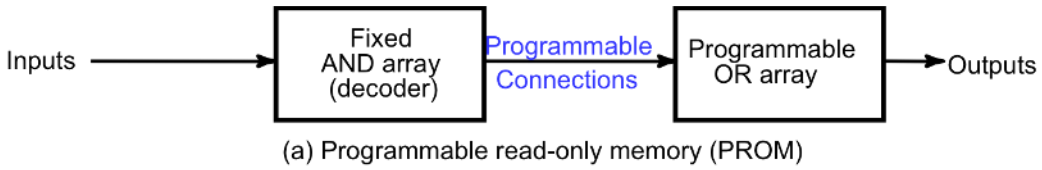
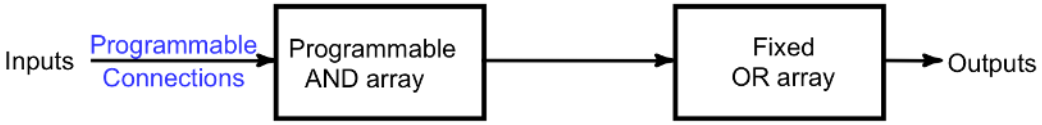
PROGRAMMABLE LOGIC DEVICES

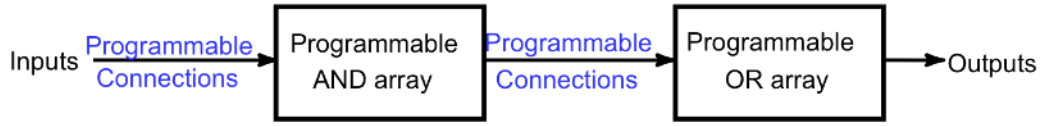
- ***Read Only Memory* (*ROM*)** - a fixed array of AND gates and a programmable array of OR gates
- ***Programmable Array Logic* (*PAL*)** - a programmable array of AND gates feeding a fixed array of OR gates.
- ***Programmable Logic Array* (*PLA*)** - a programmable array of AND gates feeding a programmable array of OR gates.
- ***Complex Programmable Logic Device* (*CPLD*) /*Field- Programmable Gate Array* (*FPGA*)** - complex enough to be called "architectures"



(a) Programmable read-only memory (PROM)



(b) Programmable array logic (PAL) device



(c) Programmable logic array (PLA) device

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!

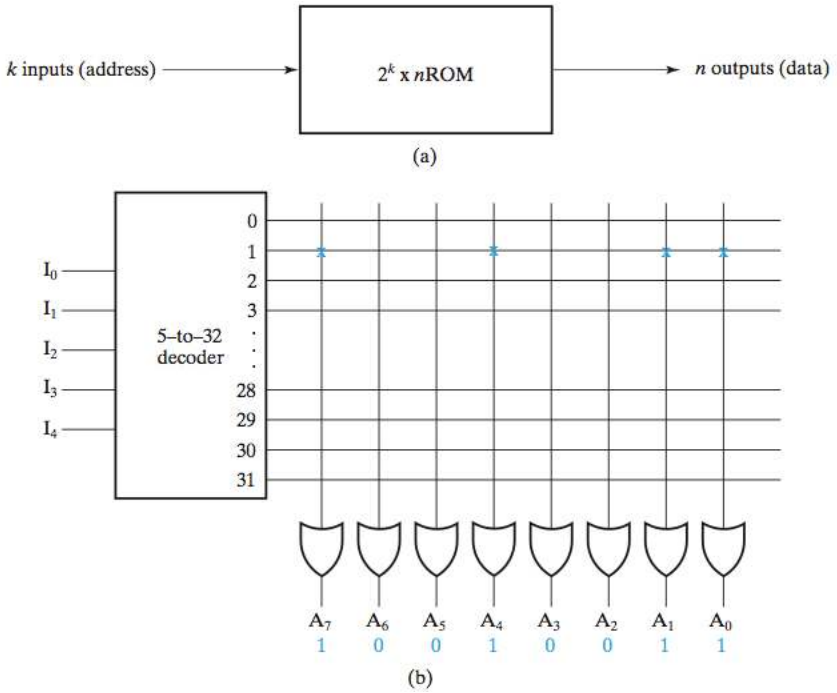
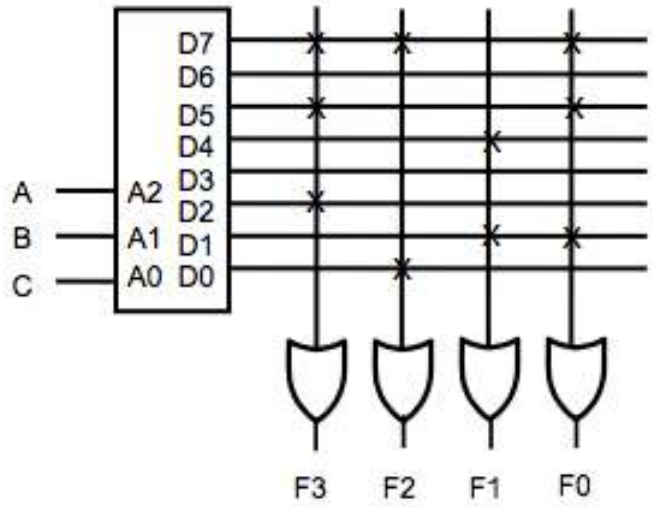


