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# Logic and Computer Design Fundamentals

## Chapter 3 – Combinational Logic Design

### Part 2 – Programmable Implementation Technologies

Charles Kime & Thomas Kaminski

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## Overview

- Part 1 - Implementation Technology and Logic Design
  - Design Concepts and Automation
    - Fundamental concepts of design and computer-aided design techniques
  - The Design Space
    - Technology parameters for gates, positive and negative logic and design tradeoffs
  - Design Procedure
    - The major design steps: specification, formulation, optimization, technology mapping, and verification
  - Technology Mapping
    - Mapping from AND, OR, and NOT to other gate types
  - Verification
    - Does the designed circuit meet the specifications?
- Part 2 - Programmable Implementation Technologies
  - Read-Only Memories, Programmable Logic Arrays, Programmable Array Logic
    - Technology mapping to programmable logic devices

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## Overview

- Why programmable logic?
- Programmable logic technologies
- Read-Only Memory (ROM)
- Programmable Logic Array (PLA)
- Programmable Array Logic (PAL)
- VLSI Programmable Logic Devices - covered in VLSI Programmable Logic Devices reading supplement

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## Why Programmable Logic?

- Facts:
  - It is most economical to produce an IC in large volumes
  - Many designs required only small volumes of ICs
- Need an IC that can be:
  - Produced in large volumes
  - Handle many designs required in small volumes
- A programmable logic part can be:
  - made in large volumes
  - programmed to implement large numbers of different low-volume designs

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## Programmable Logic - Additional Advantages

- Many programmable logic devices are *field-programmable*, i. e., can be programmed outside of the manufacturing environment
- Most programmable logic devices are *erasable* and *reprogrammable*.
  - Allows "updating" a device or correction of errors
  - Allows reuse the device for a different design - the ultimate in re-usability!
  - Ideal for course laboratories
- Programmable logic devices can be used to prototype design that will be implemented for sale in regular ICs.
  - Complete Intel Pentium designs were actually prototype with specialized systems based on large numbers of VLSI programmable devices!

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## Programming Technologies

- Programming technologies are used to:
  - Control connections
  - Build lookup tables
  - Control transistor switching
- The technologies
  - Control connections
    - Mask programming
    - Fuse
    - Antifuse
    - Single-bit storage element

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## Programming Technologies

- The technologies (continued)
  - Build lookup tables
    - Storage elements (as in a memory)
  - Transistor Switching Control
    - Stored charge on a floating transistor gate
      - Erasable
      - Electrically erasable
      - Flash (as in Flash Memory)
    - Storage elements (as in a memory)

## Technology Characteristics

- Permanent - Cannot be erased and reprogrammed
  - Mask programming
  - Fuse
  - Antifuse
- Reprogrammable
  - Volatile - Programming lost if chip power lost
    - Single-bit storage element
  - Non-Volatile
    - Erasable
    - Electrically erasable
    - Flash (as in Flash Memory)

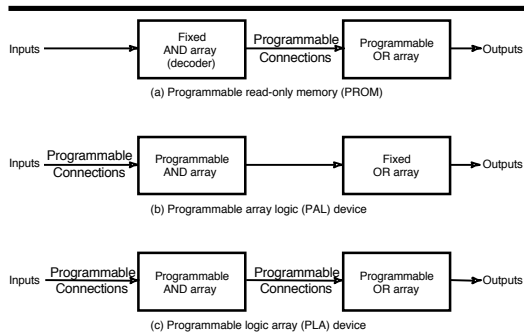
## Technology Characteristics

- Build lookup tables
  - Storage elements (as in a memory)
- Transistor Switching Control
  - Stored charge on a floating transistor gate
    - Erasable
    - Electrically erasable
    - Flash (as in Flash Memory)
  - Storage elements (as in a memory)

## Programmable Configurations

- Read Only Memory (ROM) - a fixed array of AND gates and a programmable array of OR gates
- Programmable Array Logic (PAL)<sup>®</sup> - a programmable array of AND gates feeding a fixed array of OR gates.
- Programmable Logic Array (PLA) - a programmable array of AND gates feeding a programmable array of OR gates.
- Complex Programmable Logic Device (CPLD) / Field-Programmable Gate Array (FPGA) - complex enough to be called "architectures" - See VLSI Programmable Logic Devices reading supplement

