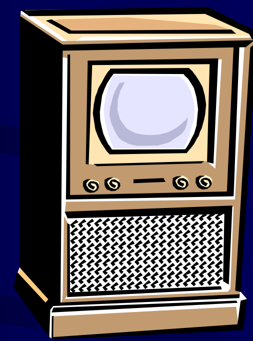
Controlled Impedance & Time Domain Reflectometry (TDR)

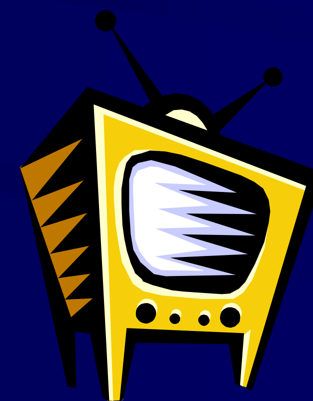
Bob Neves

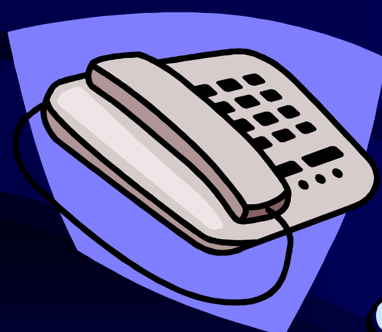
President

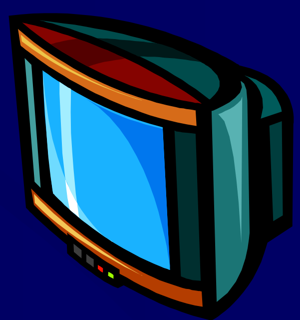
Microtek Laboratories

Circuit Advances

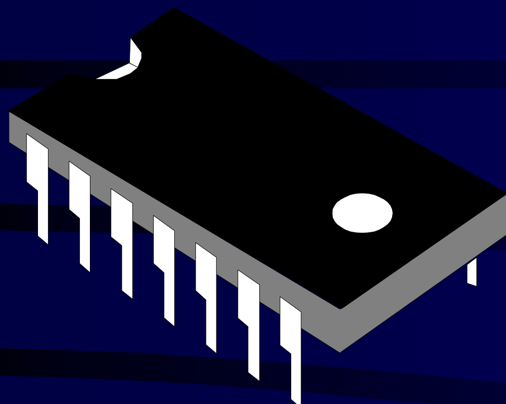


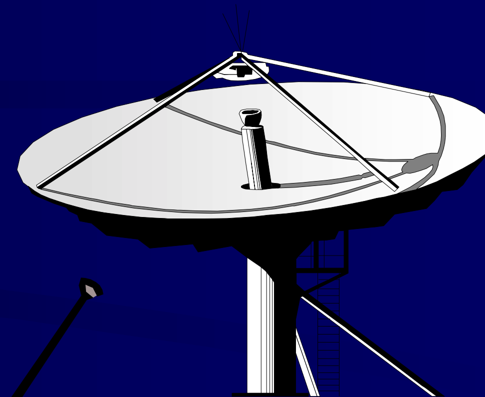


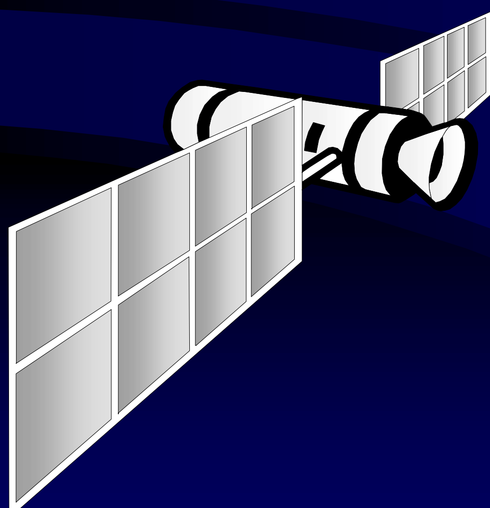


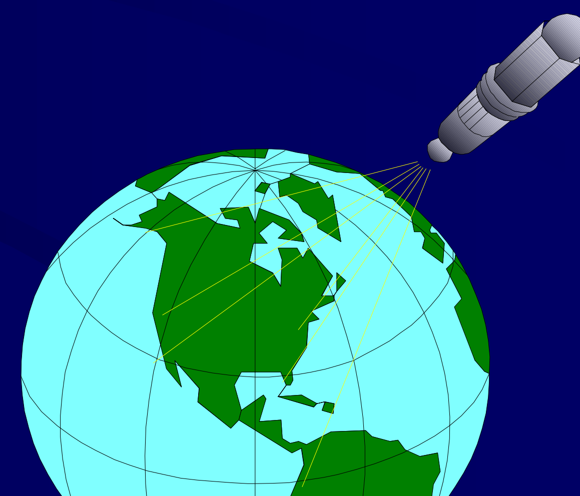


