

# Testing Digital Systems I

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## Lecture 2: Types of Test

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# Testing Principle

- Performed by
  - Automatic Test Equipment (ATE)
  - On-chip Built-in Self Test (BIST)

The diagram illustrates the testing principle. It shows a flow from input patterns to a digital circuit, then to output responses, and finally to a comparator which produces a test result. The input patterns are represented as a vertical list: ---11, ---00, ---, ---01. The output responses are: 10--, 00--, ---, 01--. The comparator also receives a 'STORED CORRECT RESPONSE' and outputs the 'TEST RESULT'.


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## Tests for Manufacturing Defects

- Chip
  - Production Test
    - Wafer Sort or probe
      - Test Site
      - Die
    - Final Package
    - Burn In
    - Outgoing inspection
    - System Test
  - Incoming Inspection or Acceptance
- Board
  - In-Circuit or Bed-of Nails
  - Functional or Edge Connector
- System


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## Testing For Wearout Defects

- On-Line Testing or Checking
  - Concurrent checking techniques are designed to ensure that error is reported when the system produces incorrect outputs
    - Data Integrity
  - Techniques
    - Embedded Checkers – Error Detection
    - Periodic Diagnostic Programs
    - Watchdog Checks
- Repair or Diagnostic Tests


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## Testing For Transient Disturbances

- On-Line Testing or Checking
  - Embedded Checkers – Error Detection
  - Watchdog Checks


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## Important Observation

- Part can Operate Correctly with a Defective Component
  - Defect isn't Bad Enough to Prevent Correct Operation
    - CMOS gate-oxide short,
    - low  $\beta$ , ...
  - Can cause intermittent errors**
  - Component is Redundant


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## Major Testing Categories

- **Implicit**
  - On-Line Test for Run-time Errors
    - Concurrent Checking, Monitoring, Built-in Test
- **Explicit**
  - Test for permanent defects
  - Referred to as “off-line testing” or simply “testing”


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## Implicit Testing

- **Concurrent Checking, Monitoring, On-Line Test, Built-in Test**
  - Test of operational system - Normal system inputs
  - Errors detected as they occur
  - Temporary as well as permanent faults
  - Identifies failed units for repair
- **Circuit level techniques**
  - Hardware faults detected
  - Prevents undetected data errors
- **System level techniques**
  - In Addition, Detect Control and Software Faults
    - Control flow checking


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## Implicit (Concurrent) Testing

- System level techniques
  - Memory Protection
  - Watchdog Timer
  - Watchdog Processor
    - Generalization of watchdog timer
    - Small processor operating in parallel with checked processor


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## Implicit (Concurrent) Testing

- Circuit level techniques
  - Registers and Busses - parity code
  - RAM - Modified Hamming Code
  - Arithmetic Unit - Residue Code or Parity Prediction
  - Duplication


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## Temporary Failures

- **Transient**
  - Caused by environmental disturbances such as power-supply disturbances, electromagnetic interference, and radiation sources in space or terrestrial environments
  - Conductively Coupled - Supply voltage dip
  - Air coupled
    - Electromagnetic
    - Electrostatic
- **Intermittent**
  - Caused by flaws or latent manufacturing defects
  - Resulting in loss of noise margin, drive capability
    - Pattern sensitive faults


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## Explicit Testing

- **Off-line test for permanent faults**
  - Special test inputs used
- **Output response analysis**
  - Stored Response
  - Comparison (gold unit)
  - Compact Testing
    - Signature Analysis (LFSR)


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## Explicit Test Techniques

- Parametric Test
  - measures electrical properties of pin electronics
    - delay, voltages, currents, etc.
    - fast and cheap
  - Measure or "threshold" analog parameters
    - DC — Voltage levels, drive current, power,...
    - AC — Rise, fall, delay times
- Boolean Test
  - Digital test of logic operation
  - Also called functional test
- Quasi-Boolean Test (AC test)
  - Delay Fault Test


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## Explicit Tests According To Purpose

