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The Role of Impedance Control in Early Detection of Interconnect Degradation Using Time Domain Reflectometry

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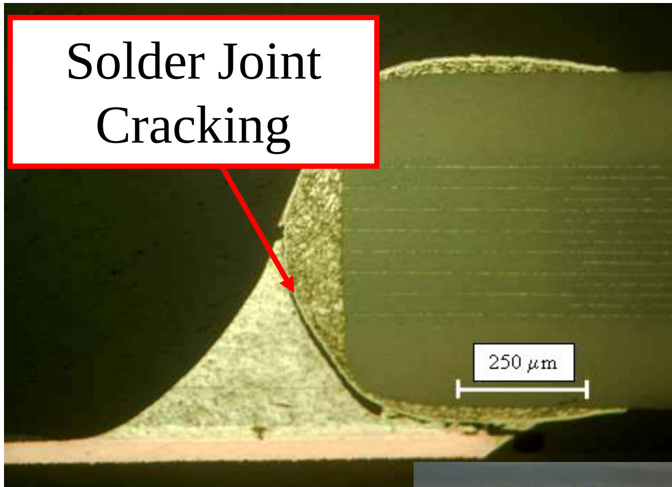
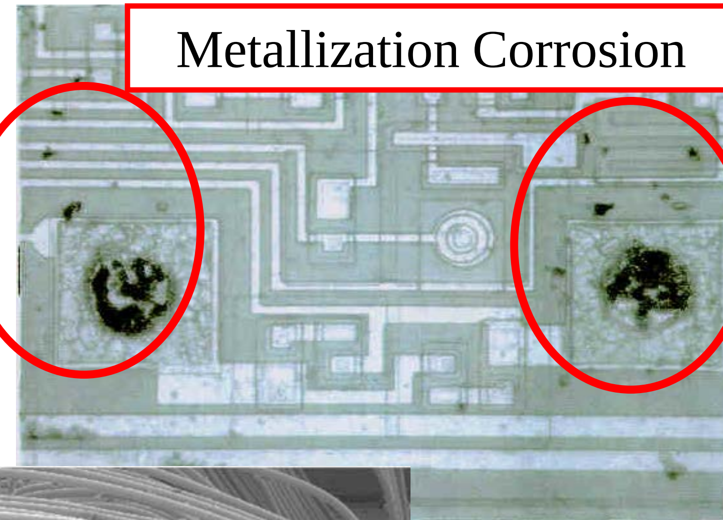
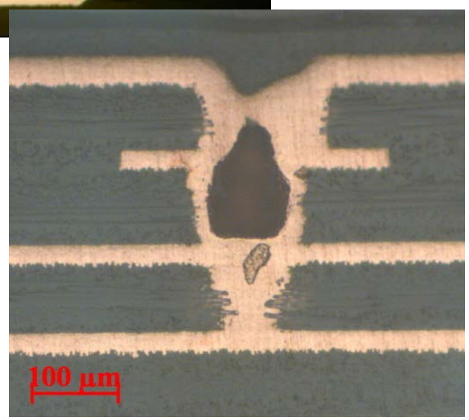
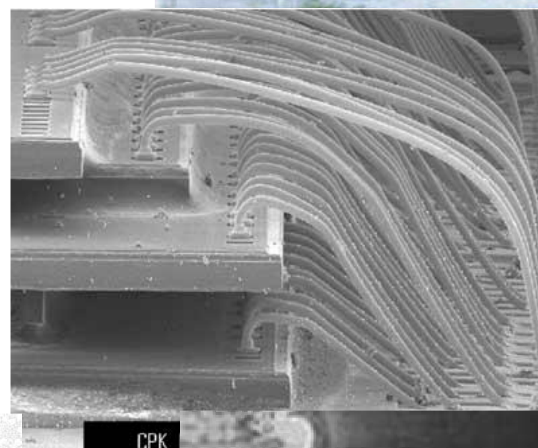
Interconnect Failure Mechanisms and Challenges