High Speed Electronics



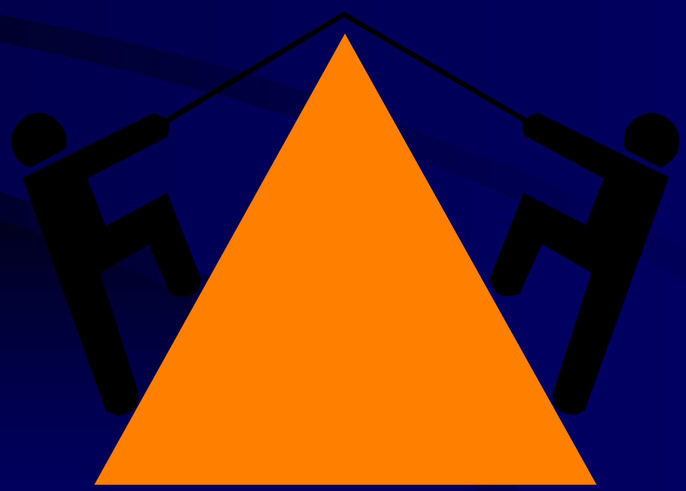






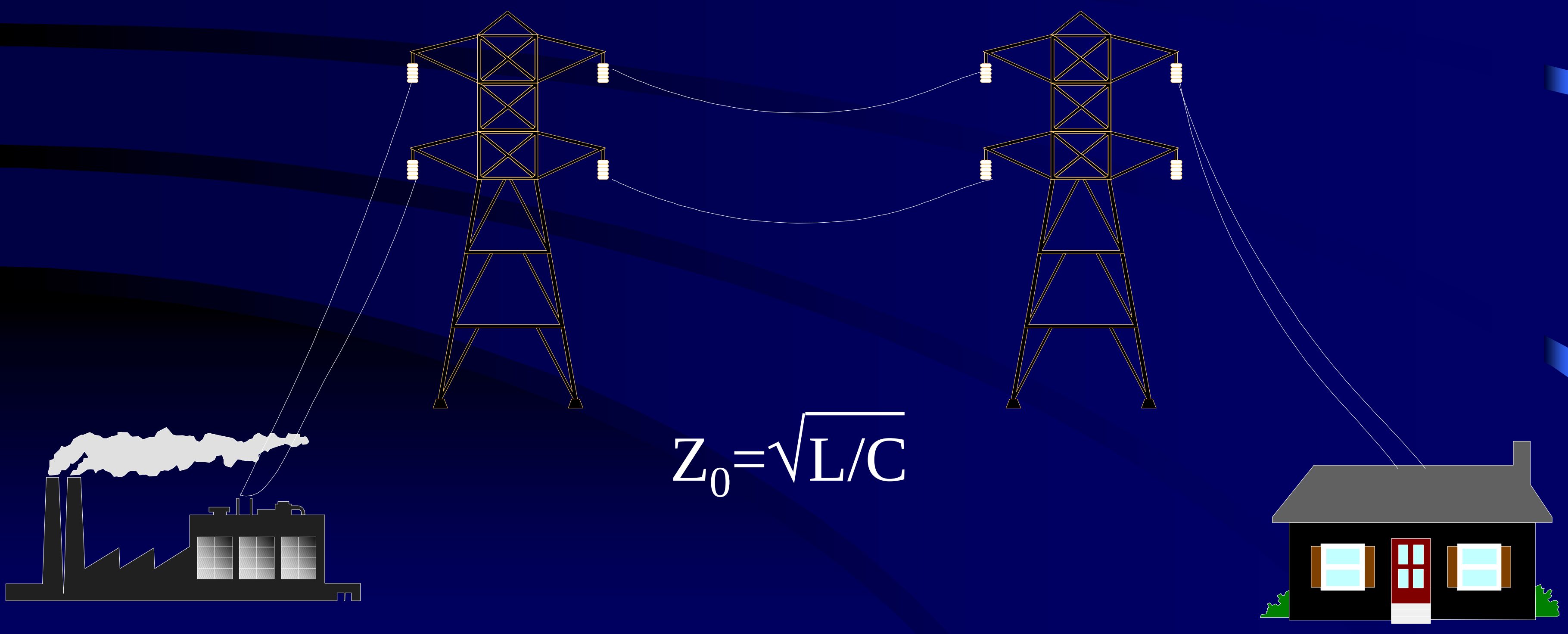
What Is Impedance?

Impedance is defined as the Resistance offered by an Electronic Circuit to an AC Signal



Characteristic Impedance Z_0

The Ratio of Voltage to Current of a Wave Moving Down a Transmission Line



$$Z_0=\sqrt{L/C}$$

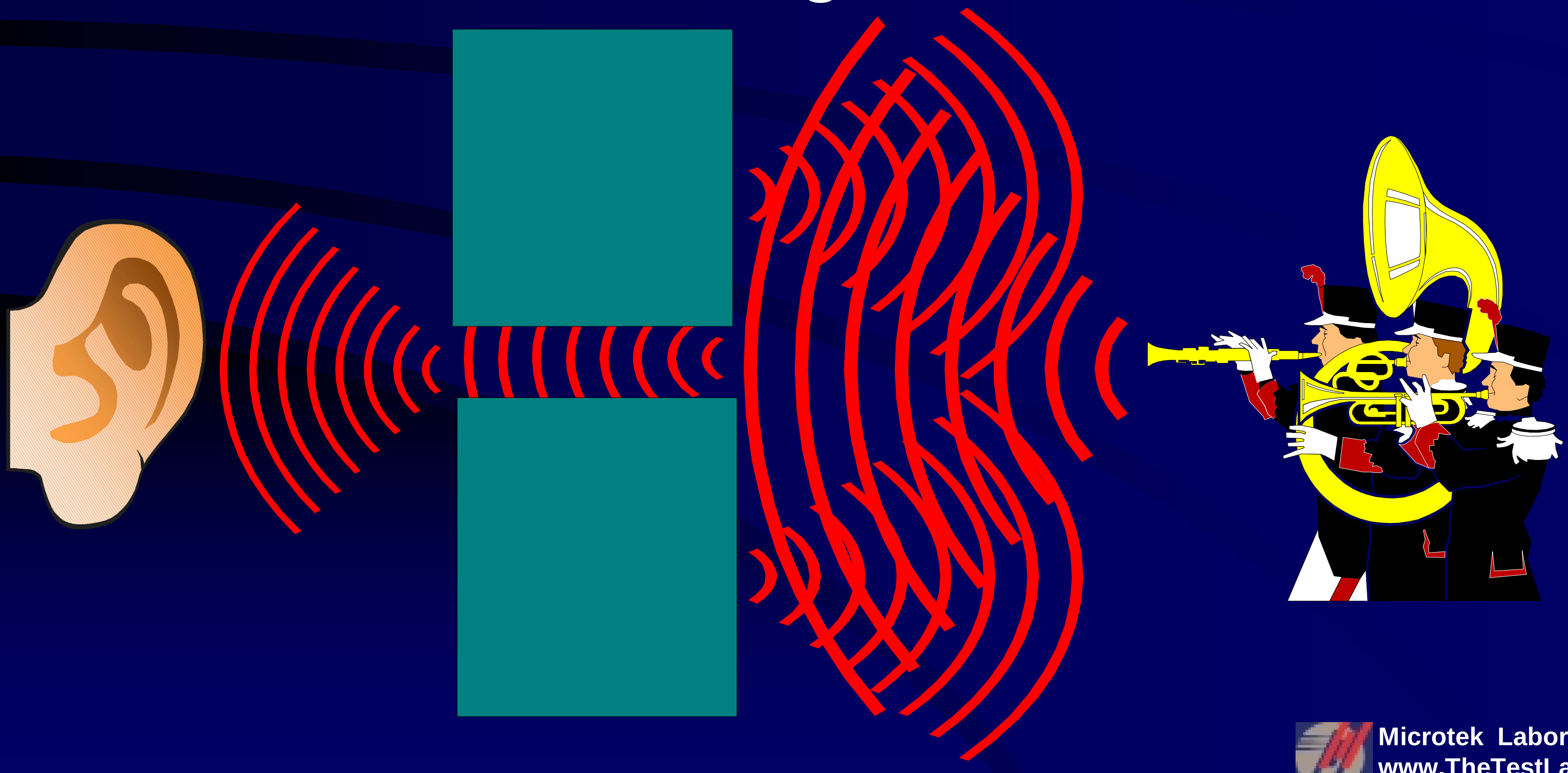
Circuit Impedance “Z”

