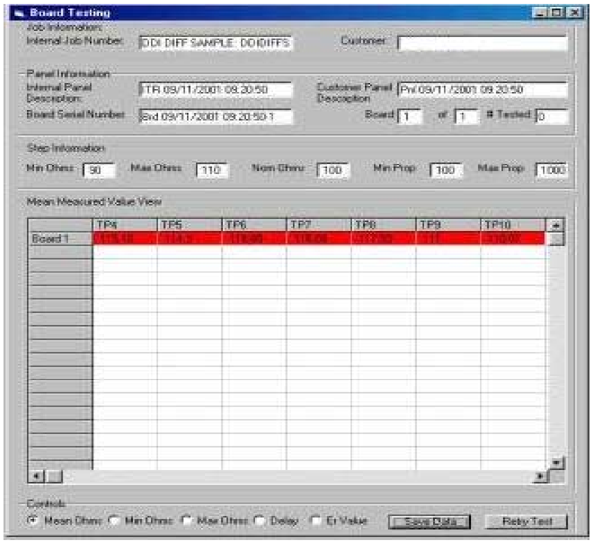
SYSTEM COMPONENTS

Precision Motion Devices
Precision robotic or mechanical motion devices bring accuracy of probe placement and control over force and angle of the probe onto the DUT. These mechanisms significantly improve the repeatability of the testing process. System repeatability can achieve a standard deviation of under 0.03 ohms. As compared to studies on manual methodologies where repeatability can exceed 2 ohms, this is a significant improvement.

System Size
System test bed sizes can vary, permitting the testing of small boards and coupons to large panels and backplanes.

Test Software
Automated measurement algorithms as part of the System's software control system permit a more linear calibration procedure over a wider range of impedances, automatic switching of test frequencies and the control of the different methods of differential TDR testing. These algorithms also permit verification of the test results on the fly to insure the validity of the data.

Operator Software
Graphical User Interface (GUI) software provides a factory friendly interface for the operator. Often the test operator need not touch the TDR instrumentation or know how it works thus reducing the skill level of test personnel.



Board Testing

Job Information:
Internal Job Number: DDI DIFF SAMPLE: DDIDIFFS
Customer:

Panel Information
Internal Panel Description: TR 09/11/2001 09:20:50
Customer Panel Description: Pnl 09/11/2001 09:20:50
Board Serial Number: Brd 09/11/2001 09:20:50:1
Board 1 of 1 # Tested 0

Step Information
Min Ohms: 90
Max Ohms: 110
Nom Ohms: 100
Min Prop: 100
Max Prop: 1000

Mean Measured Value View

	TP4	TP5	TP6	TP7	TP8	TP9	TP10
Board 1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Controls
● Mean Ohms ○ Min Ohms ○ Max Ohms ○ Delay ○ Er Value

Figure 4 – Operator Screen

DUT Fixturing
Flexible fixturing of the DUTs within the System permits quick changeover from one design to another and eliminates operator interaction with the DUT during testing. The DUT fixture and robotic holding of probes also significantly reduce the maintenance issues created by static damage to the TDR instrument and operator handling of the probe. Static reducers like ionizer guns can also be incorporated within the System to reduce static and minimize damage.

Automatic Verification
On-board verification stations, which contain calibrated airlines, allow the System to automatically verify its calibration at shorter intervals without operator intervention.

Probe Changer
Automatic probe changing systems within the System eliminate the need for proper probe selection by an operator and reduce the time to test DUTs with multiple pitch test pad structures.

Data Handling

Automatic data storage and retrieval in a Statistical Process Control (SPC) friendly database structure allows the data to be manageable and portable. Extensive reporting capabilities are needed to meet various users, and their customers, requirements.

In-Line Processing

Both horizontal bed and vertically orientated Systems can be coupled to board auto load/unload or conveyer systems to further reduce the time to test.

SYSTEM MEASUREMENT ACCURACY

The mechanization of the testing procedure allows for the use of higher resolution components such as the TDR instrumentation, the cable assemblies connecting the probe to the instrumentation and the probes themselves which in turn permits a higher level of measurement accuracy. (Studies have demonstrated that there can be up to 1 ohm of difference in impedance test readings with probes having a long ground lead - high inductance ground path [4])

Higher test resolution is achieved through the improvement of signal rise and falltimes. These values dictate both how short an impedance discontinuity on a DUT can be before the test system detects it and how short a DUT trace can be and still be measured by the System. Test studies done on Rambus CRIMM boards indicate that with a System rise time of 34 psec and fall time of 53 psec, that ½" long traces can be accurately measured. [5] Better System resolution also allows the gathering of realistic data of propagation time, effective dielectric constant and the effects of vias on overall trace impedance.

SYSTEM THROUGHPUT

Time studies at several PWB manufacturers report that typical times for controlled impedance measurements on coupons with manual test techniques is approximately 30 secs per test point. Time studies on one automated System indicate testing times from 2-5 secs per test point (independent of whether the DUT was a coupon of panel) demonstrating a throughput increase over manual techniques of 6-15 times.

IPC-D-356B

The IPC has recently introduced an updated electrical test data format standard. This format contains a definition of impedance test criteria and makes it possible for electrical test CAM software to gather and then output the impedance test information file required by the System. At least one electrical tester CAM software supplier has already provided the necessary interface and output to allow creation of System test definition files.

SYSTEM PAYBACK

The high cost of manual testing techniques including labor, equipment maintenance, facility overhead, and lost production conservatively permit a payback for an automated tester system of under a year.

CONCLUSION

There are significant challenges that PWB manufacturers face to meet the current and growing demands for high frequency testing of their products. As in the past where automated systems were developed to handle the growing need for traditional open and short circuit testing, automated systems are now available and being developed to meet the new requirements. The advantages of an automated system over the conventional manual probing techniques are great and include significant cost savings and throughput improvement. Once again, automation has provided a solution to meet increasing PWB production test requirements.

REFERENCES

[1], [4] Intel Corporation, Printed Circuit Board (PCB) Test Methodology, Revision 1.6, January 2000

[2] Mike Tranchmontange, “Utilizing TDR to Measure Dielectric Constant, Er”, Tektronix Application Note, Circa 1997

[3] Compaq, HP, Intel, etc., “Universal Serial Bus Specification Rev 2.0”, April 2000

[5] Introbotics Corporation, “Measuring Short PWB Traces, Rambus TDR Benchmark”, September 2000