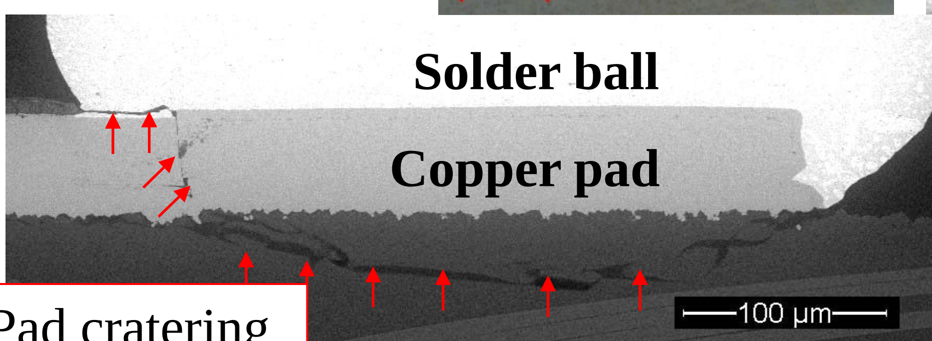


HDI Microvia Voiding



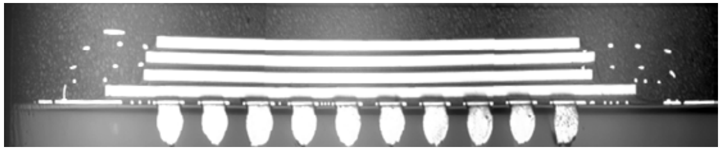


Stacked Die Wirebonding



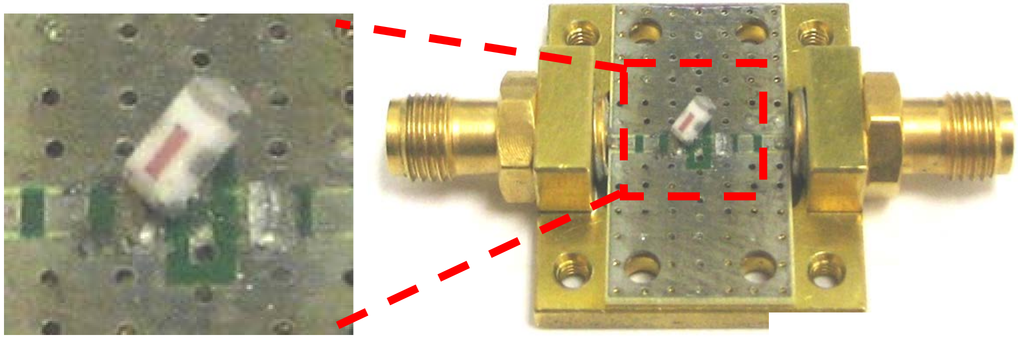
Early Detection of Interconnect Degradation

- Failure of a single interconnect could cause a circuit to lose functionality.
- Early detection allows reduction of:
  - risks associated with adoption of new materials, processes, or packaging technologies;
  - uncertainties surrounding actual usage conditions;
  - likelihood of unanticipated failure in safety- or mission-critical applications;
  - costs associated with a product's operation and maintenance.

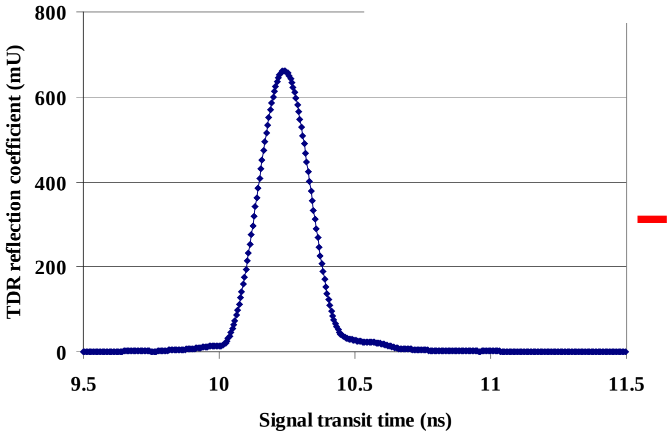


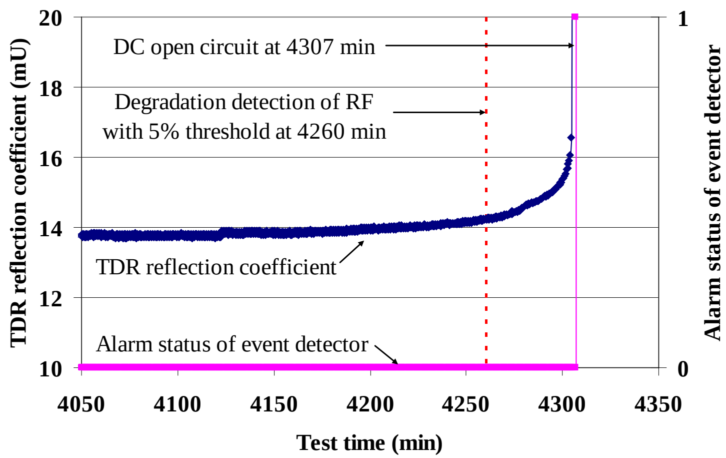
Time Domain Reflectometry (TDR)

- TDR can be used to detect impedance variations within a circuit as discrete peaks in the time domain.
- The TDR reflection coefficient (Γ) is a function of the characteristic impedance of the circuit, Z_0, as well as the impedance of the device under test, Z_L.



$$\Gamma = \frac{V_{reflected}}{V_{incident}} = \frac{Z_L - Z_0}{Z_L + Z_0}$$





Practical Considerations for Product Monitoring with TDR

1. A selection must be made of the circuits which are to be monitored → based on criticality or expected life.
2. A stable interface is needed between the test circuit and the test equipment → connector, test points, or permanent connection.
3. The monitoring circuit and activity should not have an adverse effect on the operation or reliability of the product → control of test timing, maintenance operation, or multiplexing.
4. *The circuit must be suitable for monitoring using high frequencies, allowing detection of small changes in impedance, in the range of 10 to 100 mOhms.*
    - Does this require impedance controlled board with simple and uniform TL between interconnect and test equipment?

