Unit 9: Combinational Circuit Timing

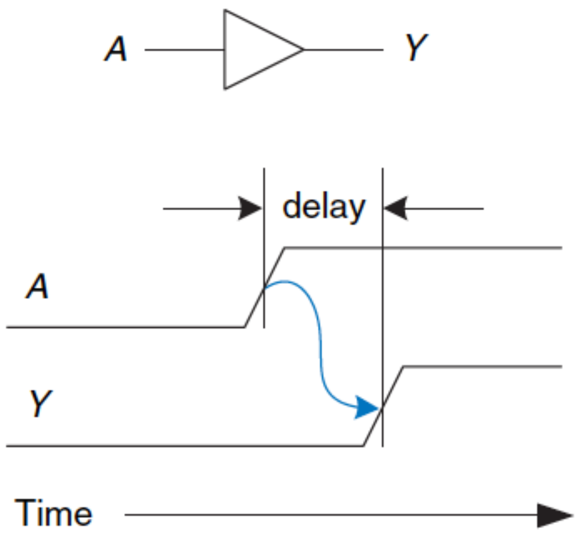
CSE 220: System Fundamentals I

Stony Brook University

Joydeep Mitra

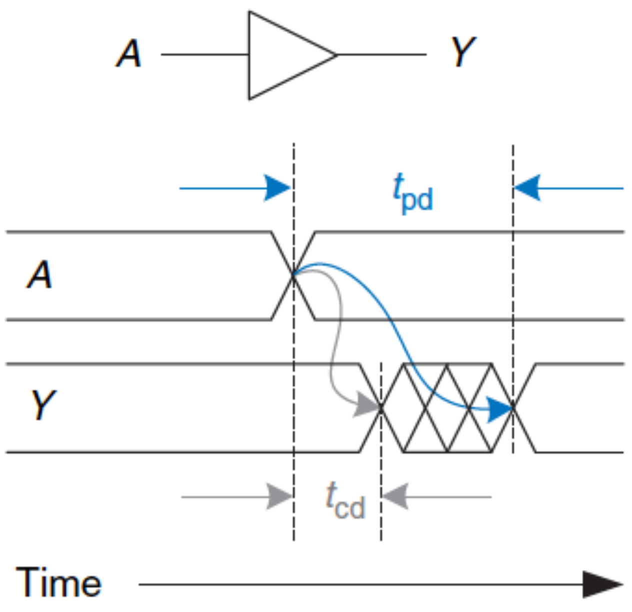
Timing of Circuits

- Recall that a key aspect of functional specification of a circuit is timing
- Generally, circuits have delay, i.e., the time it takes for the output signal to change when the input signal changes. We need to account for delay to design fast circuits
- This delay is represented as a *timing diagram*
  - The transition from LOW to HIGH is called the **rising edge** and HIGH to LOW is called the **falling edge**
  - We measure *delay* from the 50% point of the input signal to the 50% point of the output signal
  - The 50% point is the point where the signal is halfway between the LOW and HIGH values as it transitions



