

Circuits

1 Key Circuits

Combinatorial/Combinational Circuits:

- **Adders** - Add the contents of two registers
- **Decoders** - Use a binary number to activate a single line (select one out of many things based on a number of inputs)
- **Multiplexors** - Use a binary number to select an input

Sequential circuits:

- Latches/flip-flops - basic memory element

2 Half adder

Based on the simple binary addition rules

Based on 8 simple rules:

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 0 = 1$$

$$1 + 1 = 0 \text{ with Carry}$$

$$\text{Carry} + 0 + 0 = 1$$

$$\text{Carry} + 0 + 1 = 0 \text{ with Carry}$$

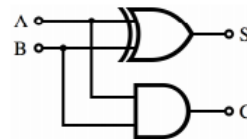
$$\text{Carry} + 1 + 0 = 0 \text{ with Carry}$$

$$\text{Carry} + 1 + 1 = 1 \text{ with Carry}$$

Inputs: A, B

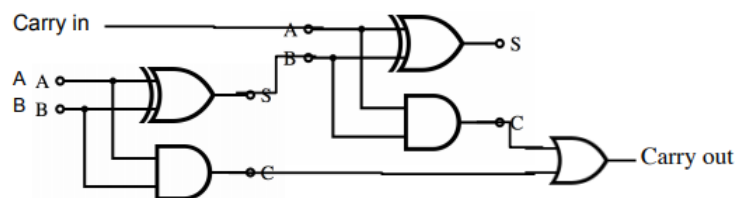
Outputs: Sum, Carry

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1



3 Adder

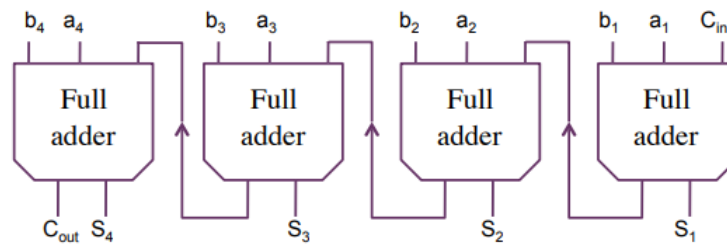
Input is not just A and B, but A, B and the carry from the previous bit Use two half-adders: Add A and B first, then add in the carried bit:



"Full adder"

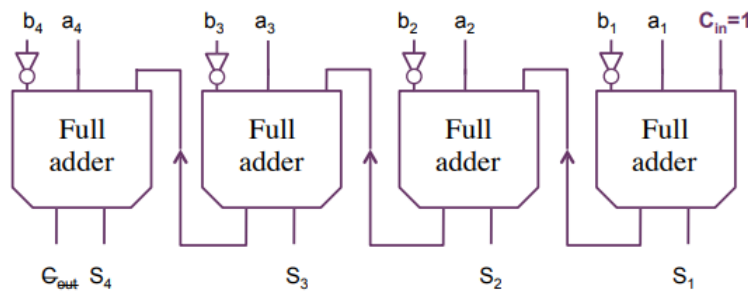
4 Chaining adders

Full adders can be chained to give more bits of input



5 Subtractor

Using two's complement negative we can subtract numbers. Flip each of the bits with a not gate. Set the carry in to 1 in order to add 1



The NOT gates and setting $C_{in}=1$ give the effect of converting b to $-b$.

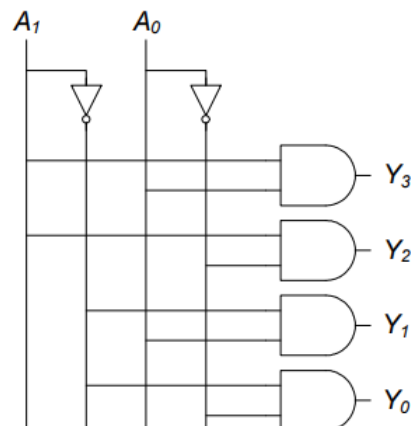
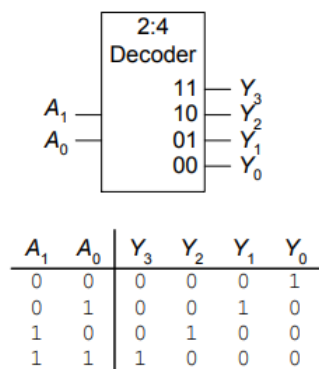
6 Decoder

This is used to identify which piece of memory is being talked about when giving an address

This is what a decoder does:

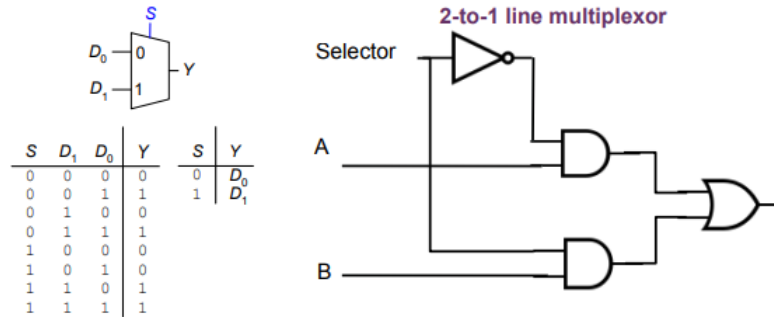
- N inputs. $2N$ outputs.
- Only one output is high at a time.
- Which one depends on the input

2-bit decoder:



Larger decoders require multi-input AND gates to be constructed in two-level logic. This requires a lot of circuitry for large decoders. Can create deeper circuits with fewer transistors, at the cost of slower response.

