Overview of Testing - Organization

- Purpose of Testing
  ⇒ Why test?
  ⇒ What do we test for?
- Testing During the Product Life Cycle
  ⇒ Typical Product Life Cycle
  ⇒ Life Cycle for Complex Systems
- The Testing Problem
  ⇒ Testing Complexity
  ⇒ Testing Cost
- Other Testing Issues
  ⇒ Types of Testing
  ⇒ Testing Terminology
Overview of Testing

- Purpose of testing is to detect:
  - Design errors during development process
    - Design verification via logic & timing simulation
  - Defects during the manufacturing process
    - Evaluation of test effectiveness via fault simulation
    - Application of tests via test machines at:
      - Wafer level
      - Device level
      - Board level
      - System level (sometimes system acts as test machine)
  - Faults occurring during system operation
    - On-line testing with Error Detection/Correction Codes
    - Off-line testing with system level diagnostic tests
Overview of Testing (cont.)

- Testing during the product life cycle depends on:
  - **Application**
    - toy or home appliance – only manufacturing testing
    - nuclear missile launch system – testing throughout life cycle
  - **System reliability & availability**
    - downtime requirements & cost resulting from downtime
  - **System complexity**
    - repair requirements & repair costs
  - **Cost of product returns**
    - customers’ perception of quality & supplier
  - **Product liability costs**

- Designers/Test Engineers must consider product life cycle
Typical Product Life Cycle

Product Development & Design Verification

Specifications

Architectural Design

Gate Level Design

Transistor Level Design

Physical Design

Device Fabrication

Wafer Test

Packaging

Device Test

Behavioral Simulation

Test Bench

Logic & Timing Simulation

Functional Vectors

Timing Simulation

Functional Vectors

Test Machines

Test Vectors

Gate Faults

Transistor Faults

Bridging Faults
Continued Life Cycle for Complex Systems

- PCB Fabrication
  - Board Test
  - System Assembly
  - System Test

- Shipping & Installation
  - Installation Test
  - In-service
  - Routine Test

- Fault Isolation & Location Test
  - Faulty PCB Replacement
  - Re-Test

- Fault Isolation & Location Test
  - On-line Fault Detection
  - Tests Fail
  - Faulty PCB(s) Shipped for Repair

- System Diagnosis
- Test Machines
- Test Vectors

Manufacturing Facility

System Operation

Overview of Testing

1/30/02
Comments on Product Life Cycle

- Simple, inexpensive, consumer products
  - Relative simple system level testing
  - May throw away faulty PCBs
    - Too expensive to repair

- Complex, expensive, highly reliable/available products
  - Require complex system level testing
    - To ensure fault-free working system
    - To identify faulty replaceable components
  - Will have faulty PCBs repaired
    - PCBs in excess of $1K
    - Too expensive to throw away

- Most systems fall somewhere between these two extremes
The Testing Problem

- Circuit complexity is increasing
  ⇒ more than 2 million transistors/chip is common
  ⇒ embedded cores⇒chips⇒MCMs⇒boards⇒systems
  ⇒ mixed-signal chips and systems (digital & analog)
  ⇒ new technologies introduce new kinds of faults
- Risk of manufacturing/fabrication defects is increasing
  ⇒ larger die size: more area ⇒ more defects
  ⇒ smaller feature size: thinner & closer lines ⇒ more opens/shorts
  ⇒ new defect models: closer lines ⇒ more cross-talk
  ⇒ higher performance: more critical paths ⇒ more delay faults
The Testing Problem (cont.)

- Test accessibility is decreasing
  - ICs have more gates & fewer pins
    - Pin count increased 1 order of magnitude in 20 years
    - Transistor count increased 5 orders of magnitude in 20 years
  - 2-sided surface-mount components & multi-layer PCBs
    - In-circuit testing is no longer feasible

- Cost of developing tests is increasing
  - **Dataquest**: 22% (1988) \(\Rightarrow\) 40% (today) of chip dev. cost
    - Manual test development requires 12-24 people-months
  - Algorithmic complexity of test CAD tools \((n = \# \text{ gates})\)
    - Fault simulation = \(O(n^2)\) vs. ATPG = \(O(n^3)\)
    - “Classical” fault models are no longer accurate
      - Accurate fault models difficult to simulate/emulate
The Testing Problem (cont.)

- Automatic Test Equipment (ATE) cost is increasing
  ⇒ production ATE to test a $50 VLSI chip > $1M
    ☐ *Sematech* predicts chip tester in 2010 will cost ~ $20M
  ⇒ at-speed testing needs more expensive ATE

- Product testing goes on long after design is complete
  ⇒ cumulative testing cost must be considered
  ⇒ cost of fault location/identification and repair

![Cost per Fault](chart)

Note: *Sun Microsystems* claims multiplier > 10 for complex systems
Other Testing Issues & Terminology

• Test stimuli source:
  ⊙ internal - *self-testing*
  ⊙ test machine - *external testing*

• Signals used for test:
  ⇒ only I/O signals
    ⊙ devices – *I/O pin testing*
    ⊙ PCBs - *edge-connector testing*
  ⇒ I/O and internal signals
    ⊙ PCBs only - *bed-of-nails testing, in-circuit testing*

• Speed of test application:
  ⊙ slower than normal operation - *static testing*
  ⊙ at normal operation speed - *at-speed testing*
Other Testing Issues & Terminology (cont.)

- **Output response analysis**
  - look at the complete output response $R$
    - larger memory requirements to store all output responses
  - look at a compressed response $f(R)$ - *compacted testing*
    - higher probability of faulty circuits escaping detection

- **Checking the output response:**
  - the system checks itself - *self-testing*
  - a test machine - *external testing*

- **Type of output responses checked:**
  - logic values - *logic testing*
  - output response time (set-up/hold time) - *speed testing*
  - I/O voltages & currents - *parametric testing*
  - power supply current – *$I_{DDQ}$ or $I_{DDt}$ testing*
Other Testing Issues & Terminology (cont.)

- System level testing:
  - concurrent with normal operation - on-line testing
  - while system is out-of-service - off-line testing

- Test sequence:
  - fixed, always apply same test - pre-computed testing
  - dynamic, based on test results thus far - adaptive testing

- Ultimate goal of test:
  - Quality: # defective products shipped to customers?
  - Quality target: typically < 100 DPM (Defects Per Million)
  - But how do we evaluate and ensure the quality?