## ROM, PAL and PLA Configurations

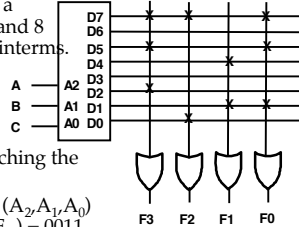


## Read Only Memory

- Read Only Memories (ROM) or Programmable Read Only Memories (PROM) have:
  - N input lines,
  - M output lines, and
  - $2^N$  decoded minterms.
- Fixed AND array with  $2^N$  outputs implementing all N-literal minterms.
- Programmable OR Array with M outputs lines to form up to M sum of minterm expressions.
- A program for a ROM or PROM is simply a multiple-output truth table
  - If a 1 entry, a connection is made to the corresponding minterm for the corresponding output
  - If a 0, no connection is made
- Can be viewed as a *memory* with the inputs as *addresses of data* (output values), hence ROM or PROM names!

## Read Only Memory Example

- Example: A 8 X 4 ROM (N = 3 input lines, M = 4 output lines)
- The fixed "AND" array is a "decoder" with 3 inputs and 8 outputs implementing minterms.
- The programmable "OR" array uses a single line to represent all inputs to an OR gate. An "X" in the array corresponds to attaching the minterm to the OR
- Read Example: For input  $(A_2, A_1, A_0) = 011$ , output is  $(F_3, F_2, F_1, F_0) = 0011$ .
- What are functions  $F_3, F_2, F_1$  and  $F_0$  in terms of  $(A_2, A_1, A_0)$ ?



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## Programmable Array Logic (PAL)

- The PAL is the opposite of the ROM, having a programmable set of ANDs combined with fixed ORs.
- Disadvantage
  - ROM guaranteed to implement any M functions of N inputs. PAL may have too few inputs to the OR gates.
- Advantages
  - For given internal complexity, a PAL can have larger N and M
  - Some PALs have outputs that can be complemented, adding POS functions
  - No multilevel circuit implementations in ROM (without external connections from output to input). PAL has outputs from OR terms as internal inputs to all AND terms, making implementation of multi-level circuits easier.

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## Programmable Array Logic Example

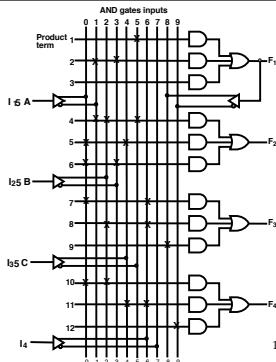
- 4-input, 3-output PAL with fixed, 3-input OR terms
- What are the equations for  $F_1$  through  $F_4$ ?

$$F_1 = A'B' + C'$$

$$F_2 = A'BC' + AC + AB'$$

$$F_3 = ?$$

$$F_4 = ?$$



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## Programmable Logic Array (PLA)

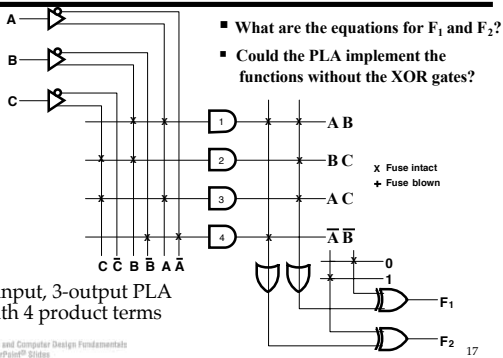
- Compared to a ROM and a PAL, a PLA is the most flexible having a programmable set of ANDs combined with a programmable set of ORs.
- Advantages
  - A PLA can have large N and M permitting implementation of equations that are impractical for a ROM (because of the number of inputs, N, required)
  - A PLA has all of its product terms connectable to all outputs, overcoming the problem of the limited inputs to the PAL Ors
  - Some PLAs have outputs that can be complemented, adding POS functions
- Disadvantage
  - Often, the product term count limits the application of a PLA. Two-level multiple-output optimization reduces the number of product terms in an implementation, helping to fit it into a PLA.

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## Programmable Logic Array Example

- 3-input, 3-output PLA with 4 product terms



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