Purpose of Standard

- Originally a DFT technique for PCBs
- Lets test instructions and test data be serially fed into a *component-under-test* (CUT)
  - Allows reading out of test results
- JTAG can operate at chip, PCB, and system levels
- Allows control of tri-state signals during testing
- Lets other chips collect responses from CUT
- Lets system interconnect be tested separately from components
- Lets components be tested separately from wires
Basic Idea of Boundary Scan

A Board Containing 4 IC’s with Boundary Scan
1149.1 Boundary-Scan Architecture

Hardware Components of 1149.1

- A test access port (TAP) consisting of:
  - 4 mandatory pins: Test data in (TDI), Test data out (TDO), Test mode select (TMS), Test clock (TCK), and
  - 1 optional pin: Test reset (TRST)
- A test access port controller (TAPC)
- An instruction register (IR)
- Several test data registers
  - A boundary scan register (BSR) consisting of boundary scan cells (BSCs)
  - A bypass register (BR)
  - Some optional registers
    - Device-ID register, design-specified registers such as scan registers, LFSRs for BIST, etc.
Basic Operations

1. Instruction sent (serially) through TDI into instruction register.
2. Selected test circuitry configured to respond to the instruction.
3. Test pattern shifted into selected data register and applied to logic to be tested
4. Test response captured into some data register
5. Captured response shifted out; new test pattern shifted in simultaneously
6. Steps 3-5 repeated until all test patterns are applied.

System View of Interconnect

[Diagram showing interconnect system with labeled components like System logic input, B/S cell, System 2-state output, System 3-state output, and System bidirectional pin.]
Boundary-Scan Circuitry in A Chip

Data registers

- Boundary scan register: consists of boundary scan cells
- Bypass register: a one-bit register used to pass test signal from a chip when it is not involved in current test operation
- Device-ID register: for the loading of product information (manufacturer, part number, version number, etc.)
- Other user-specified data registers (scan chains, LFSR for BIST, etc.)
A Typical Boundary-Scan Cell (BSC)

- **Operation modes**
  - Normal: IN → OUT (Mode = 0)
  - Shift: TDI → ... → IN → OUT → ... → TDO (ShiftDR = 1, ClockDR)
  - Capture: IN → R1, OUT driven by IN or R2 (ShiftDR = 0, ClockDR)
  - Update: R1 → OUT (Mode_Control = 1, UpdateDR)

TAP Controller

- A finite state machine with 16 states
- Input: TCK, TMS
- Output: 9 or 10 signals included ClockDR, UpdateDR, ShiftDR, ClockIR, UpdateIR, ShiftIR, Select, Enable, TCK and TRST* (optional).
Main functions of TAP controller

- Providing control signals to
  - Reset BS circuitry
  - Load instructions into instruction register
  - Perform test capture operation
  - Perform test update operation
  - Shift test data in and out
States of TAP Controller

- Test-Logic-Reset: normal mode
- Run-Test/Idle: wait for internal test such as BIST
- Select-DR-Scan: initiate a data-scan sequence
- Capture-DR: load test data in parallel
- Shift-DR: load test data in series
- Exit1-DR: finish phase-1 shifting of data
- Pause-DR: temporarily hold the scan operation (e.g., allow the bus master to reload data)
- Exit2-DR: finish phase-2 shifting of data
- Update-DR: parallel load from associated shift registers

Note: Controls for IR are similar to those for DR.

Instruction Set

- BYPASS
  - Bypass data through a chip
- SAMPLE
  - Sample (capture) test data into BSR
- PRELOAD
  - Shift-in test data and update BSR
- EXTEST
  - Test interconnection between chips of board
- Optional
  - INTEST, RUNBIST, CLAMP, IDCONE, USERCODE, HIGH-Z, etc.
**BYPASS Instruction**

- **Purpose:** Bypasses scan chain with 1-bit register

**Execution of BYPASS Instruction**
Execution of SAMPLE Instruction

Execution of PRELOAD Instruction
Execution of EXTEST Instruction (1/3)

- Shift-DR (Chip1)

Execution of EXTEST Instruction (2/3)

- Update-DR (Chip1)
- Capture-DR (Chip2)
Execution of EXTEST Instruction (3/3)

- Shift-DR (Chip2)

![Diagram of Shift-DR (Chip2)]

External Test

- Example of testing interconnects
  - Input: \(X X X X X \ 101 X \ X X X X \ X X X X X\)
  - Output: \(X X X X X \ X X X X \ 000 X \ X X X X\)

![Diagram of External Test Example]
Execution of INTEST Instruction (1/4)

- Shift-DR

Execution of INTEST Instruction (2/4)

- Update-DR
Execution of INTEST Instruction (3/4)

- Capture-DR

Execution of INTEST Instruction (4/4)

- Shift-DR
Internal Test

- Example of testing chip logic
  - Input:  X 1 0 X X   X X X X X
  - Good output: X 0 X X X   X X X X X

RUNBIST Instruction

- Purpose:
  - Allows to issue BIST command to component through JTAG hardware
  - Optional instruction
  - Lets test logic control state of output pins
    - Can be determined by pin boundary scan cell
    - Can be forced into high impedance state
  - BIST result (success or failure) can be left in boundary scan cell or internal cell
    - Shift out through boundary scan chain
  - May leave chip pins in an indeterminate state (reset required before normal operation resumes)
IDCODE Instruction

- Purpose: Connects the component device identification register serially between TDI and TDO
  - In the Shift-DR TAP controller state
- Allows board-level test controller or external tester to read out component ID
- Required whenever a JEDEC identification register is included in the design

Optional / Required Instructions

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td><strong>BYPASS</strong></td>
<td>Mandatory</td>
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<tr>
<td><strong>CLAMP</strong></td>
<td>Optional</td>
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<tr>
<td><strong>EXTEST</strong></td>
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</tr>
<tr>
<td><strong>HIGHZ</strong></td>
<td>Optional</td>
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<tr>
<td><strong>INTEST</strong></td>
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<tr>
<td><strong>RUNBIST</strong></td>
<td>Optional</td>
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<tr>
<td><strong>SAMPLE I PRELOAD</strong></td>
<td>Mandatory</td>
</tr>
<tr>
<td><strong>USERCODE</strong></td>
<td>Optional</td>
</tr>
</tbody>
</table>
Serial Board / MCM Scan

Parallel Board / MCM Scan
Summary

- Boundary Scan Standard has become absolutely essential
  - No longer possible to test printed circuit boards with bed-of-nails tester
  - Not possible to test multi-chip modules at all without it
  - Supports BIST, external testing with Automatic Test Equipment, and boundary scan chain reconfiguration as BIST pattern generator and response compacter
  - Now getting widespread usage