The Interaction Between The Resistive, Capacitive, & Inductive Portions of the Circuit Load

$$| Z | = \sqrt{R^2 + 2\pi fL - .5\pi fC}$$

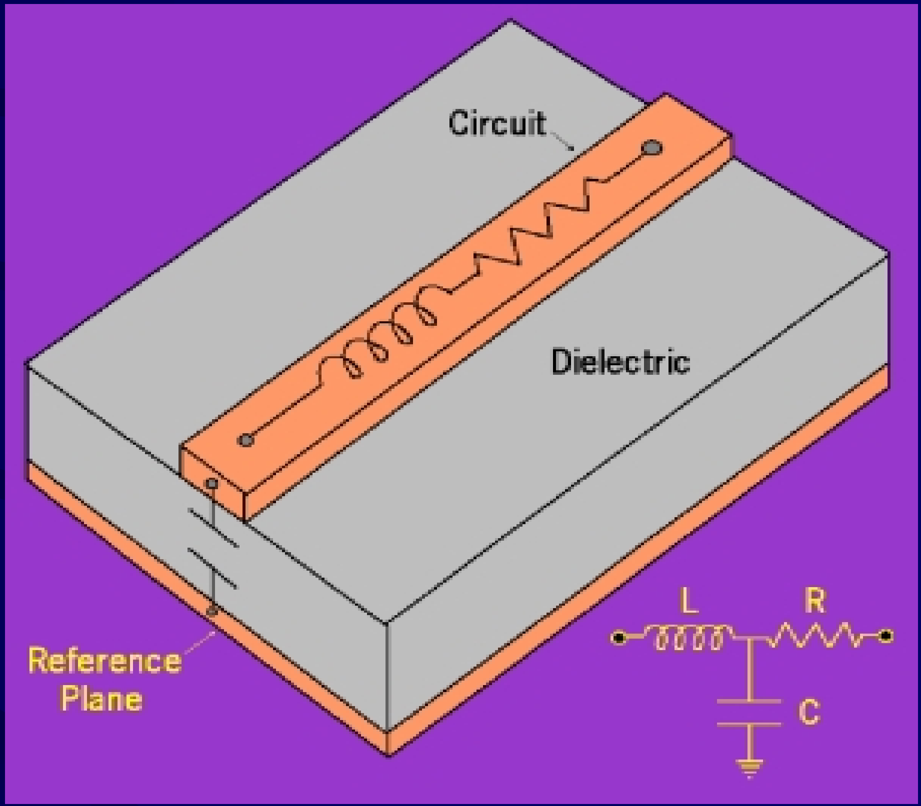
Impedance Matching

Both Circuit & Characteristic Impedance must be matched in order to obtain maximum signal transfer



Impedance Properties of a PWB Trace

- **Capacitance**; Developed Between Circuit & Reference (Maximum Effect on Z_0)
- **Inductance**; Field Created by Signal On Trace (Secondary Effect on Z_0)
- **Resistance**; Signal Attenuation Caused By Trace (Minimal Effect on Z_0)