Effect of Board Substrate and Circuit Design

- In practice, circuits often do not have controlled impedance.
- It would be valuable to know the extent to which TDR monitoring could be implemented on boards which are not designed for high frequency applications.
- Three board types with identical circuits, but differences in the substrate material or ground plane, were designed with varying levels of impedance control:
  - **High level:** substrate for high frequency applications (RO4003) with ground plane;
  - **Medium level:** standard PCB substrate (FR4) with ground plane; and
  - **Low level:** FR4 substrate with no ground plane (ground trace under some signal traces).

Layout of Test Boards: Top Surface

- The top side of each board contained five circuits with varying levels of complexity in geometry and components.

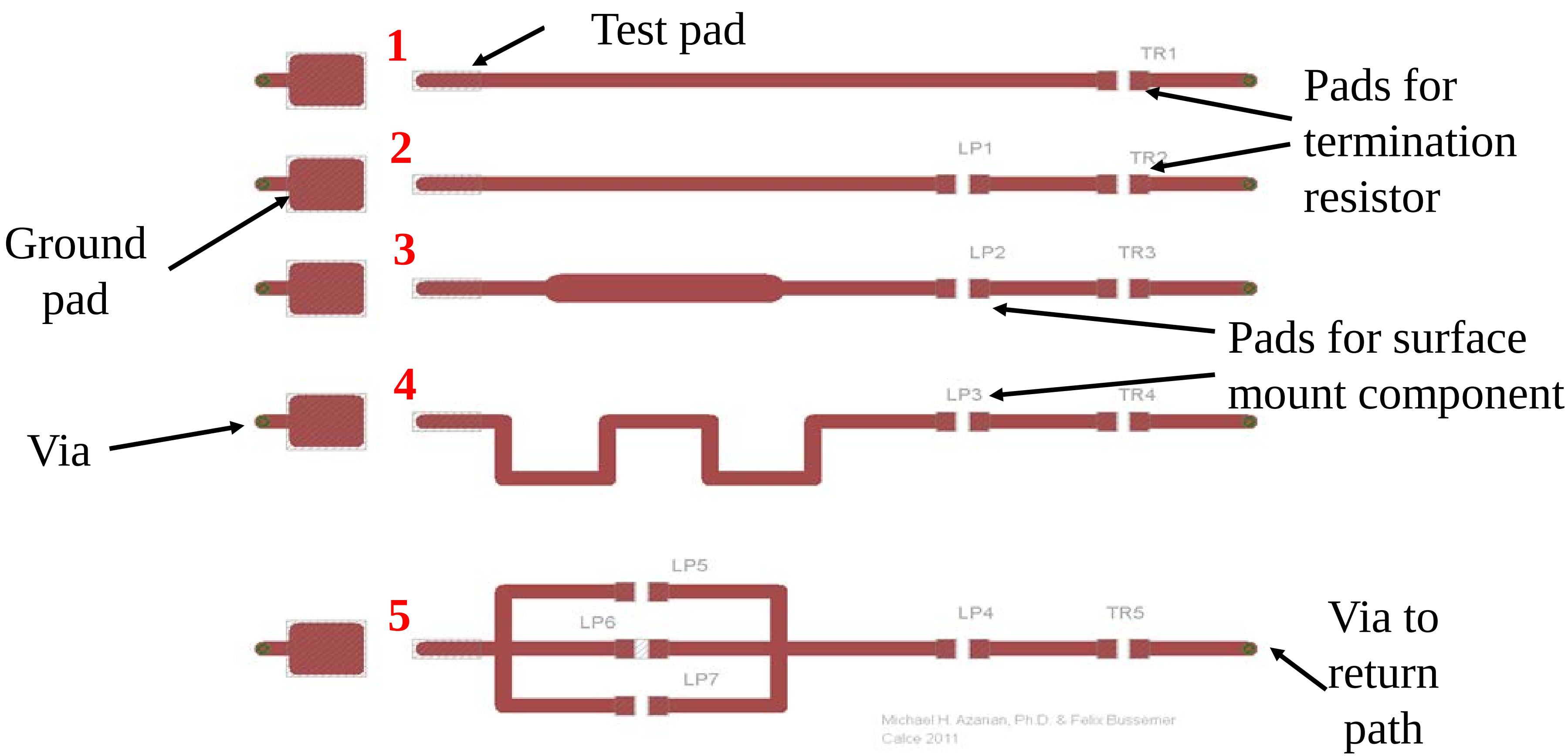
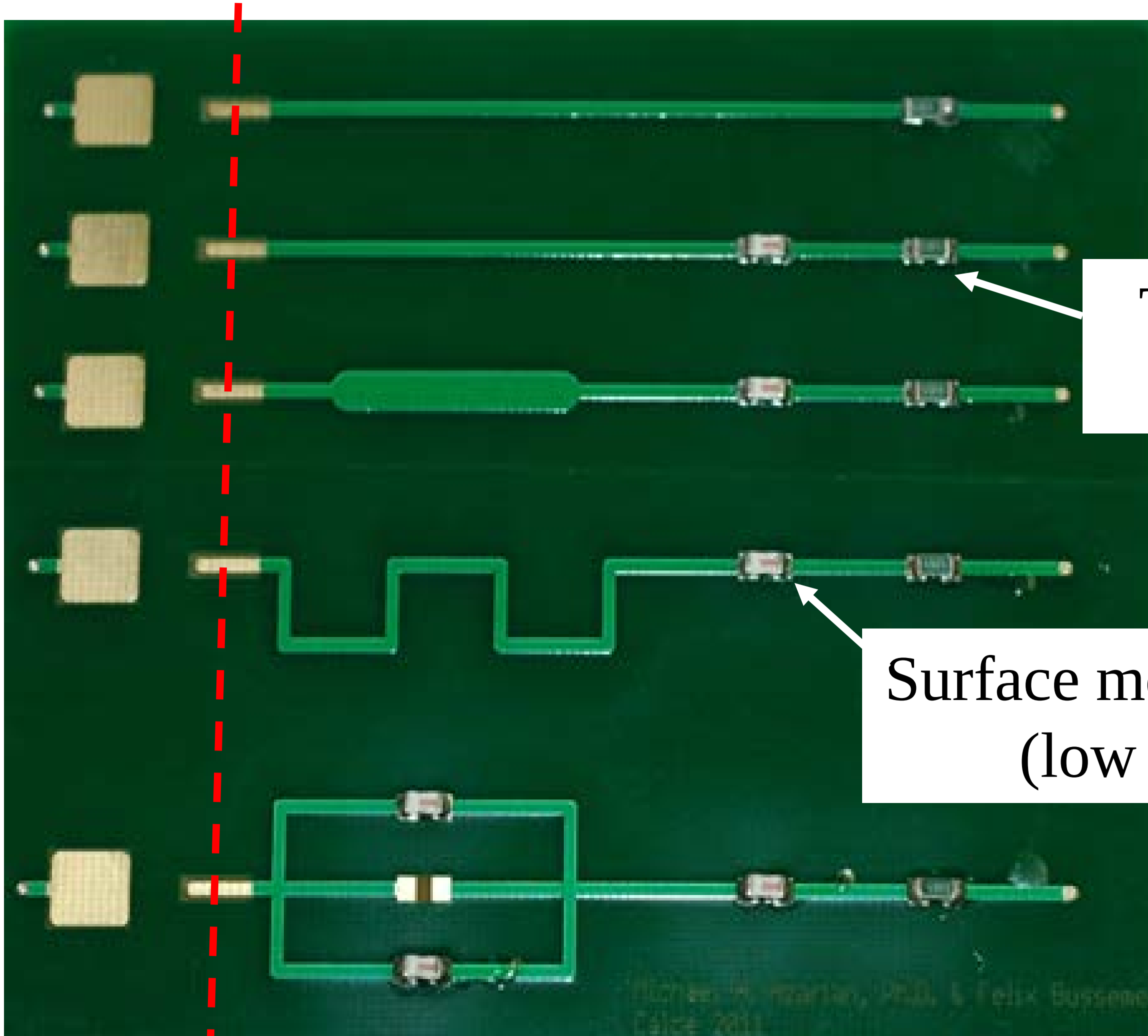