- Characterization Test
- Production or Manufacturing Test
- Reliability (Accelerated Life) Test
- Stress Screen (Burn-In) Test
- Acceptance or Incoming Inspection
- Quality Test
- Repair, diagnosis, fault location


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## Characterization Test

- Performed on new designs
- Measurement of Device Parameters and their Interactions
- performed on a sampled parts from different manufacturing lots
  - to account for process variation
- All Practical Combinations of
  - Supply Voltage
  - Temperature
  - Timing Conditions
  - Parametric Variations
- Shmoo Plot
- Used to
  - Set Final Specifications
  - Identify Areas to Improve Process to Increase Yield

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## Characterization Test (cont)

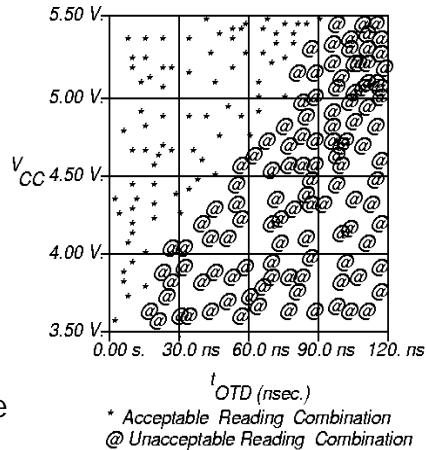
- Worst-case test
  - Choose test that passes/fails chips
  - Select statistically significant sample of chips
  - Repeat test for every combination of 2+ environmental variables
  - Plot results in *Shmoo plot*
  - Diagnose and correct design errors
- Less intensive characterization test performed during production life of chips to improve design and process to increase yield

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## Shmoo Plot

- Identify manufacturing defects.
- Identify areas where the manufacturing process steps (e.g., process optimization, wafer/batch monitoring parameters and procedures) and design characteristics (e.g., clock system design, timing critical paths) can be improved in order to increase yield.



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## Production Or Manufacturing Test

- Sort Out Defective Parts
- Bin Parts for Different Specifications
- Must cover high coverage of modeled faults
- Must minimize test time (to control cost)
- No fault diagnosis
- Tests every device on chip
- Only checked whether the part will operate according to specification
- Both mechanical properties such as package seal, and the electrical properties must be tested
- Test at speed of application or speed guaranteed by supplier

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## Production Or Manufacturing Test

- Chip
  - Wafer Sort or Probe
    - done before wafer is scribed and cut into chips
    - Includes test site characterization
      - specific test devices are checked with specific patterns to measure:
        - Gate threshold
        - Polysilicon field threshold
        - Poly sheet resistance, etc.
    - Final Package test
    - IDDq
    - Very-Low Voltage (VLV)
    - Burn In
    - System test

} As a part of reliability test


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## Electrical Test During Wafer Sort

- Gross Tests
  - Test for gross defects, e.g., Iddq, pin leakage, opens, shorts, etc.
- DC or Static Parametric Tests
  - Measure voltage, current and power levels.
- AC Parametric Tests
  - Timing measurements of parameters such as propagation delay, setup and hold times.
- Boolean Tests
  - Ensure correct device logic behavior.
- Semi-Boolean (Delay) Tests
  - Ensure path delays are within specifications.


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## Production Or Manufacturing Test

- Board
  - Bare Board
  - In-Circuit or Bed-of Nails
  - Functional or Edge Connector


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## Reliability (Accelerated Life) Test

- Test to Estimate Time to Failure in Normal Operation
  - Part is tested after high temperature and high voltage stress
  - Attention is paid so that the lifetime of defect-free parts is not significantly degraded due to stresses


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## Stress Screen (Burn-in) Test

- Some chips that pass production test will fail very quickly thereafter
- Process:
  - Subject chips to high temperature & over-voltage supply, while running production tests
    - 40% above normal supply voltage, temperature above 100 C, time of 30 hours
    - forcing failure in these "weak" chips
- Catches:
  - *Infant mortality* cases (short burn-in time required)
    - these are damaged chips that will fail in the first 2 days of operation – causes bad devices to actually fail before chips are shipped to customers
  - *Freak failures* (long burn-in time required)
    - devices having same failure mechanisms as reliable devices