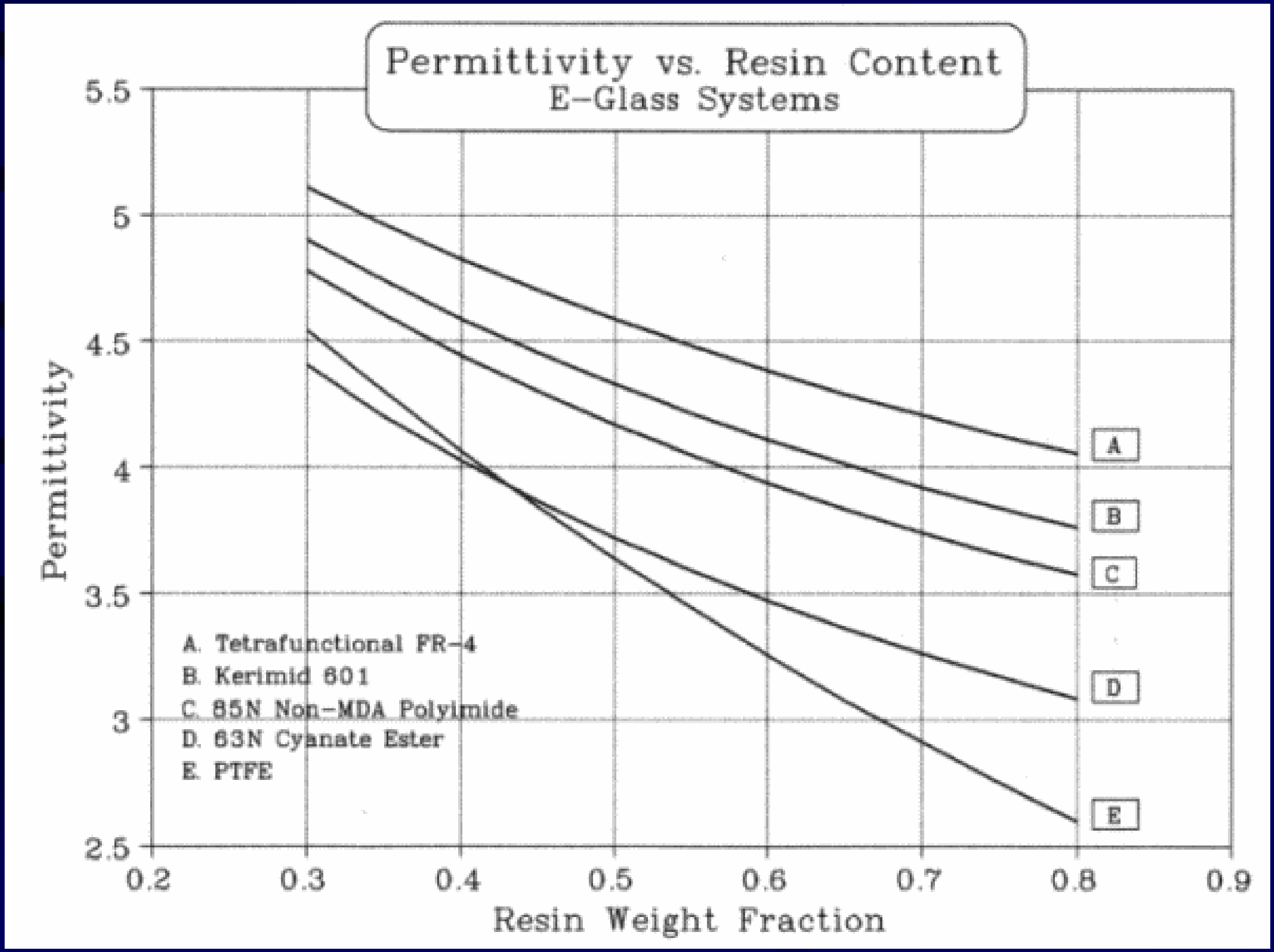
PWB Material Dielectric Properties

- FR-4
  - D_k ~ 4.3 – 5.2
  - Loss ~ 0.015 -.02
- FR-4 (PPO)
  - D_k ~ 3.5 – 4.8
  - Loss ~ 0.007 – 0.012
- Polyimide
  - D_k ~ 3.9 - 4.8
  - Loss ~ 0.009 - 0.015
- PTFE
  - D_k ~ 2.1 – 3.5; 4.5; 10.0
  - Loss ~ 0.0009 – 0.003
- Non-PTFE HF Material
  - D_k ~ 3.2 – 3.5
  - Loss ~ 0.002 - .003
- E-Glass
  - D_k ~ 6.5 – 6.7

PWB Manufacturing Influences on Impedance

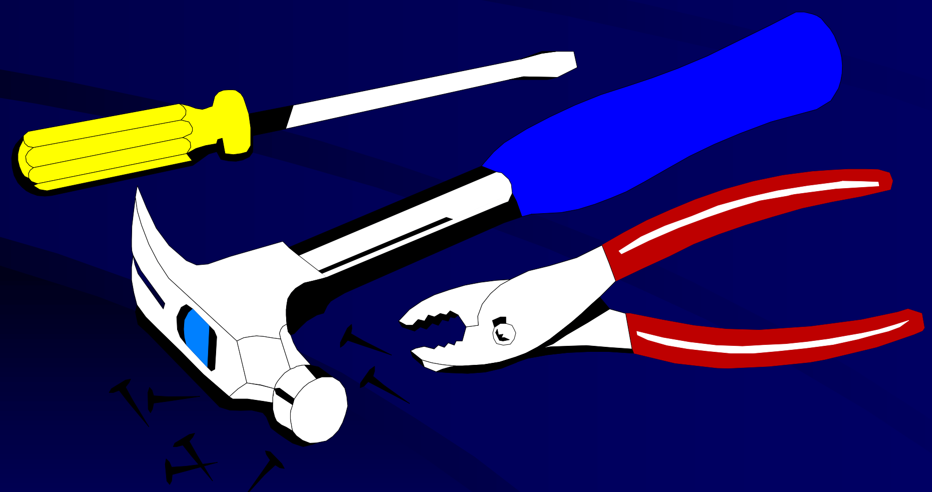
- Dielectric Makeup
  - Glass / Resin Ratio
  - Weave Properties
  - Other Reference Planes
- Lamination Characteristics
  - Resin Squeeze Out
  - Thickness Variation on Panel
- Soldermasks
  - Different Dk
  - Thickness variations
- Conductor Characteristics
  - Line Width Variations
  - Copper Treatment
  - Mouse Bites

Dielectric Constant vs Resin Content



Time Domain Reflectometry (TDR)

Analysis Tool which indirectly measures Characteristic Impedance "Z_0"



TDR Described as "Closed Loop" Radar

Sends Out Pulse and Analyzes Signal Reflections.

Impedance Calculations

Reflection Coefficient

$$\rho = V_{reflected} / V_{incident}$$

Characteristic Impedance (Zo)

$$Z_o = Z_{ref} (1 + \rho) / (1 - \rho)$$

Where:

Z_{ref} = Known (reference) Impedance

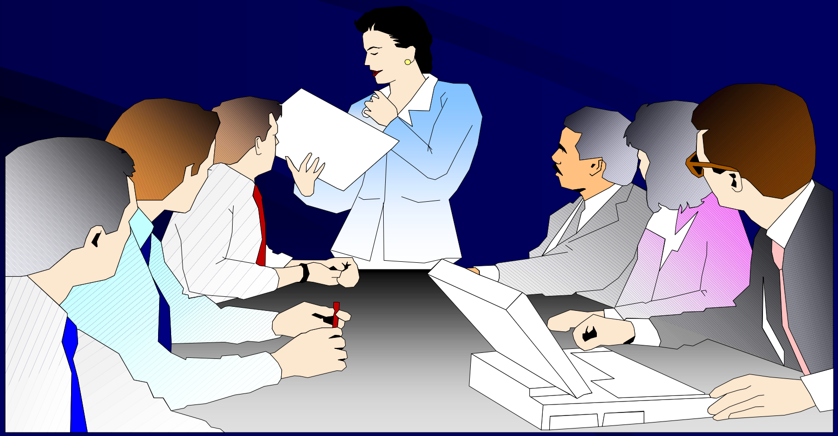
ρ = Measured reflection coefficient

Standardization of Test Methods

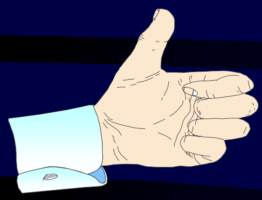
- IPC-TM-650 Method 2.5.5.7
- IEC 1189-3E07

Stored Reference Method

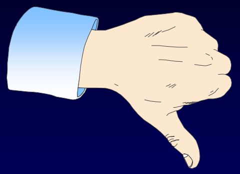
In-Situ Method



Stored Reference Method

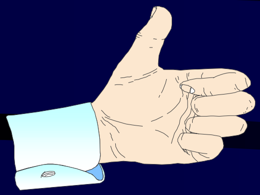


- Stores Reference Impedance Waveform In TDR Memory
- Compares Measured Reflection Coefficient (ρ) To Stored Reference
- Useful When Impractical To Have Reference Impedance In Test Setup