Figure: Block diagram and Internal Logic of a ROM

- Depending on the programming technology and approaches, read-only memories have different names
    1. ROM – mask programmed
    2. PROM – fuse or antifuse programmed
    3. EPROM – erasable floating gate programmed
    4. EEPROM or E^2PROM – electrically erasable floating gate programmed
    5. FLASH memory: electrically erasable floating gate with multiple erasure and programming modes.

- 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) = 001, 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)?



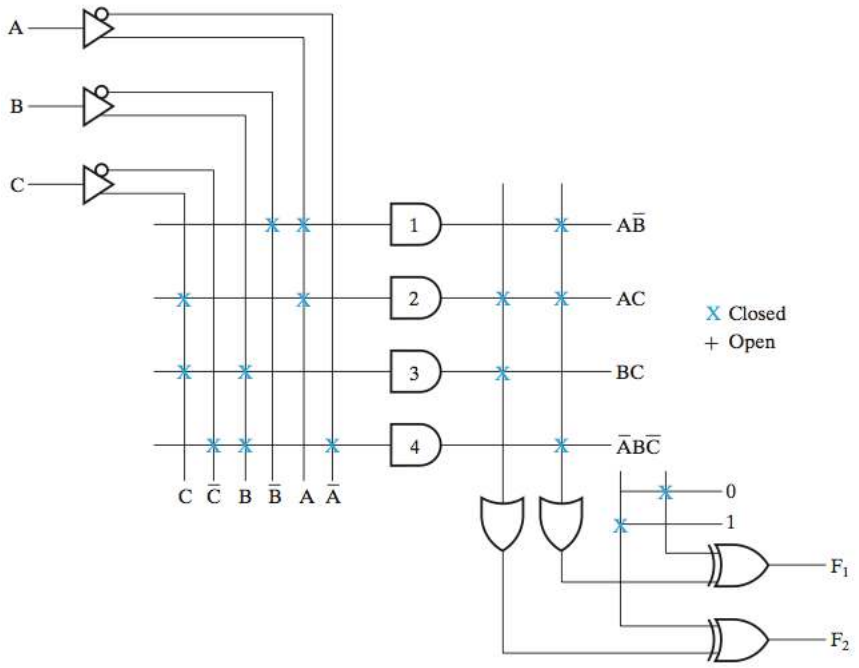
PROGRAMMABLE LOGIC ARRAY (PLA)

- 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
- Disadvantages
  - Often, the product term count limits the application of a PLA.
  - Two-level multiple-output optimization is required to reduce the number of product terms in an implementation, helping to fit it into a PLA.
  - Multi-level circuit capability available in PAL not available in PLA. PLA requires external connections to do multi-level circuits.

Programmable Logic Array Example

F1=AB' + AC + A'BC'

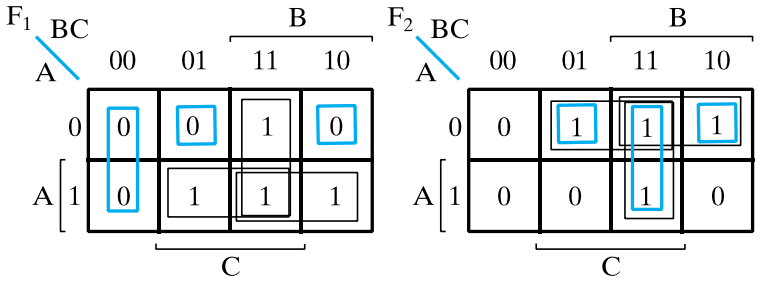
F2= (AC+BC)'



- What are the equations for F_1 and F_2?
- Could the PLA implement the functions without the XOR gates?
- 3-input, 3-output PLA with 4 product terms

Example 6-3 from Mano: Implementing a Combinational Circuit Using a PLA

F1(A,B,C)= Σm(3,5,6,7)
F2(A,B,C)= Σm(1,2,3,7)



$F_1 = AB + AC + BC$
$\overline{F_1} = \bar{A}\bar{B}C + \bar{A}B\bar{C} + B\bar{C}$

$F_2 = \bar{A}B + \bar{A}C + BC$
$F_2 = \bar{A}\bar{B}C + \bar{A}B\bar{C} + BC$

The solution is:

$$F_1 = \overline{\bar{A}\bar{B}C + \bar{A}B\bar{C} + B\bar{C}}$$

$$F_2 = \bar{A}\bar{B}C + \bar{A}B\bar{C} + BC$$

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.