7 Multiplexor



A multiplexor has $k+2^k$ inputs and 1 output.

The first k inputs (selector) represent a binary number.

The output takes the value of the remaining input indexed by this binary number.

Consider many memory locations connected to the inputs. Using the selector we can select which is loaded into a register connected to the output.

- This allows us to select between data streams

8 Tristate



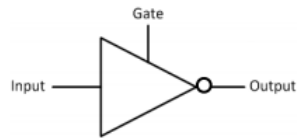
A single transistor could work, but the output is not driven.

Input	Enable	Output
0	0	Floating
0	1	0
1	0	Floating
1	1	1

Linear truth table

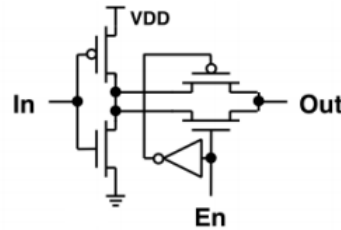
- Driven low - connected to low voltage line
- Driven high - connected to high voltage line
- Floating - not connected to anything
- This helps when there are weak signals in the circuit

8.1 Inverting Tristate



Input	Enable	Output
0	0	Floating
0	1	1
1	0	Floating
1	1	0

Linear truth table

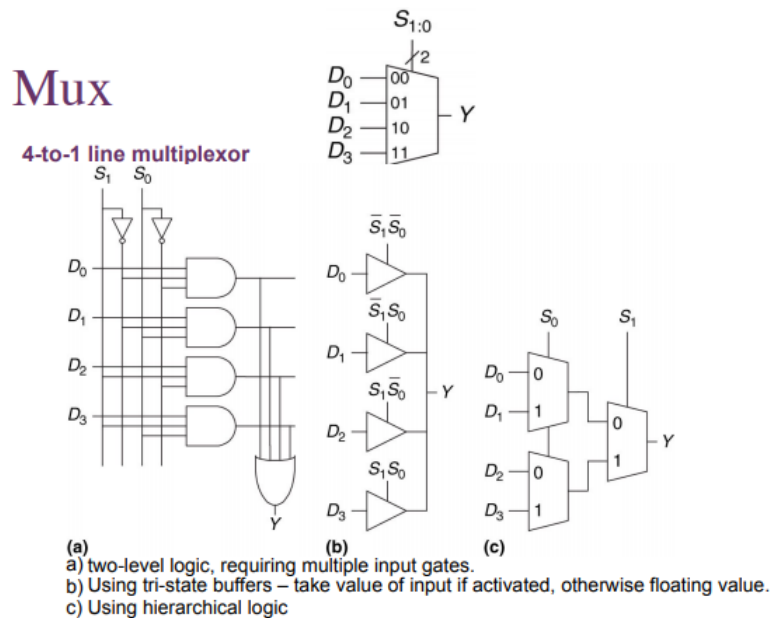


Here the output is driven by direct connection to VDD or ground.

Also a pair of transistors are used to control transmission, which aids 'voltage drain' (an issue we won't explore).

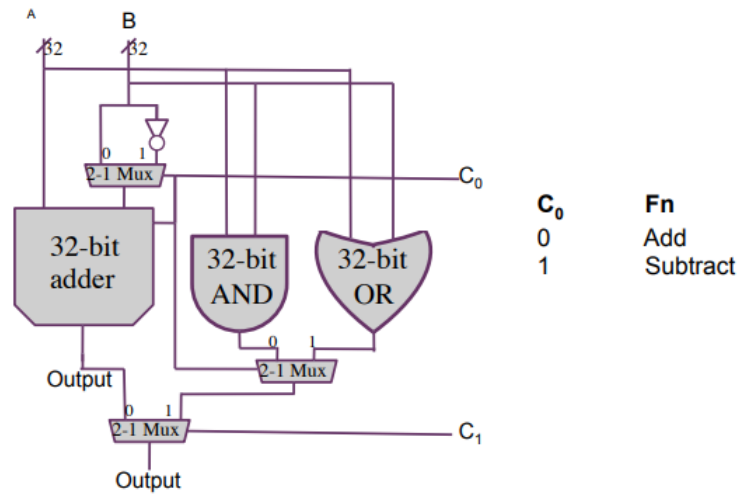
- Means the output is driven directly from either the high or low voltage line.
- Makes the driven signal strong
- When not enabled get floating output
- Actual tristate just an inverted inverted tristate

9 Mux



- Using tristate gates a much more efficient multiplexor can be formed
- Multiplexors can also be made using hierarchical logic, chaining them together

10 Building a simple ALU



- The mux is used for the subtraction part of the circuit as it can invert the data line
- Using the two control bits you can decide between ADD, SUBTRACT, AND, OR.