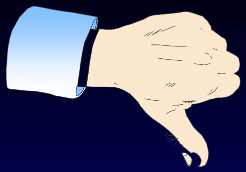


- Can Have Measurement Error From Machine Drift

In-Situ Method



- Utilizes Reference Impedance Standard In Test Setup
- Measures Reflection Of Both Unknown And Reference Standard Simultaneously



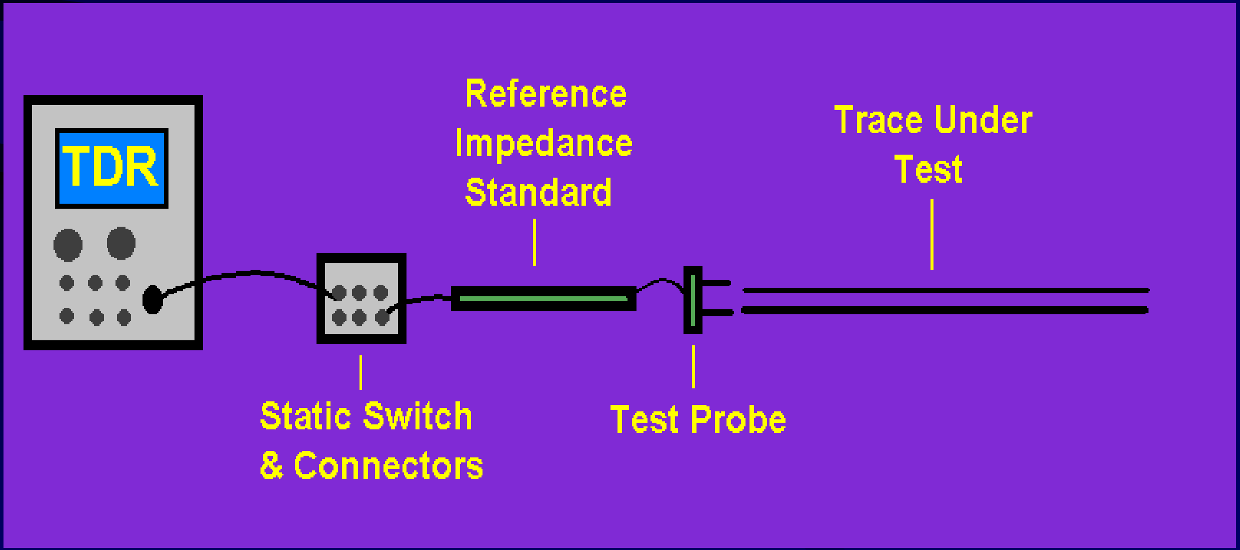
- Reference Standard Increases Cabling Length & Interconnections

RAMBUS Reqirements

- Low Impedance Test Requirements
  - 28 Ω Requirement
  - IPC-TM-650 Method 2.5.5.7.1
  - Intel Technical Report (Controlled Impedance Design & Test
  - Intel: Printed Circuit Board (PCB) Test Methodology (Rev 1.6)
  - Custom Probes & Test Setup

Test System Setup

- Test Probes & Connections
- Interconnection Wiring
- Reference Standard
- Static Protection



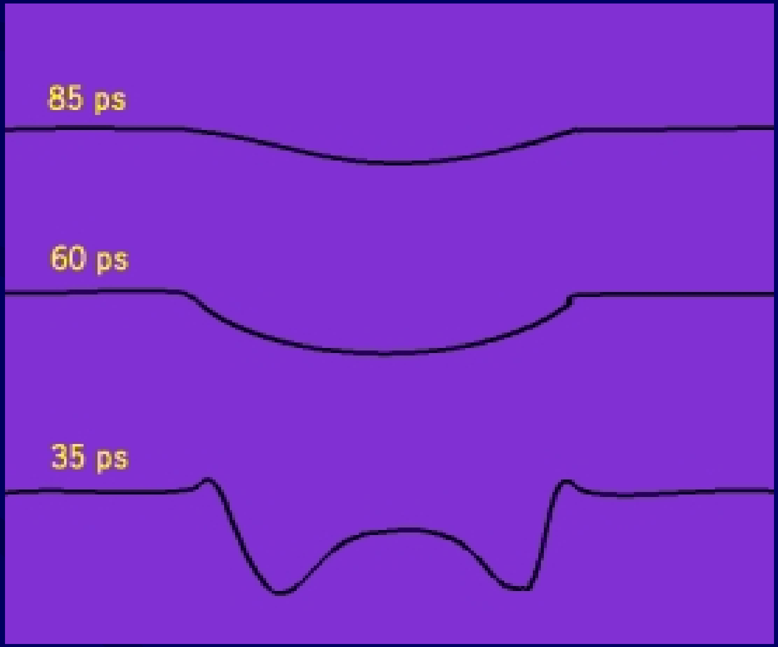
System Performance vs. Signal Pulse Rise Time

System Rise Time Calculation (t_r)

$$t_{r\ system} \cong \sqrt{(t_{r\ step\ gen})^2 + (t_{r\ sampler})^2 + (t_{r\ test\ setup})^2}$$

