P524: Survey of Instrumentation and Laboratory Techniques Week 6

10/1/2024

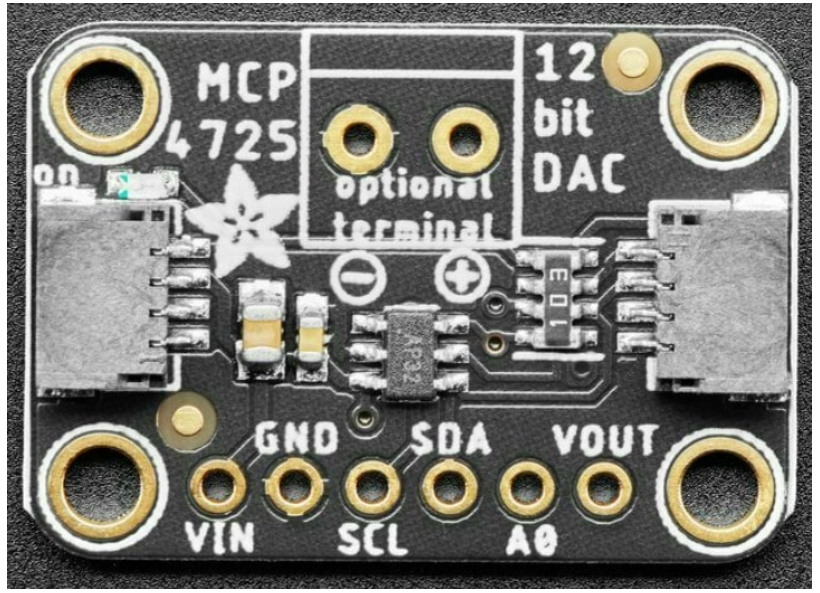
Week 6: sensors-4

Digital to Analog Converter (DAC)

makes V(t) w/ arbitrary waveform

MCP4725 12-bit DAC

- I2C communication (Addr: 0x64)
  - **A0** allow you to change the I2C address.
  - If A0 is connected to **VDD/VIN** the address is **0x63**



VOUT is the voltage out from the DAC! The voltage will range from 0V (when the DAC value is 0) to VDD/Vin (when the DAC 'value' is the max 12-bit number: 0xFFF)

Analog to Digital Converter (ADC)

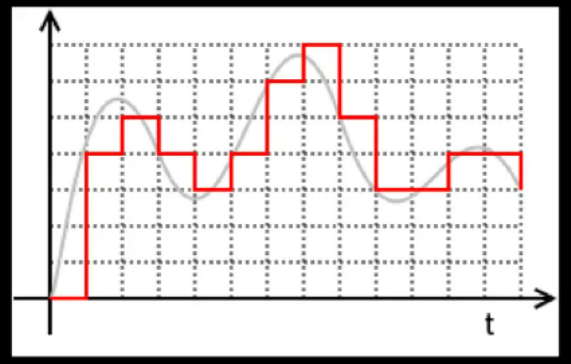
digitizes a voltage signal into digital number

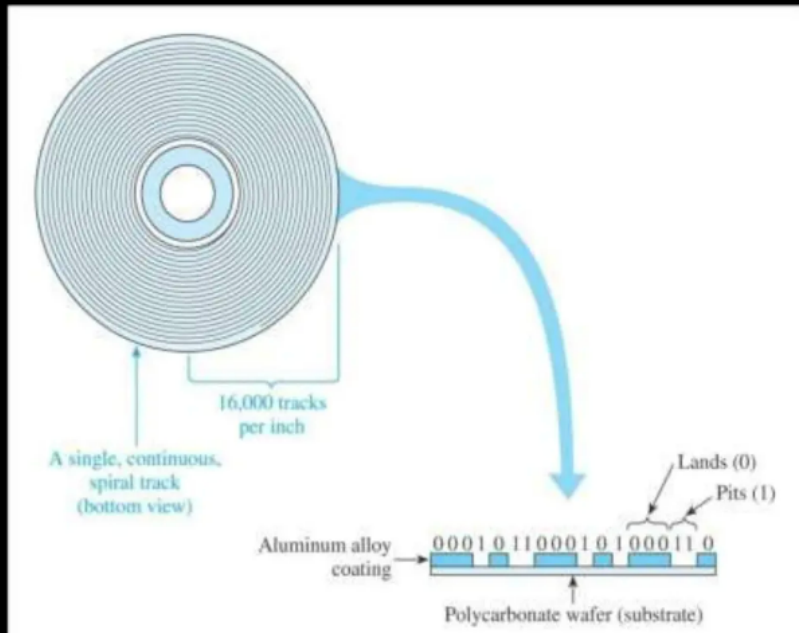
- MEGA 2560: A0-A15 (10-bit)
- Feather M0 Adalogger: A0, A1 (12-bit)