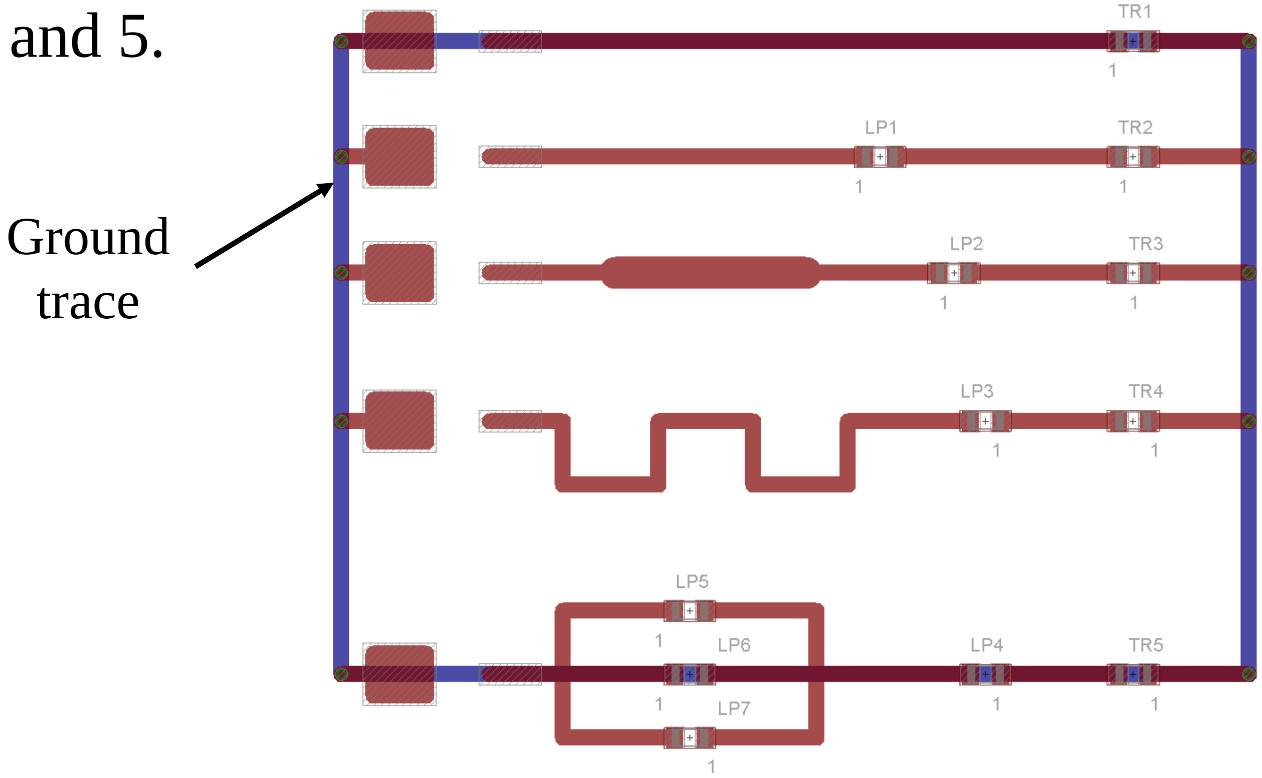
Image of Board Assembled with Components