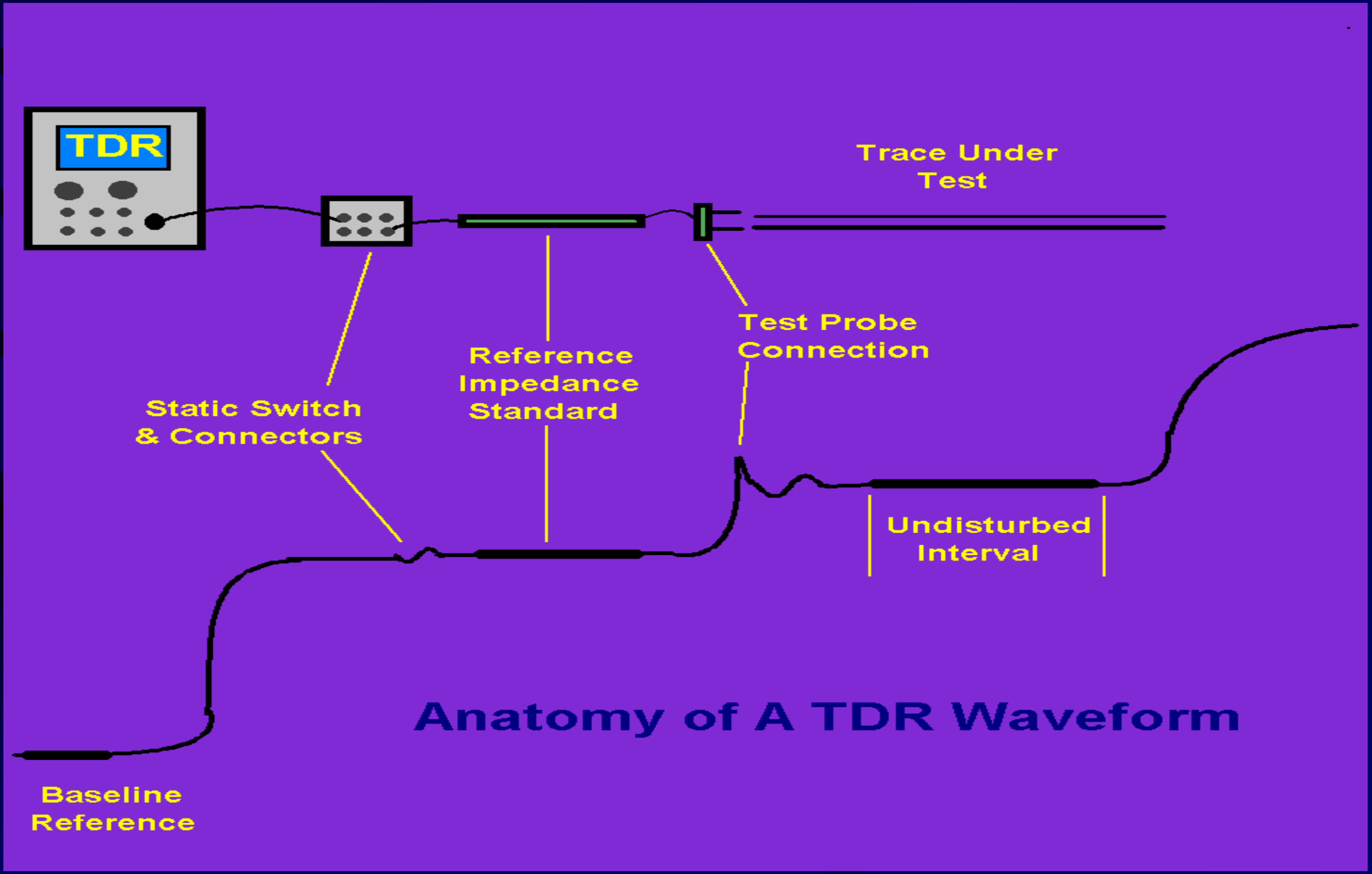
System Rise Times

Two Discontinuities 2mm apart on a GF PWB trace.