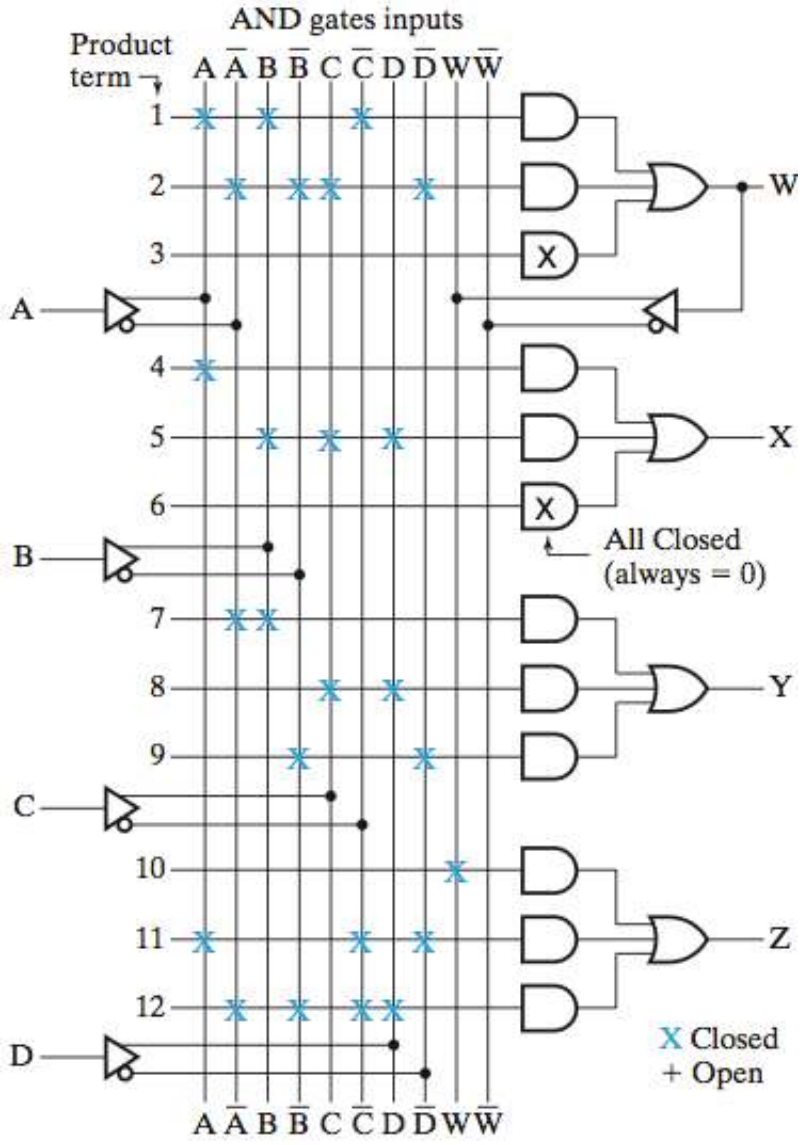
Programmable Array Logic Example

- 4-input, 3-output PAL with fixed, 3-input OR terms
- What are the equations for F1 through F4?

W(A,B,C,D) = Σm (2,12,13)
X(A,B,C,D) = Σm (7,8,9,10,11,12,13,14,15)
Y(A,B,C,D) = Σm (0,2,3,4,5,6,7,8,10,11,15)
Z(A,B,C,D) = Σm (1,2,8,12,13)

Simplifying the four function to a minimum number of terms results in the following Boolean functions

W= ABC'+A'B'CD'
X = A+BCD
Y = A'B+CD+B'D'
Z = ABC'+A'B'CD'+AC'D'+A'B'C'D = W+AC'D'+A'B'C'D


AND gates inputs
Product term
A Ā B B̄ C C̄ D D̄ W W̄
1
2
3
4
5
6
7
8
9
10
11
12
A
B
C
D
W
X
Y
Z
X
X
All Closed (always = 0)
X Closed
+ Open