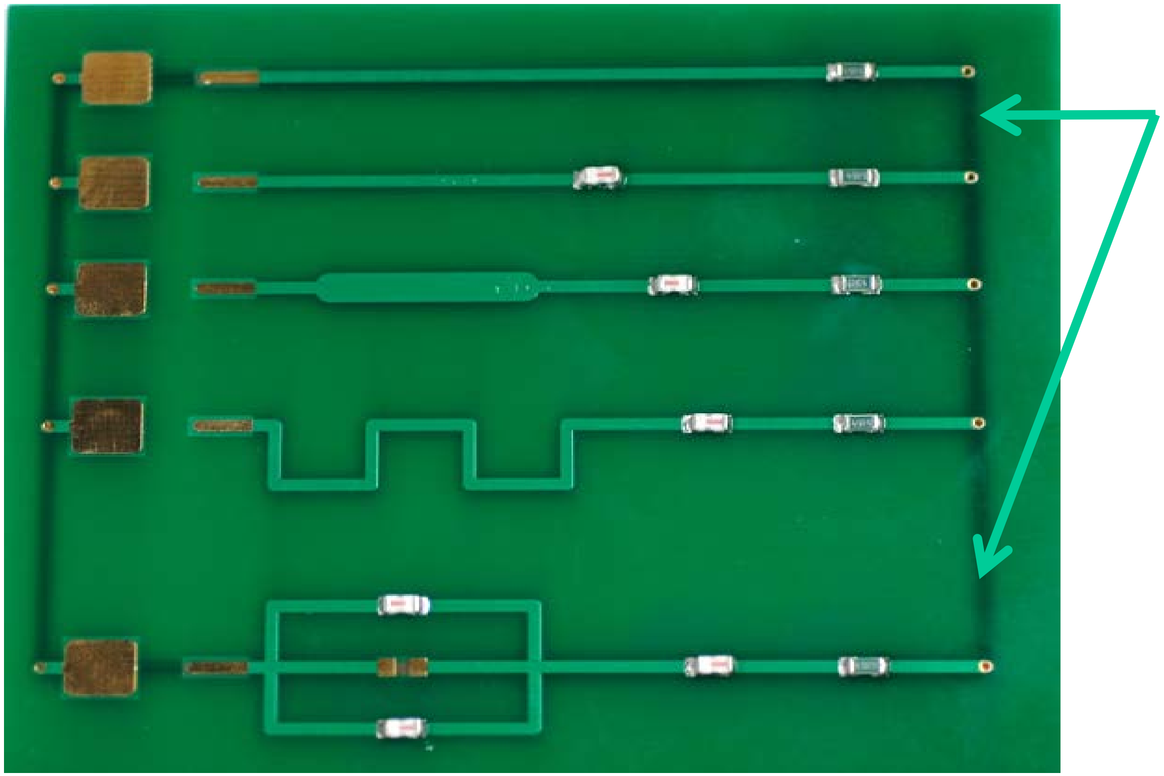
Board was cut and connectorized

Design of Ground Planes

- The bottom side of the two boards with ground planes was a continuous layer of copper.
- The bottom side of the FR4 board without the ground plane contained a ground trace laid out in a rectangular pattern under circuits 1 and 5.