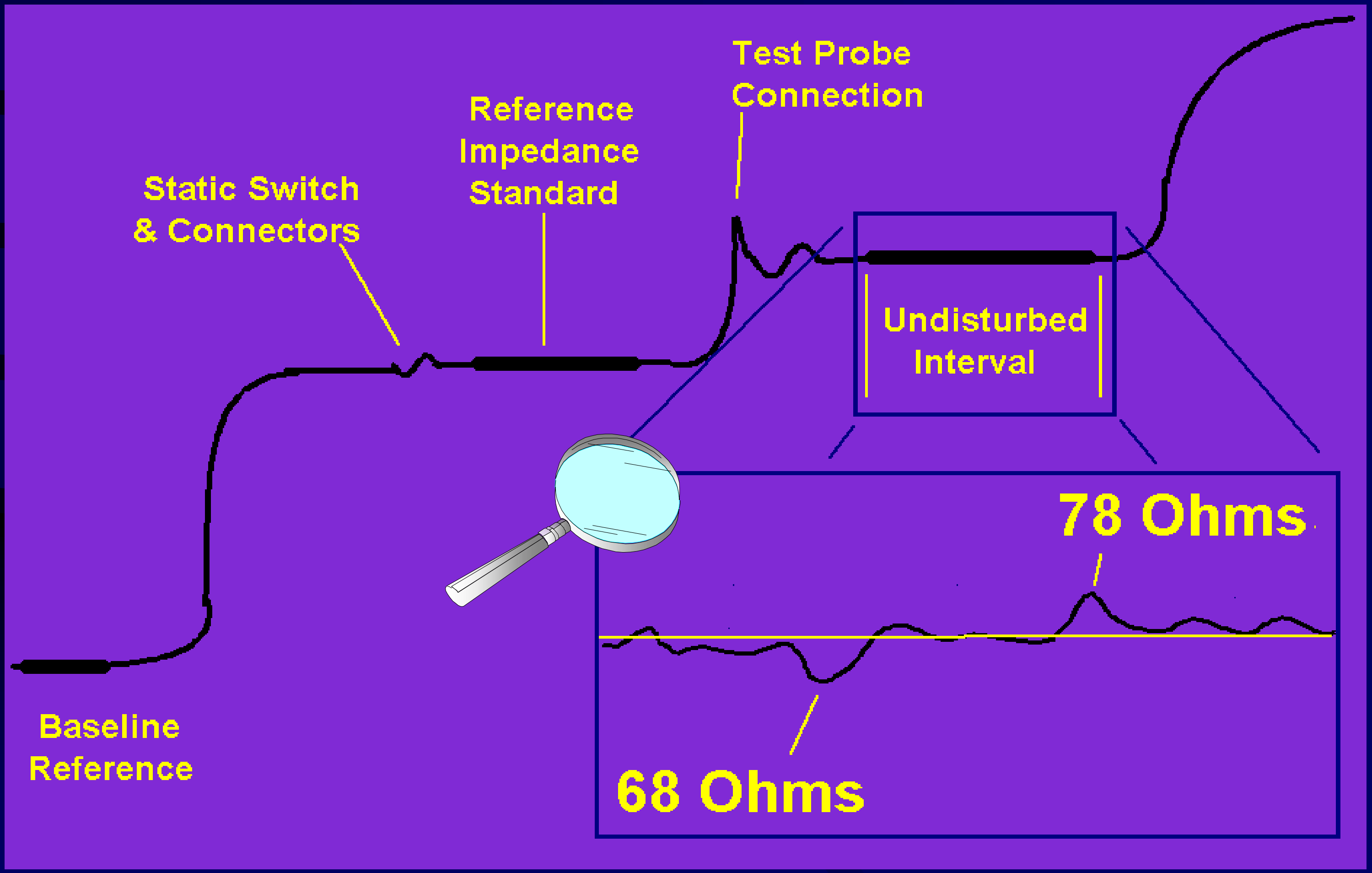
TDR Waveform

Comprised of 512 to 2048 Individual Data Points



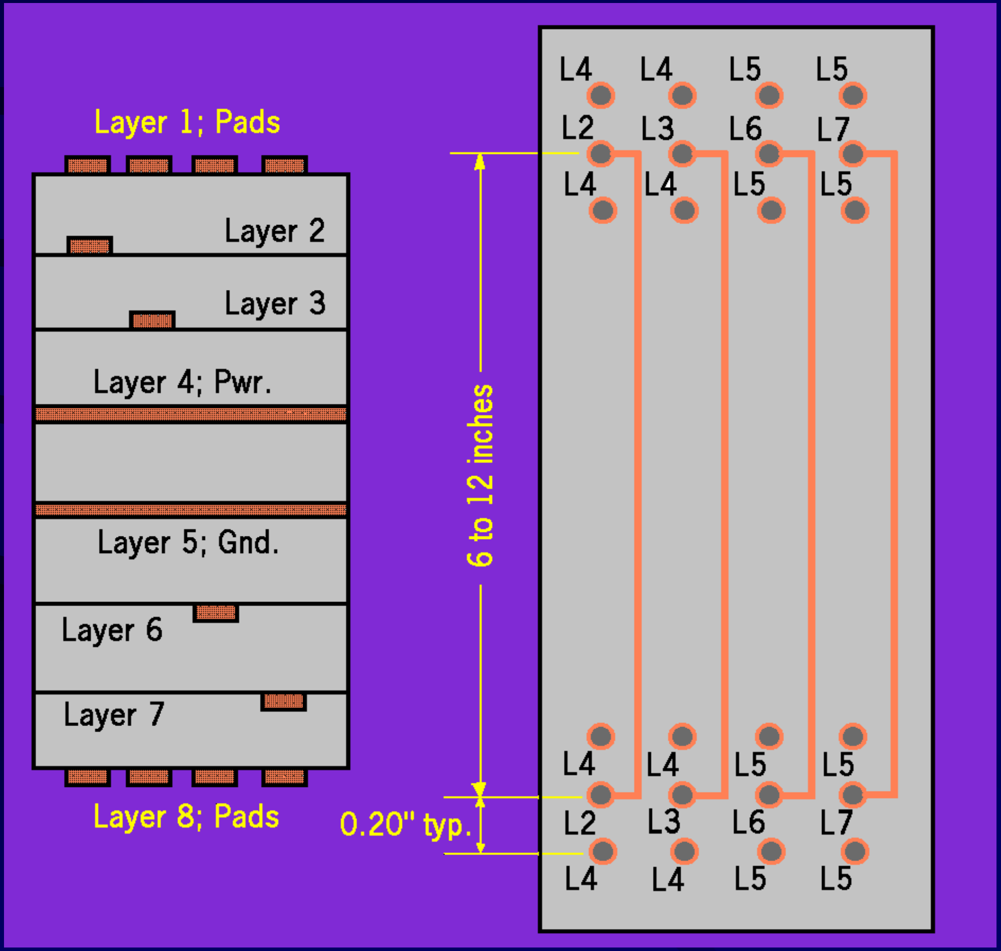
Waveform Analysis

Nominal Zo = 72 Ohms

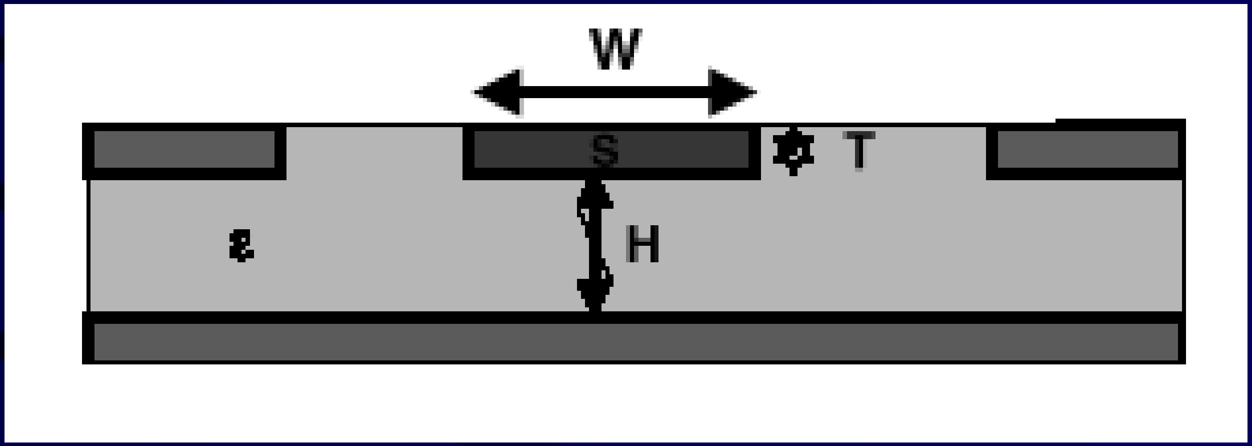


TDR Test Coupon

Representative of PWB Design Characteristics

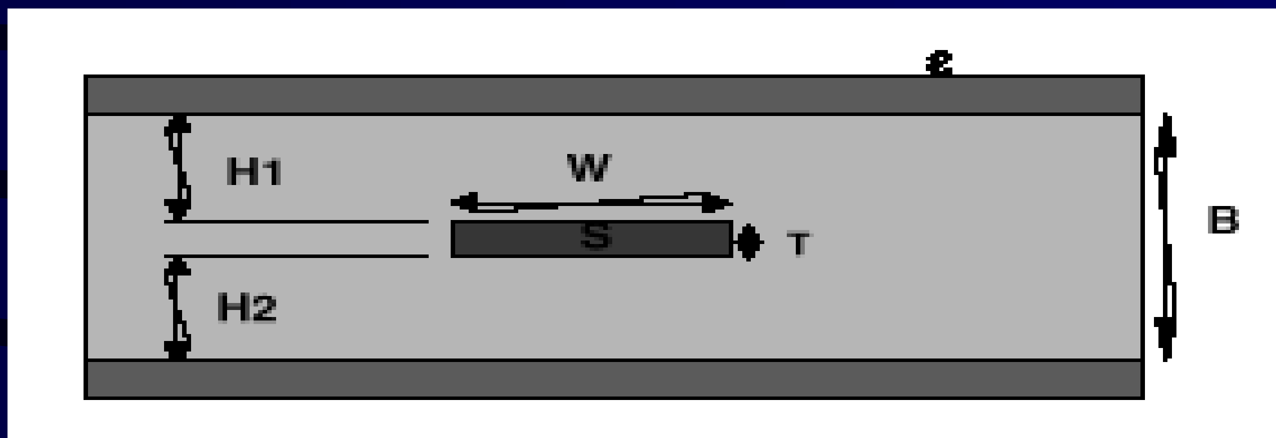


Microstrip Cross Section



W = Trace Width
T = Trace Thickness
H = Trace Height

Stripline Cross Section



W = Trace Width

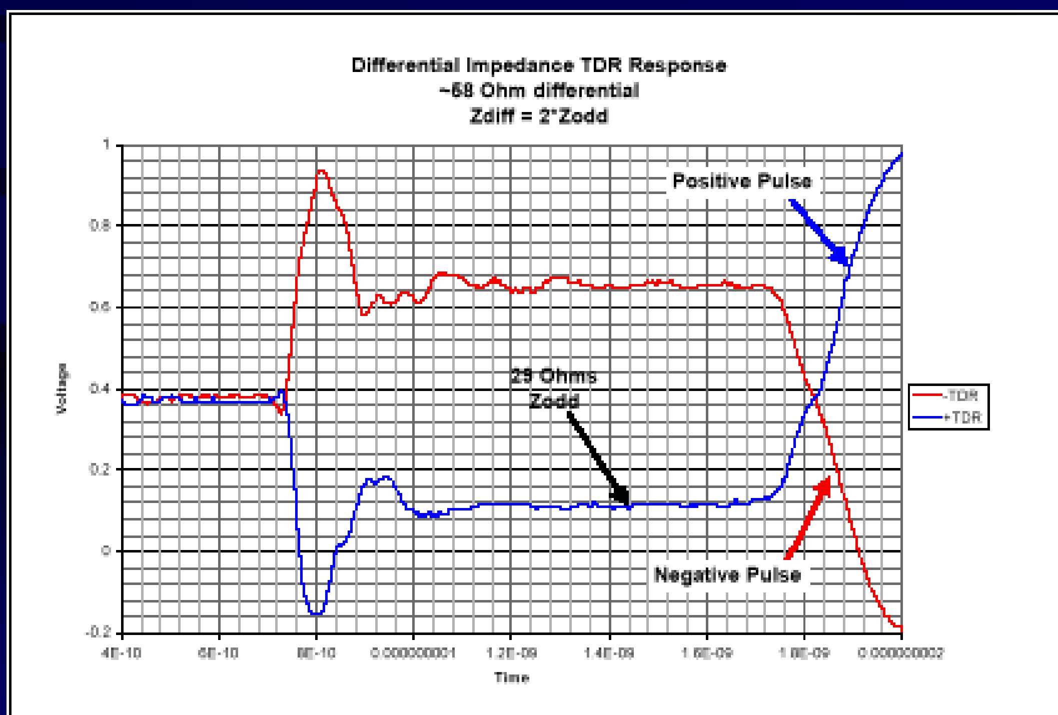
T = Trace Thickness

H1 = 1st Dielectric Thickness

H2 = 2nd Dielectric Thickness

Differential Impedance

- Sends Positive Pulse Down One Line & Negative Pulse Down A Parallel Line



Considerations for Accuracy & Repeatability for TDR Test

- Cable Interconnection Quality

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- Probe Application Force

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- Calculation Variance
- Environmental Conditions

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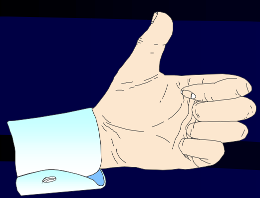
- Cable Interconnection Quality
- Probe Application Force
- Variations in Machine Setup
- Quality of Reference Standard
- Calculation Variance
- Environmental Conditions
- Test Probe Configuration

TDR Equipment

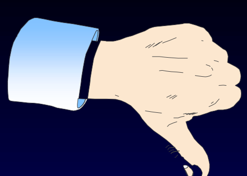
- **Tektronix**
  - **11800 (CSA 803) Series ***
    - **using SD24 TDR test head**