Digital electronics, e.g., CD, DVD

Does a CD player use an ADC or DAC?

- Sound is an analog signal.
- On a CD, digital sound is encoded as 44.1 kHz, 16 bit audio.
  - The original wave is 'sliced' 44,100 times a second - and an average amplitude level is applied to each sample.
  - 16 bit means that a total of 65,536 different values can be assigned, or quantized to each sample.
- DVD-Audio can be 96 or 192 kHz and up to 24 bits resolution





Digitization is the process of transforming information into 1's and 0's.

ADC: Analog to Digital Conversion.

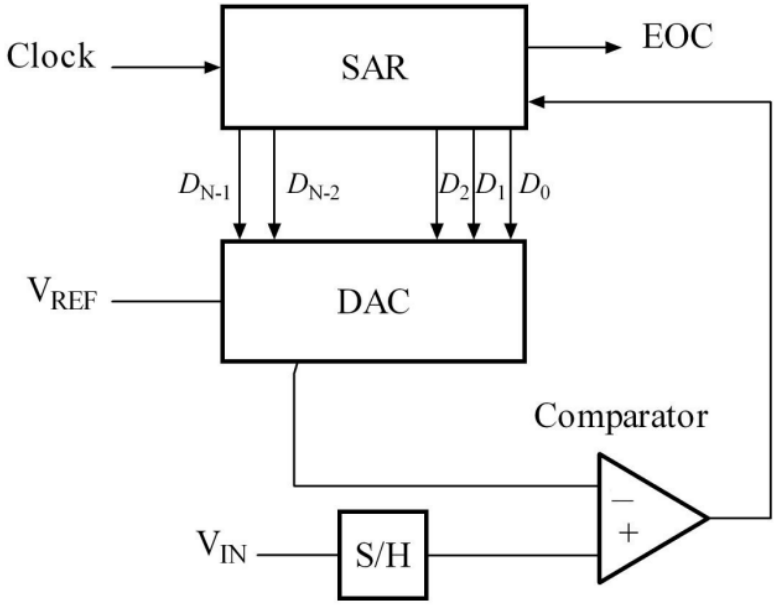
DAC: Digital to Analog Conversion

Successive-AppRoximation (SAR) ADC

A successive-approximation ADC is a type of analog-to-digital converter that converts a continuous analog waveform into a discrete digital representation using a binary search through all possible quantization levels before finally converging upon a digital output for each conversion.

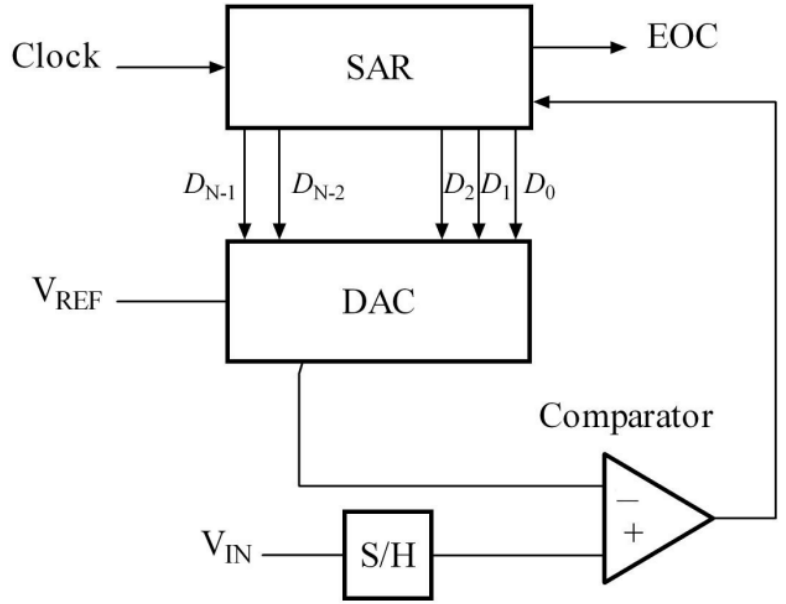
It consists of four subcircuits:

1. A sample-and-hold circuit to acquire the input voltage V_{in}.
2. An analog voltage comparator that compares V_{in} to the output of the internal DAC and outputs the result of the comparison to the successive-approximation register (SAR).
3. A successive-approximation register subcircuit designed to supply an approximate digital code of Vin to the internal DAC.
4. An internal reference DAC that, for comparison with V_{ref}, supplies the comparator with an analog voltage equal to the digital code output of the SAR_{in}.



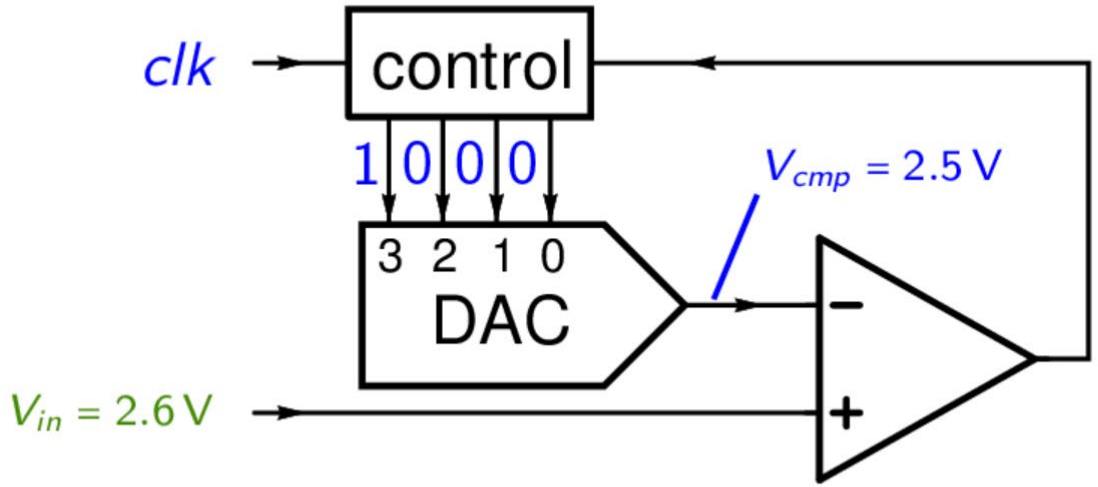
SAR ADC

- The successive approximation register is initialized so that the most significant bit (MSB) is equal to a digital 1.
- This code is fed into the DAC, which then supplies the analog equivalent of this digital code ($V_{ref}/2$).
- The DAC output voltage is fed into the comparator circuit for comparison with the sampled input voltage.
- If this analog voltage exceeds V_{in}, then the comparator causes the SAR to reset this bit; otherwise, the bit is left as 1. Then the next bit is set to 1 and the same test is done, continuing this binary search until every bit in the