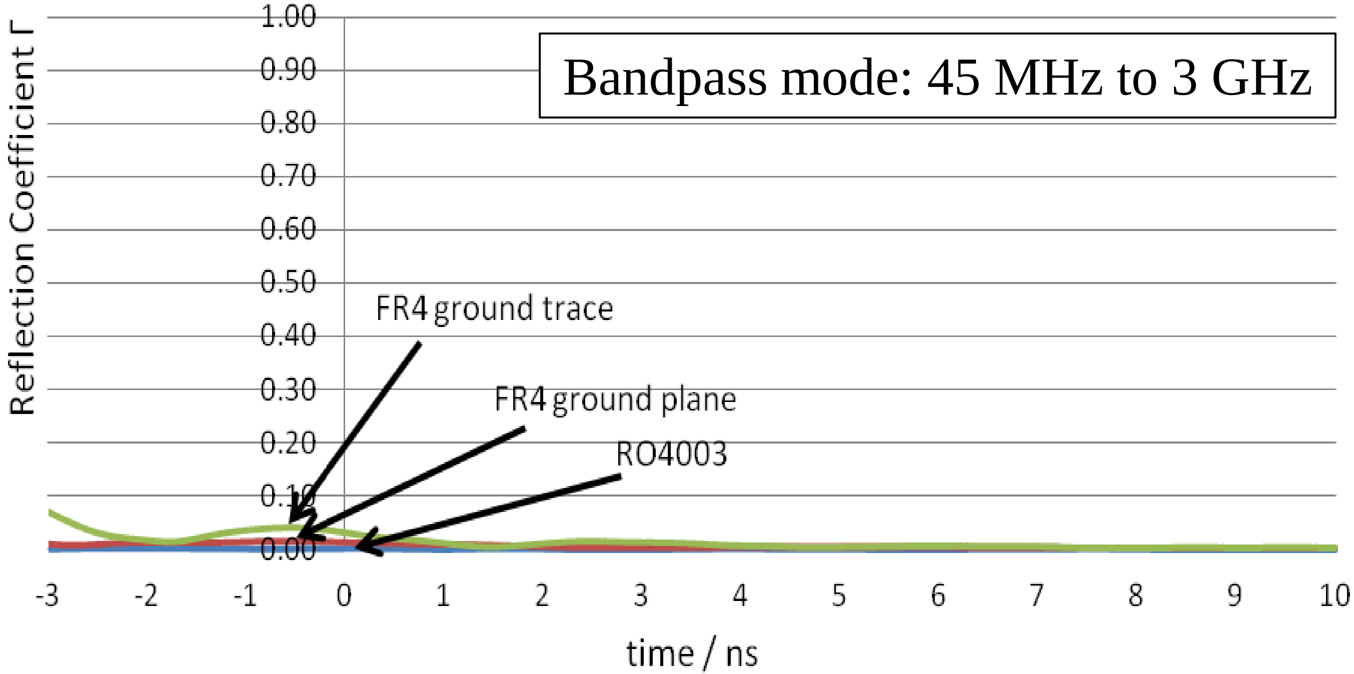


Board with a Ground Trace Instead of a Ground Plane



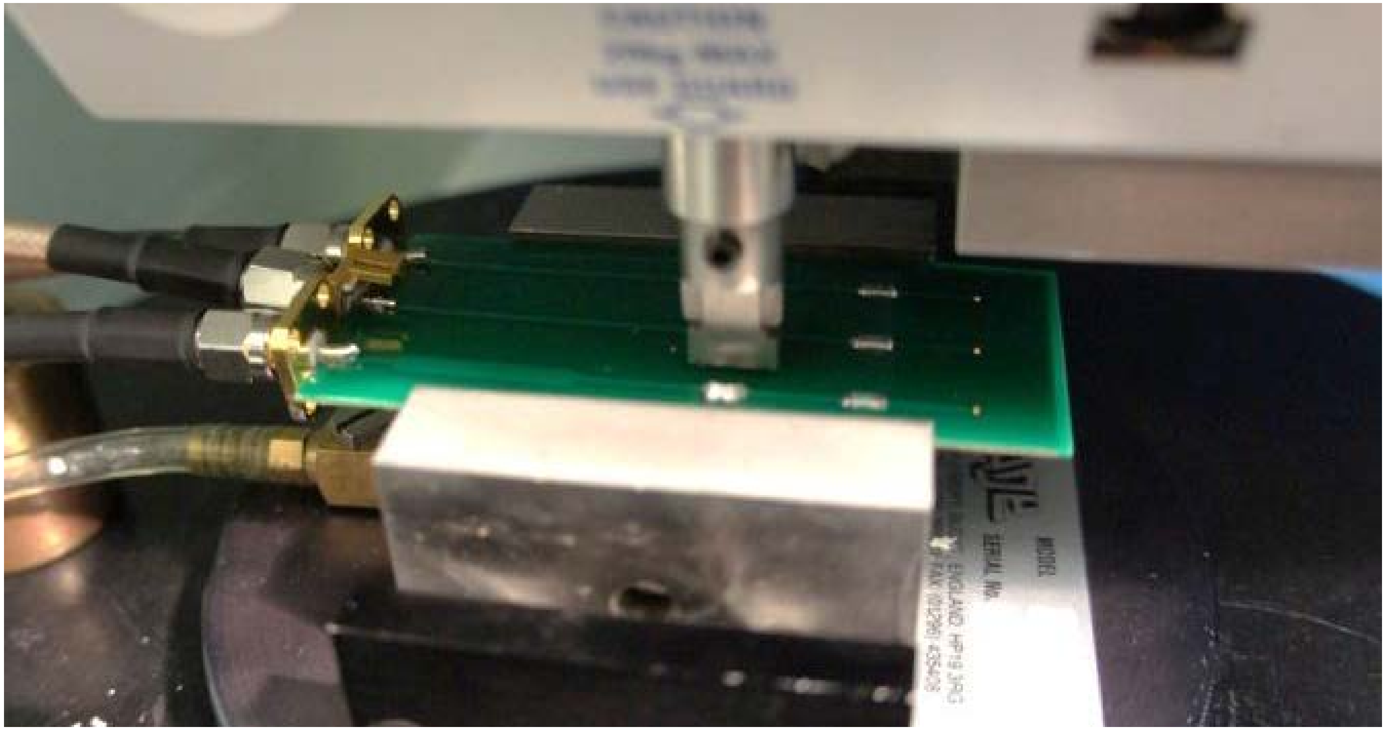
- The ground trace was used to explore the feasibility of making TDR measurements on a board that does not have a dedicated ground plane.