  - **7854 Oscilliscope**
    - **TDR Head**
  - **1502 / 1503 Cable TDR**
- **HP54750A Series ***
  - **HP54753A Single Ended TDR**
  - **HP54754A Differential TDR**
- **Polar CITS500S ***

*** Rambus Approved**

Metallic Cable TDR (Tek 1502/3)

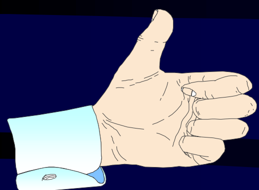


- Easy Setup
- Inexpensive
- Excellent Process Control Tool

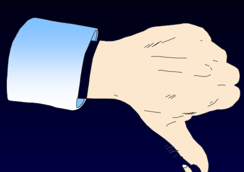


- Slow Rise Time ≈ 200ps
- Single Point Measurement
- Loss of Accuracy at High Z_0

Using Capacitance to Characterize Impedance



- Easy Setup
- Inexpensive
- Excellent Process Control Tool
- Compatible with Point to Point Testers



- Only Measures Capacitive Element of Z_0
- Does Not Account for Inductive
- Portion of Z_0

Conclusions

- Requirements for Specific Impedance Will Increase in the Future
- Accurate Measurement of Characteristic Impedance is Difficult to Obtain
- Standardization is Necessary and Available
- The Test Apparatus and Setup Must be Carefully Considered
- Limitations of TDR Test Must be Understood
- Data Manipulation Must Reflect Design Need

Supplementary Information

- PCB Test Methodology Doc From Intel
- TDR Theory (AN 1304- 2) From HP

- URLs: (Click on to Link)
  - Intel Corporation
    - http://developer.intel.com/ial/home/sp/index.htm
  - Hewlett- Packard
    - www.tmo. hp.com/tmo/
  - Tektronix
    - www.tek.com/Measurement/scopes/
  - Polar
    - www. polar.co.uk