

## 1. Timing

### a. Worst case path

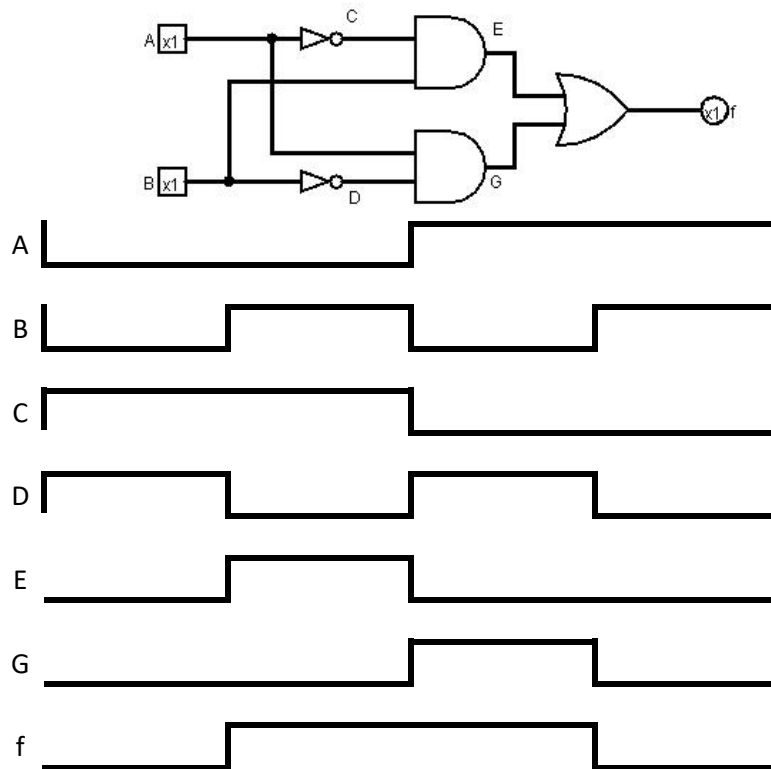
- Route through a circuit that takes the longest in terms of gates
- In the example below, worst case path is 3 gates
- Either  $A \rightarrow \text{NOT} \rightarrow \text{AND} \rightarrow \text{OR}$  or  $B \rightarrow \text{NOT} \rightarrow \text{AND} \rightarrow \text{OR}$
- Worst case path determines clock speed
  - Need to wait for all gates to finish to get output before we start new clock cycle
- Can also assign times to each type of gate to determine time output is generated

### b. Timing diagram

- Visual representation of truth tables at different parts of a digital logic circuit
- Initial values of inputs iterate over all possible combinations (like a truth table)
- Truth values at later points are shown based on each of those combinations

### c. Example

- Implementation of XOR using only AND, OR, NOT
- $A \oplus B = A * \sim B + \sim A * B$
- Assume that we have the following gate delays: NOT = 3 ns, AND = 5 ns, OR = 4 ns. What is the clock time of the circuit?

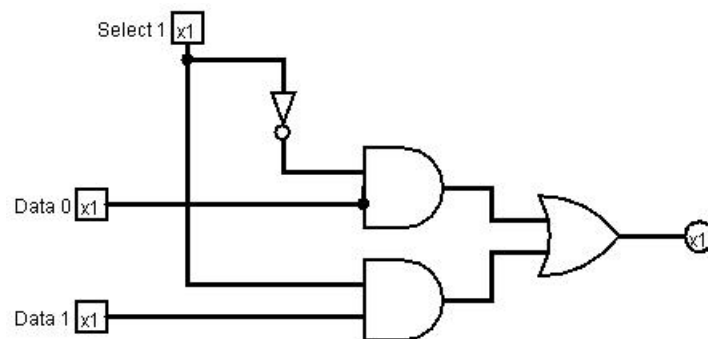


## 2. Combinational circuit building blocks

- Talked about gates so far
- We now move on to other important pieces of digital design

### 3. Multiplexors

- a. Also known as MUXes
- b. MUXes select one output from multiple inputs
  - i. Used to control signal and data routing
- c. For  $n$  data inputs, a MUX has  $s = \lceil \log_2 n \rceil$  select bits that control which input we select.
- d. Implementation
  - i.  $n$  AND gates
    1. Each one has one data input
    2. Also has  $s$  select inputs
    3. The select inputs are all true for only one AND gate at a time
  - ii. One OR gate
    1.  $n$  inputs from the AND gates
    2. Only one of the AND gates will have a non-zero output (unless that gate's output is all zeroes)
- e. Can use MUXes to implement functions
  - i. Hook up constant 0s or 1s to each input
  - ii. MUX takes in input bits and outputs corresponding constant for that input
- f. Example
  - i. 2 to 1 MUX



#### ii. 4 to 1 MUX