TDR Comparison of the Three Boards Prior to Application of Stress



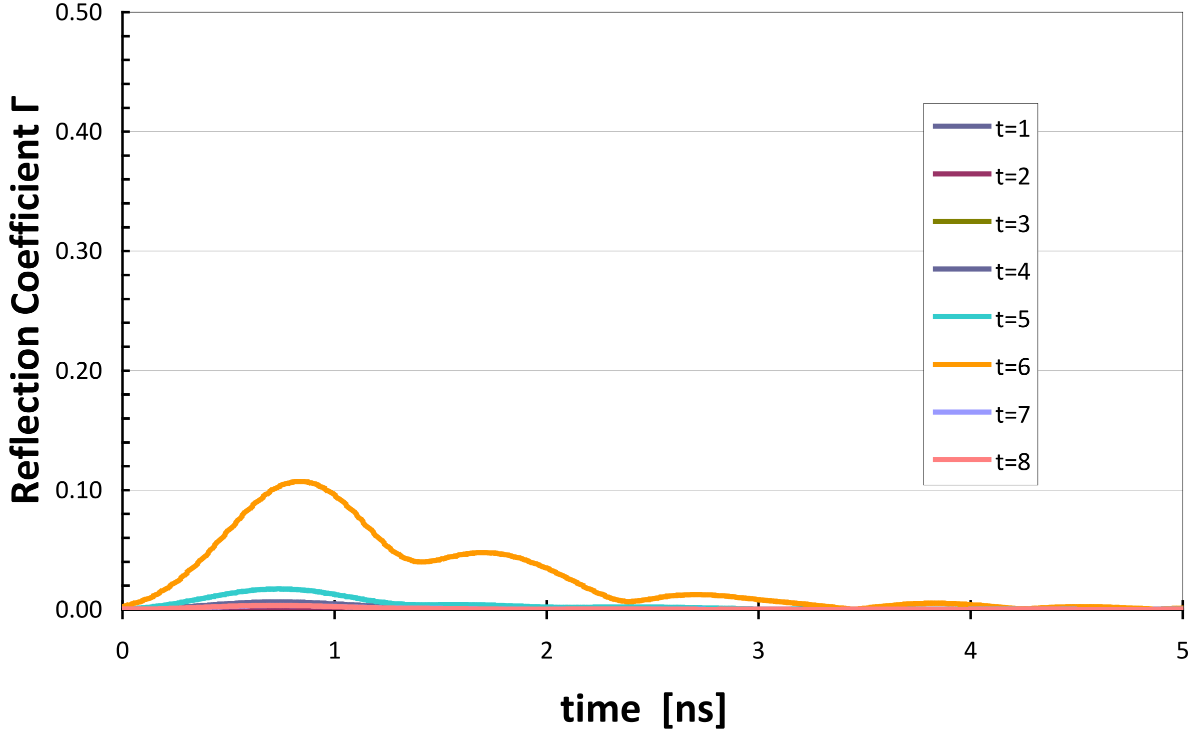
- Circuit 1 (without any components except termination resistor)
- Calibrated using identical circuit on Rogers 4003 board
- Board with ground trace has low reflection
  (circuits without the ground trace under them had high reflection: 0.6)

Application of Shear Stress to Solder Joints



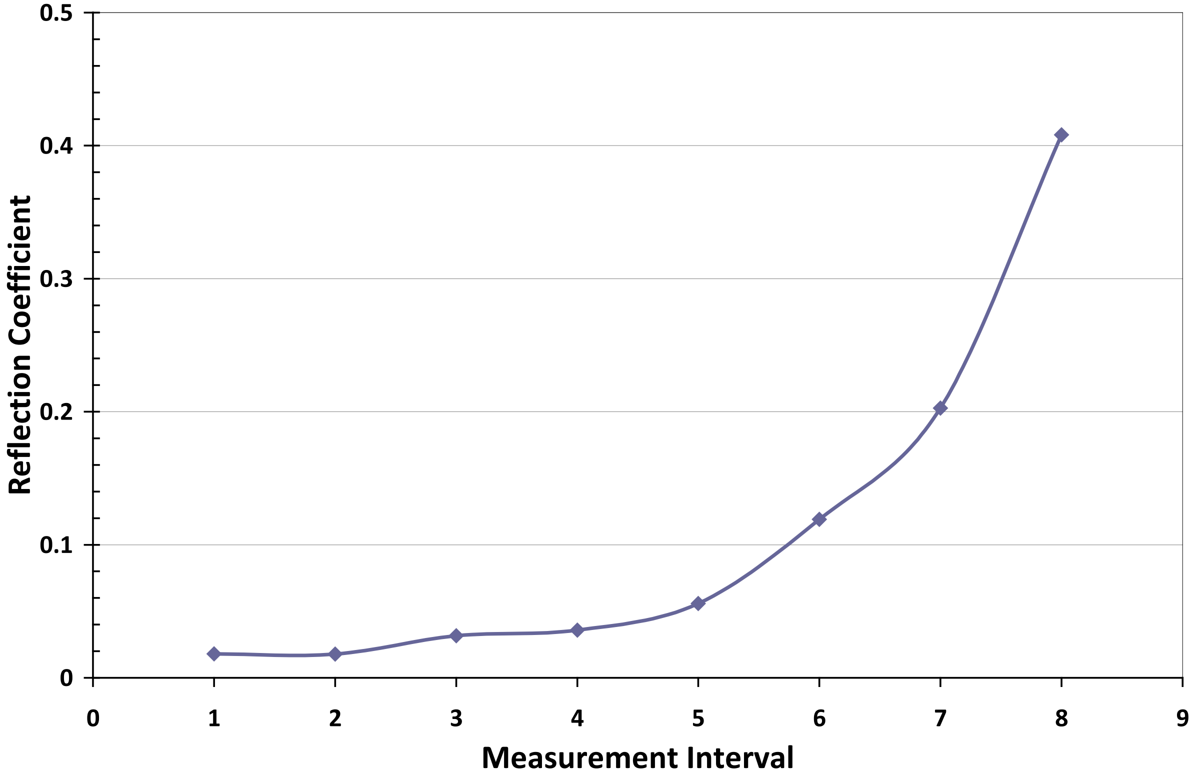
- TDR reflection coefficient was measured in real time as the surface mount component was sheared.