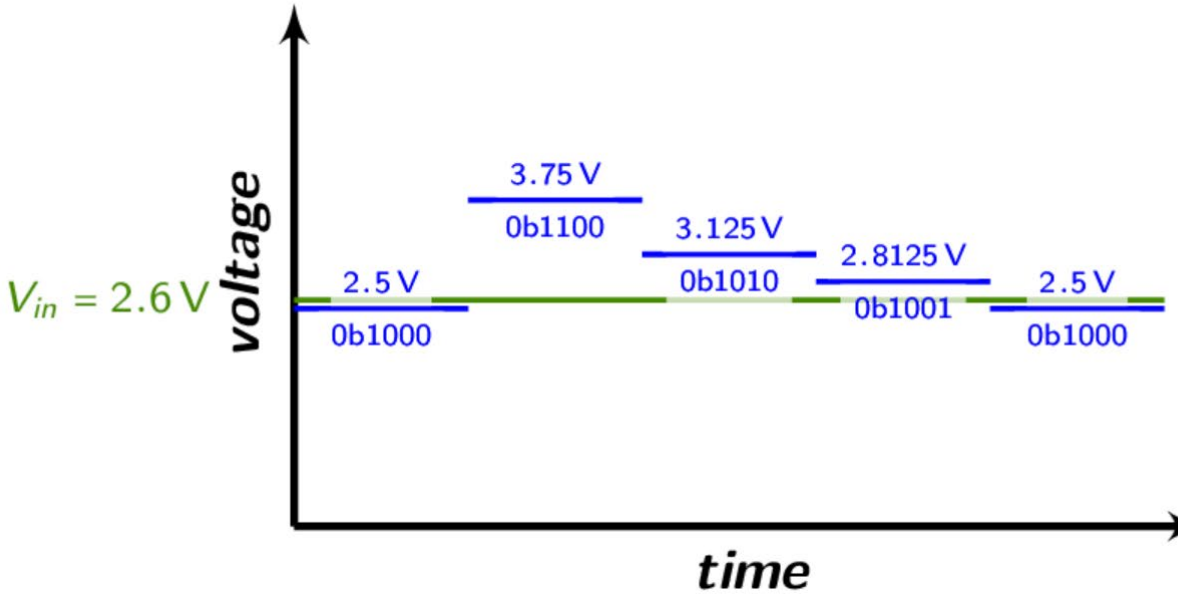


Successive Approximation – example of a 4-bit ADC

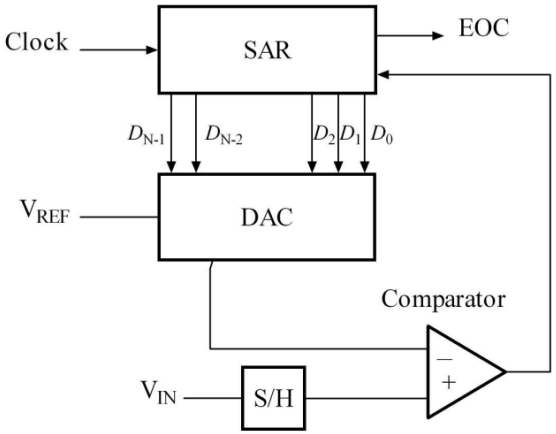
- V_{in} >= V_{cmp}, keep bit
- V_{in} < V_{cmp}, drop bit

