## Lab #10 – Digital Circuits I

The purposes of this lab are

- to illustrate the use of gates in logic circuits and to provide experience constructing such circuits
- to observe gate delays, the degradation of the performance of digital circuits at high speeds, and their dependence on the supply voltage
- to use gates, or a flip-flop, to construct a pulse generator.

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| Equipment at each station: | Centrally available: |
|---|---|
| digital oscilloscope | wire and wire cutters/stripper |
| 2 multimeters | red and black banana plug cables |
| 2 power supplies | alligator clips |
| signal generator | assorted resistors |
| standard breadboard | assorted capacitors |
| potentiometer | HP 3325 signal generator (up to 20 MHz) |
| CMOS digital ICs: | bags of LEDs |
| (4070 quad XOR, 4081 quad AND, | |
| 4013 dual flip-flop, 4075 3-input OR) | |

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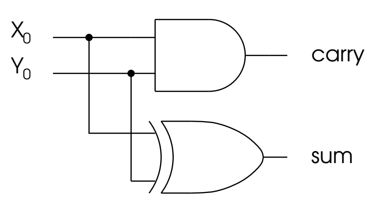
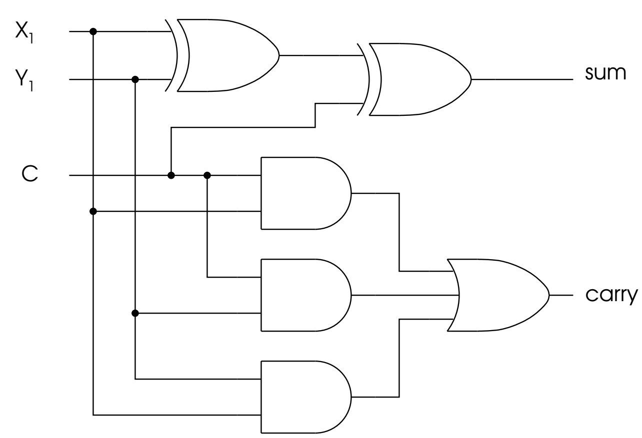
## 1. Binary Adding Circuit

The "half-adder" is a combination of an XOR and AND which executes the addition of two one-digit binary numbers (see pp. 365–368 in Fortney). The "full-adder" takes the carry digit from the half-adder and outputs a sum digit and another carry. By cascading full-adders you can sum arbitrarily large binary numbers.




Half-adder

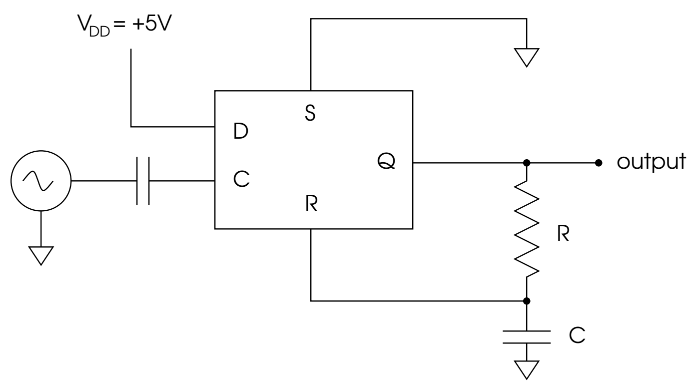



Full-adder

- Construct the "half-adder" and "full-adder" circuits from the components at hand. Do not tear down your half-adder when you build your full-adder, since you want to see them work in tandem. Use LEDs on the inputs and outputs for visual confirmation that addition is indeed taking place. Use appropriate current-limiting resistors!
- **Warning**: be sure to ground all unused inputs to CMOS ICs.
- Using a square wave as one digit input to your circuit (i.e., to either $X_0$ or $Y_0$ with the other being fixed at 0 or 1) measure the gate delay. (You might measure the compound delay through several gates, which will be a little larger and easier to measure.)

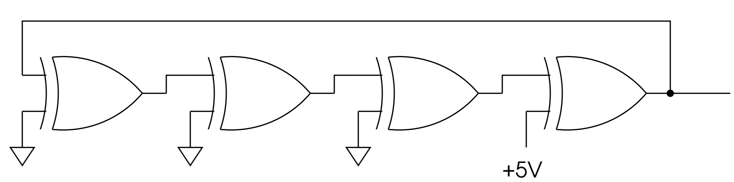
- Increase the supply voltage to your CMOS ICs, for example from 10V to 15V, and observe the change in performance.
- What do you expect to happen to your circuit if you make it do sums too fast? From your measured gate delay, calculate the frequency at which to adder should 'break'. Can you observe this result? (You may wish to use the HP3325 signal generator which goes up to 20 MHz.) Can you observe the change in performance by changing the supply voltage?
- SAVE YOUR ADDING CIRCUIT. At the end of the lab, or whenever everyone is ready, cascade your full-adder with everyone else's to create a huge adder capable of adding binary numbers with more than two digits.
- Optional: You may wish to build the two-bit multiplier circuit we discussed in lecture instead. Construct and test it.

## 2. Flip-flop Pulse Generator




Pulse generator from a flip-flop

- Construct the flip-flop circuit in the figure above, initially with $R, C = 0$ (s.c.).
- First predict what the output of this circuit should be and then measure it.
- Add some finite $R$ or $RC$ between the output and ground/reset and observe what happens. Compare the result with what you expect, being as quantitative as possible.
- Optional: By varying the values of $R$ and $C$ you can adjust the width of the pulse. Understand why. What RC time constant is controlling the pulse width?
- Optional: You may wish to build a TTL version of the flip-flop and compare the results quantitatively to your CMOS circuit.
- Optional: Build and oscillator using the gate delays shown in the figure below. Record how the oscillator frequency increases with the supply voltage.




Pulse generator from gates