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## Acceptance Or Incoming Inspection

- Test to Determine Degree of Compliance with Purchaser's Requirements
- Can be:
  - Similar to production testing
  - More comprehensive than production testing
  - Tuned to specific systems application
- Often done for a random sample of devices
  - *Sample size* depends on device quality and system reliability requirements
  - Avoids putting defective device in a system where cost of diagnosis exceeds incoming inspection cost

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## Quality Test

- Sample of Each Lot Tested
- Used by Quality Assurance Department
- Estimates Quality Level of Manufactured Parts



## Repair, Diagnosis, Fault Location


- Test to Locate Failure Site on Failed Part
  - Board or boards in system
  - Chip or chips on board
  - Net on chip
- Purpose
  - Return system or board to correct operation
  - Improve chip yield, reliability, quality



## Repair, Diagnosis, Fault Location

- Software Diagnosis Techniques
  - Fault simulation => probable fault location
- 1. Pre-calculated fault dictionaries
- 2. Post-test fault simulation

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## Repair, Diagnosis, Fault Location

- Hardware Diagnosis Techniques
  - Direct observation
    - place chip in failed state
    - observe image
      - light emission
      - thermal effects
      - focused electron beam interaction
  - Measure chip response to outside physical stimulus
    - scan chip with laser, electron beam, ion beam
    - monitor chip I/O, power supply
- Limitations
  - Defect dependent
    - Some defects don't emit light or cause heating
  - Needs access to chip transistors and internal wiring


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## Repair, Diagnosis, Fault Location

- Deprocessing
  - Remove chip layers until defect is isolated
    - ultra-fine probes
    - microscopes
      - optical, scanning-electron, scanning-probe

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## Testing Taxonomy

```

graph TD
    Testing --> DV[Design Verification]
    Testing --> ET[Explicit Testing]
    Testing --> IOT[Implicit Testing Or On-line Testing]
    ET --> Char[Characterization]
    ET --> PT[Production Test]
    ET --> RT[Reliability Test]
    ET --> QT[Qualification Test]
    ET --> Diag[Diagnosis]
    PT --> WS[Wafer Sort]
    PT --> PKT[Package Test]
    PT --> IDDQ[IDDQ]
    PT --> VLV[VLV]
    PT --> BI[Burn-in]
    PT --> MinVdd[Min Vdd]
    PT --> SHOVE[SHOVE]
    PT --> ST[System Test]
    WS --> GT[Gross Test]
    PKT --> DCP[DC parametric Test]
    PKT --> ACP[AC parametric Test]
    BI --> BT[Boolean Test]
    BI --> QBT[Quasi-Boolean (Delay) Test]
    
```

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## Types of Test

Production Test	Tests to sort out defective manufactured parts
Wafer Sort or Probe	Test of each die while still on the wafer
Final or Package Test	Test of packaged chips and separation into classes or bins (military, commercial, industrial)
Acceptance Test	A test to demonstrate the degree of compliance of a device with purchaser's requirements
Sample Test	Test of some but not all parts
Go / No Go Test	Test to determine whether device meets specification
Characterization	Test to determine actual values of device AC and DC parameters and the interaction of parameters. Used to set final specifications and to identify areas to improve process to increase yield.
Stress Screening	Test with stress (high temperature, temperature cycling, voltage, vibration, etc.) applied to eliminate short life parts
Reliability Test (Accelerated Life Test)	Test after subjecting the part to extended high temperature or voltage to estimate time to failure in normal operation
Diagnostic Test	Test to locate failure site on failed part
Quality Test	Test by quality assurance department of a sample of each lot of manufactured parts. More stringent than final test.
On-line Test*	On-line testing to detect errors that occur during normal system operation.
System Test	Test by plugging a device into an actual system and running the system.
Design Verification	Verifying the correctness of a design

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