TDR Responses Obtained During a Shear Test on Circuit 3 of the RO4003 Board



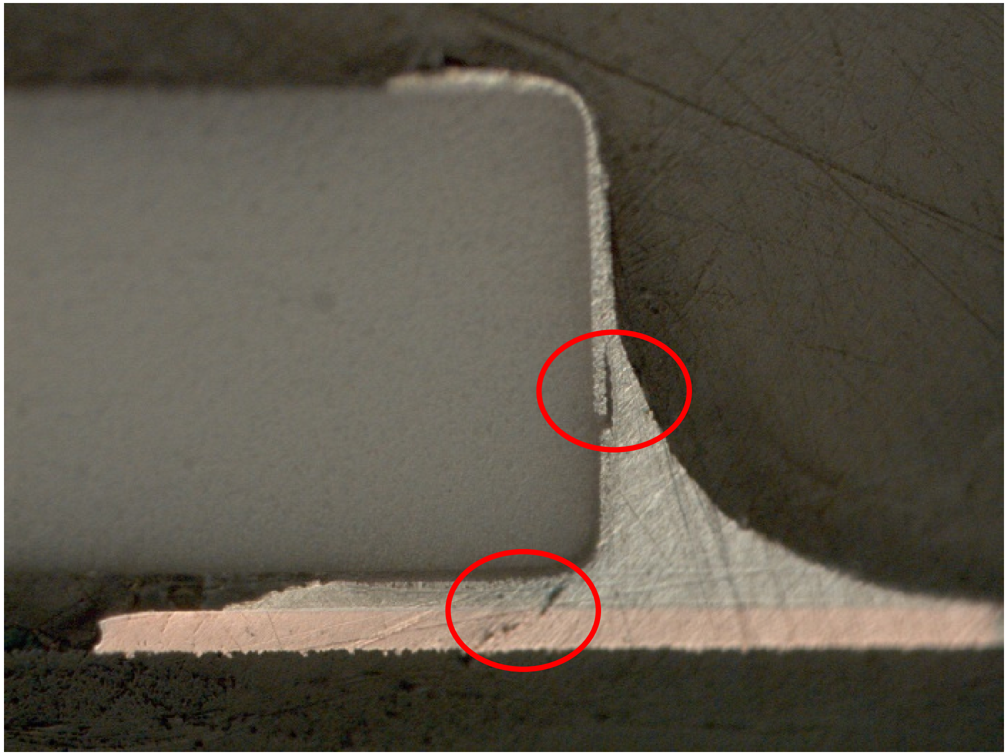
- Calibrated using healthy circuit
- All changes were easily measured against the low initial response.
- Test was manually stopped when reflection coefficient reached ~0.1.
- Possible to detect changes in reflection coefficient as small as 0.01-0.02.

Peak Reflection Coefficients During a Shear Test on Circuit 2 of FR4 Board Without Ground Plane



- Calibrated using healthy circuit
- All changes were easily measured against the low initial response.
- Degradation was easily measurable even on circuit without a ground trace.

Cross-section of Solder Joint after Shear Test of Circuit 3 of an FR4 Board Without a Ground Plane



- Test was manually terminated when reflection coefficient reached ~0.08.
- Results demonstrate that TDR can be used for crack detection on boards without impedance control.

Conclusions

- Health monitoring does not require an absolute measurement of impedance or scattering parameters, only an indication of **change**.
- Detection of interconnect degradation using TDR monitoring is feasible on FR4 substrates.
- Design for impedance control significantly improves TDR resolution and sensitivity.
- Even in the absence of a ground plane, dimensional control combined with a ground trace improves TDR response.
- *With appropriate calibration (reference state), changes in TDR reflection coefficient of as little as 0.02 were detected even on circuits on FR4 boards without a ground trace.*

Thank you.