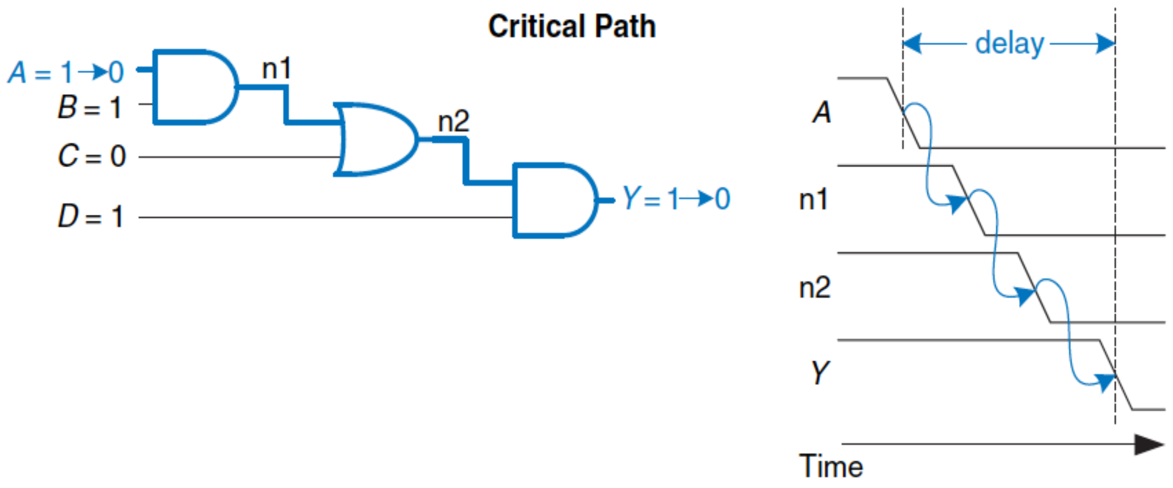
Propagation and Contamination Delay

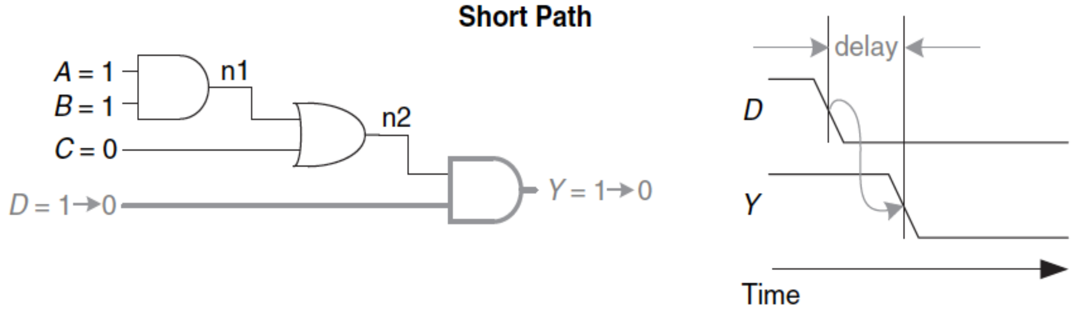
- Combination logic is characterized by **propagation delay** and **contamination delay**
- **Propagation delay (t_{pd})** is the maximum time from when an input changes until the output or outputs reach their final value
- **Contamination delay (t_{cd})** is the minimum time from when an input changes until any output starts to change its value



Calculating Delay

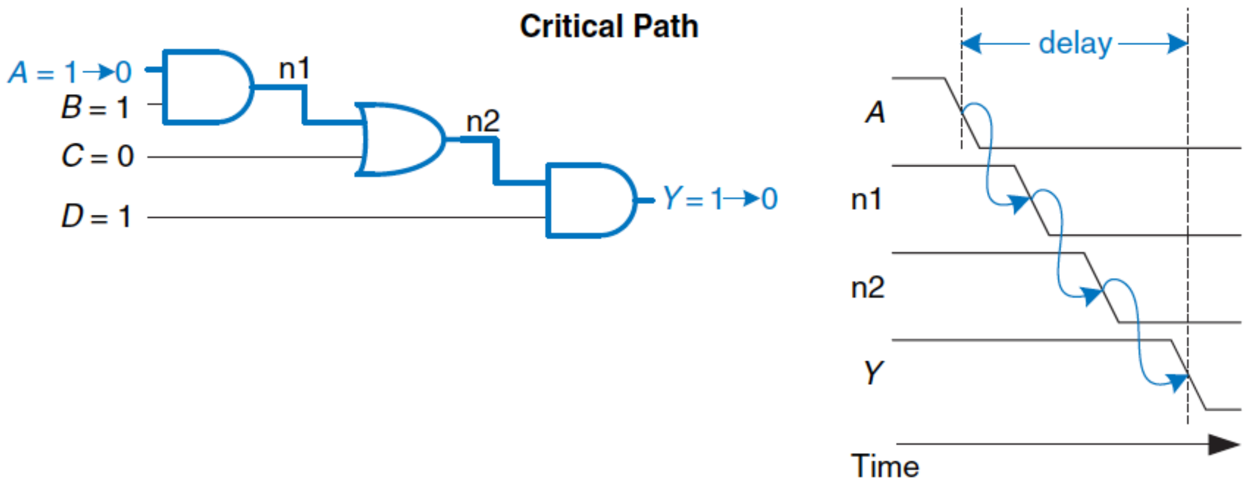
- Delays are measured by the path a signal takes from input to output
- *Propagation delay* is determined by the **critical path** and *contamination delay* by the **short path**
- **Critical path** is the longest path from an input signal to an output signal of a circuit; critical as it limits the circuit's speed
- **Short path** is the shortest path from an input signal to an output signal