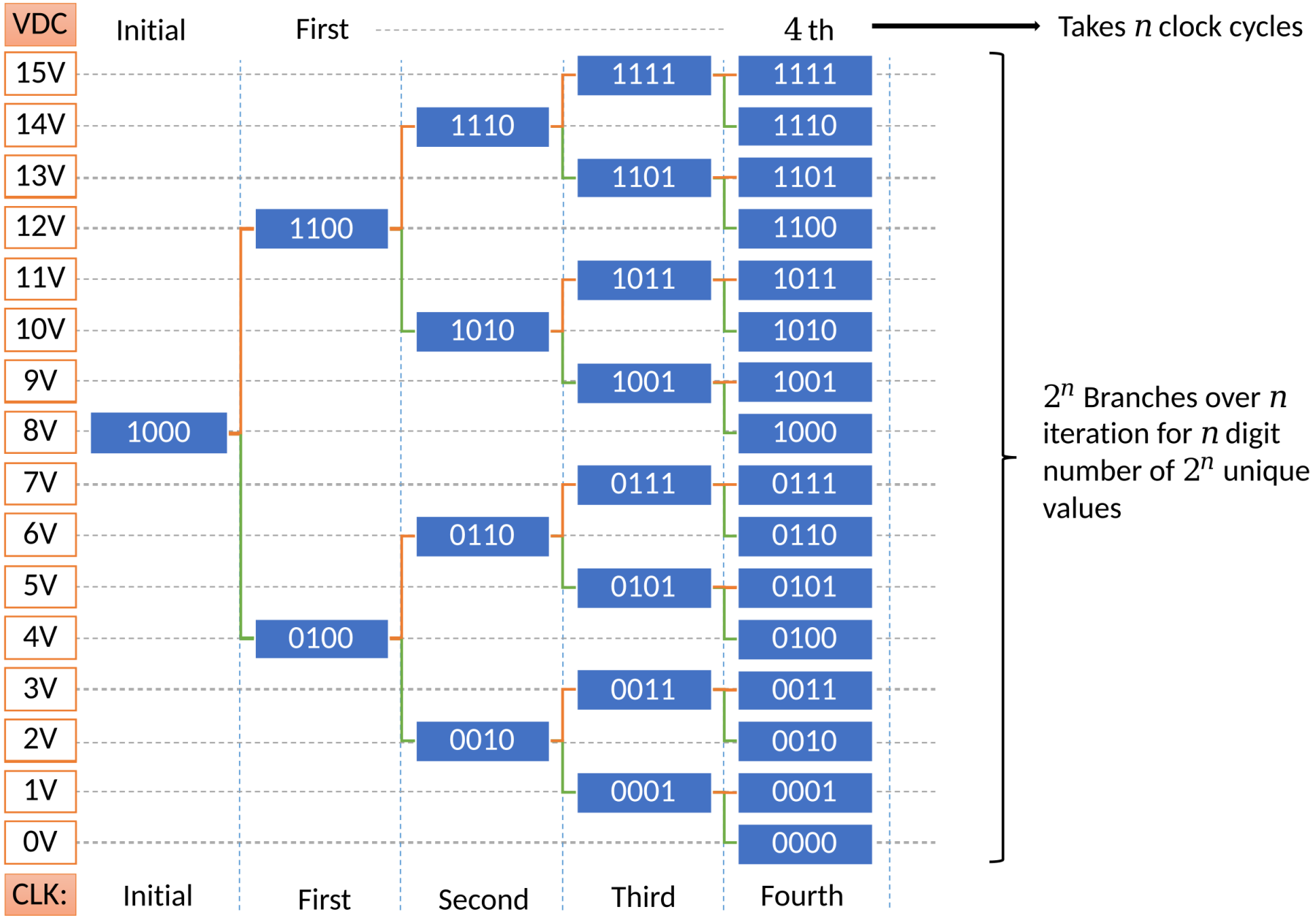


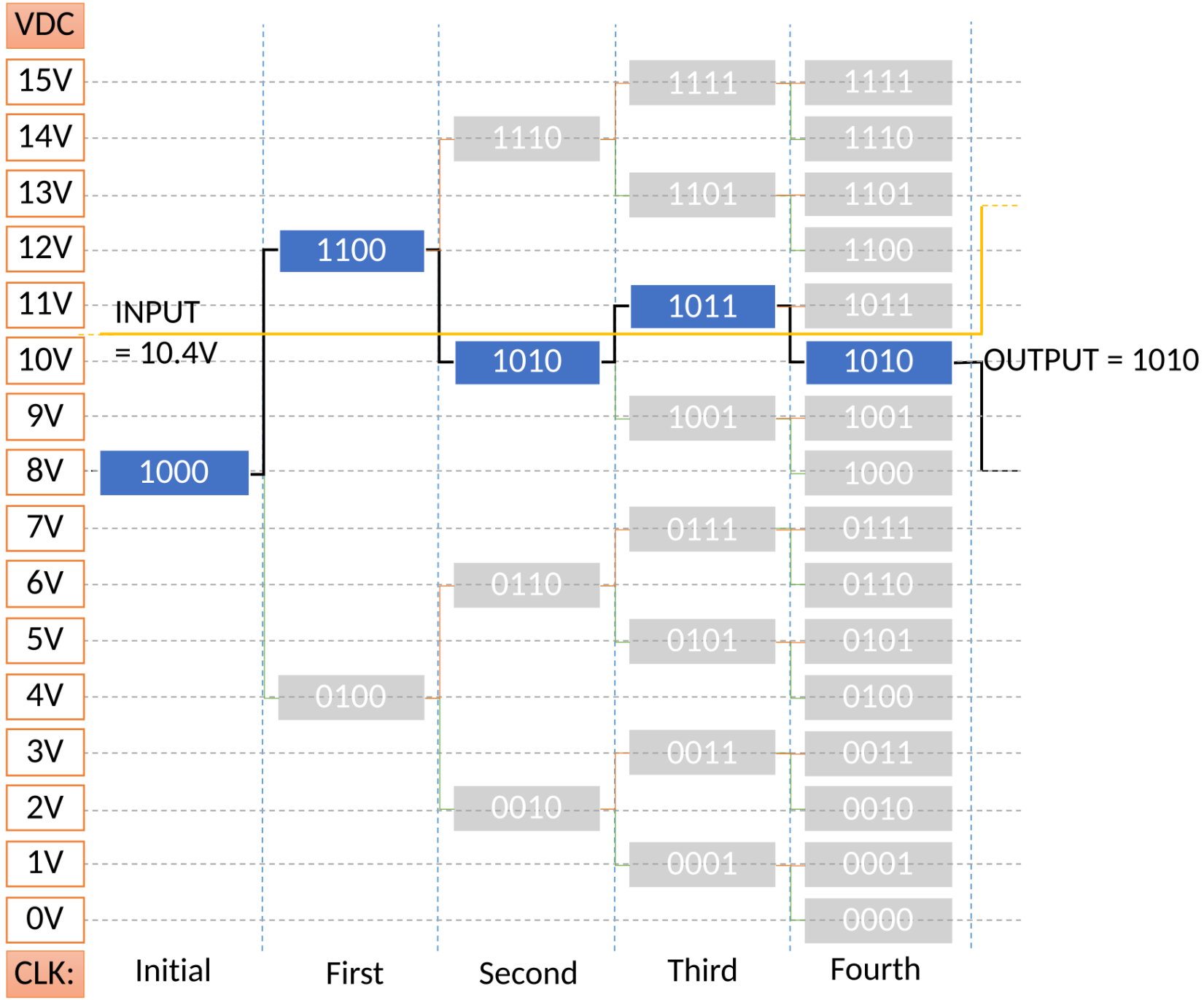
result: 0b1000 $V_{in} \approx 2.5\,V$

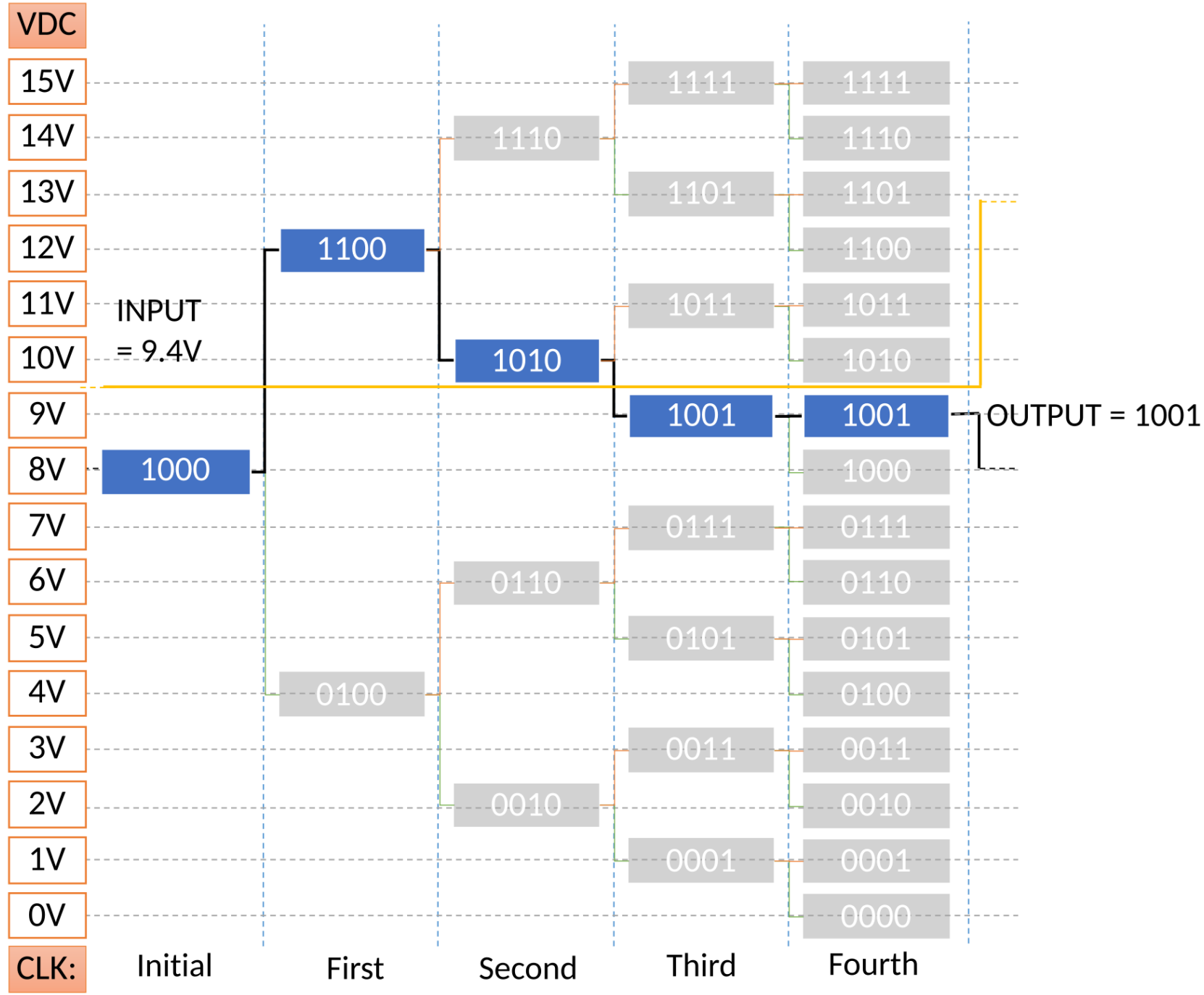


Resolution:	
5 V × 1/2	2.5000 V
5 V × 1/4	1.2500 V
5 V × 1/8	0.6250 V
5 V × 1/16	0.3125 V
...	
5 V × 1/1024	0.0049 V


Clock
SAR
EOC
D_{N-1}
D_{N-2}
D_2 D_1 D_0
V_{REF}
DAC
Comparator
V_{IN}
S/H


VDC
Initial
First
4 th
Takes n clock cycles
15V
14V
13V
12V
11V
10V
9V
8V
7V
6V
5V
4V
3V
2V
1V
0V
1000
1100
0100
1110
1010
0110
0010
1111
1101
1011
1001
0111
0101
0011
0001
1111
1110
1101
1100
1011
1010
1001
1000
0111
0110
0101
0100
0011
0010
0001
0000
CLK:
Initial
First
Second
Third
Fourth
2^n Branches over n iteration for n digit number of 2^n unique values


VDC
15V
14V
13V
12V
11V
10V
9V
8V
7V