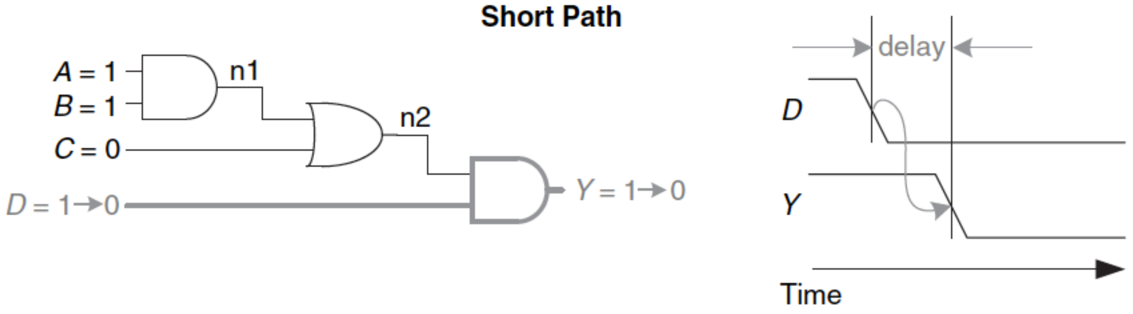




Calculating Delay

- Propagation delay is the sum of propagation delays through each element on the critical path. E.g.,
  - $t_{pd} = 2tpd\_{AND} + tpd\_{OR}$
- Contamination delay is the sum of contamination delays through each element on the short path. E.g.,
  - $t_{cd} = tcd\_{AND}$
- How do we know the delays of each element?
  - It is provided by the manufacturer
  - Calculation of these is beyond the scope of this course



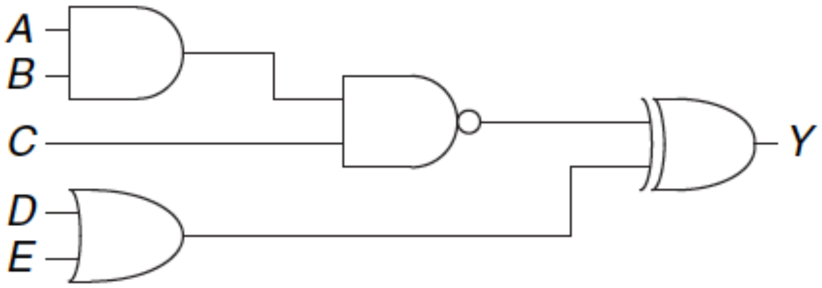


Measurement Units

- Measures of time:
  - 1 millisecond (ms) = 1 thousandth second = 10^{-3} second
  - 1 microsecond (μs) = 1 millionth second = 10^{-6} second
  - 1 nanosecond (ns) = 1 billionth second = 10^{-9} second
  - 1 picosecond (ps) = 1 trillionth second = 10^{-12} second
- Speed (or frequency) of a circuit is measured in Hertz (Hz) – amount of work done in 1 unit time (1/time)
  - 1 kilohertz (KHz) = 1 thousand Hz = 10^3 Hz
  - 1 megahertz (MHz) = 1 million Hz = 10^6 Hz
  - 1 gigahertz (GHz) = 1 billion Hz = 10^9 Hz
  - 1 terahertz (THz) = 1 trillion Hz = 10^{12} Hz

Example #1

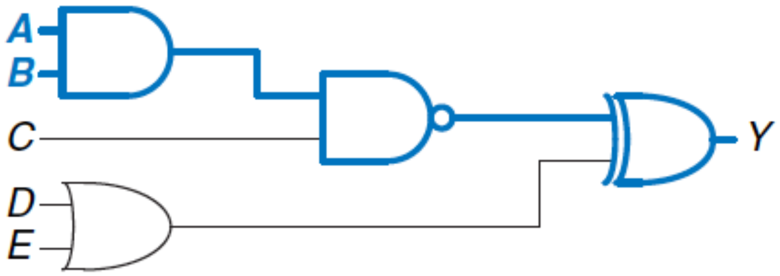
- Consider the following combinational circuit:



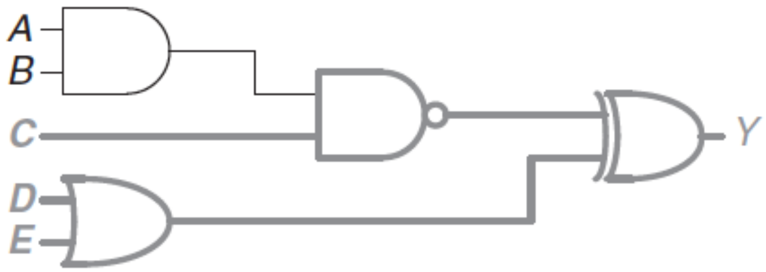
- The manufacturer told us that each gate has a propagation delay of 100 ps and a contamination delay of 60 ps
- Let’s find the propagation and contamination delays of the circuit

Example #1

- $t_{pd} = tp_{d\_AND} + tp_{d\_NAND} + tp_{d\_XOR} = 100\ ps + 100\ ps + 100\ ps = 300\ ps$