6V
5V
4V
3V
2V
1V
0V
CLK:
Initial
First
Second
Third
Fourth
INPUT
= 10.4V
1000
1100
0100
1110
1010
0110
0010
1111
1101
1011
1001
0111
0101
0011
0001
1111
1110
1101
1100
1011
1010
1001
1000
0111
0110
0101
0100
0011
0010
0001
0000
OUTPUT = 1010


VDC
15V
14V
13V
12V
11V
10V
9V
8V
7V
6V
5V
4V
3V
2V
1V
0V
CLK:
Initial
First
Second
Third
Fourth
INPUT
= 9.4V
1000
1100
1010
1001
0100
1110
0110
0010
1111
1101
1011
0111
0101
0011
0001
1111
1110
1101
1100
1011
1010
1001
1000
0111
0110
0101
0100
0011
0010
0001
0000
OUTPUT = 1001

Exercise in class: DAC, ADC, and a SAR emulator

- Work in pairs.

1. Wire up the MCP4725 DAC to Adalogger, and write a code to have the DAC ramp up its voltage output in integer steps, from 0 to 4095.
    - Keep repeating this ramp over and over again. It's OK to make the ramp go as fast as possible. Get an oscilloscope and display the DAC output voltage ramp and show it off to your instructors.

2. Have the Adalogger's ADC tell you the value of the trimpot center pin voltage and also, from time to time, the DAC output voltage.
    - Recall that you can check voltages using your multimeter.

(Homework) 12-bit SAR DAC of an unknown voltage (from the trimpot): To digitize the voltage from an adjustible trimpot, use the MCP4725 DAC and an Adalogger's ADC input pin to code up a 12-bit successive approximation ADC algorithm by defining a 12-bit SAR, as described described, and setting or clearing various bits as you hunt for the DAC voltage that's closest to the voltage on the trimpot center pin.