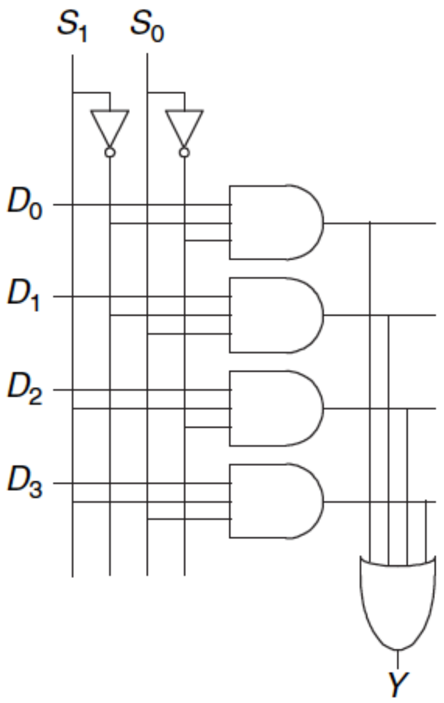


- $t_{cd} = tc_{d\_OR} + tc_{d\_XOR} = 60\ ps + 60\ ps = 120\ ps$



Example #2

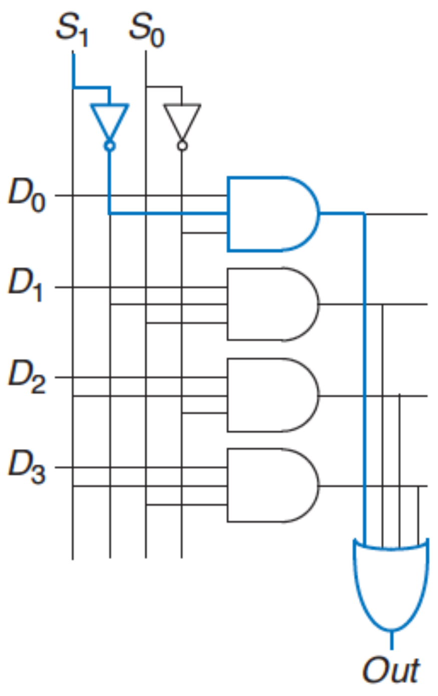
- Determine the delays of the following circuit:



Gate	Delay (ps)
AND gate	80
OR gate	90
NOT gate	30

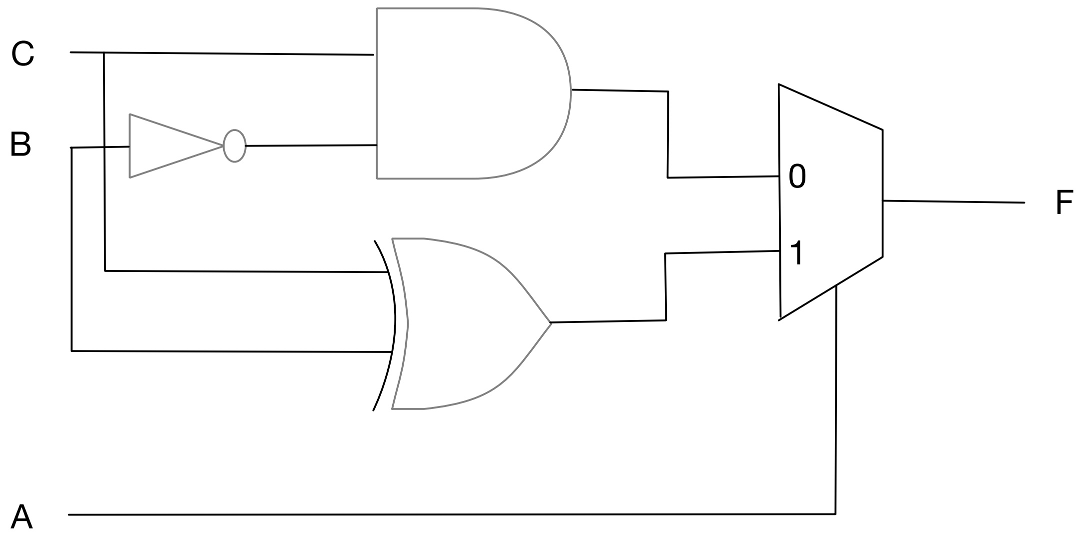
Example #2

- $t_{pd} = tp_{d\_NOT} + tp_{d\_AND} + tp_{d\_OR} = 30\ ps + 80\ ps + 90\ ps = 200\ ps$
- $t_{cd} = tc_{d\_AND} + tc_{d\_OR} = 80\ ps + 90\ ps = 170\ ps$



Example #3

- Determine the delays of the following circuit:



Element	$\mathbf{t_{cd}}$	$\mathbf{t_{pd}}$
NOT gate	0.1 ns	0.8 ns
AND gate	0.2 ns	1.2 ns
XOR gate	0.4 ns	2.1 ns
MUX	0.2 ns	1.5 ns

Example #3

- $t_{pd} = tpd\_{XOR} + tpd\_{MUX} = 2.1\,ns + 1.5\,ns = 3.6\,ns$
- $t_{cd} = tcd\_{MUX} = 0.2\,ns$