P524: Survey of Instrumentation and Laboratory Techniques
Week 11

11/3/2026

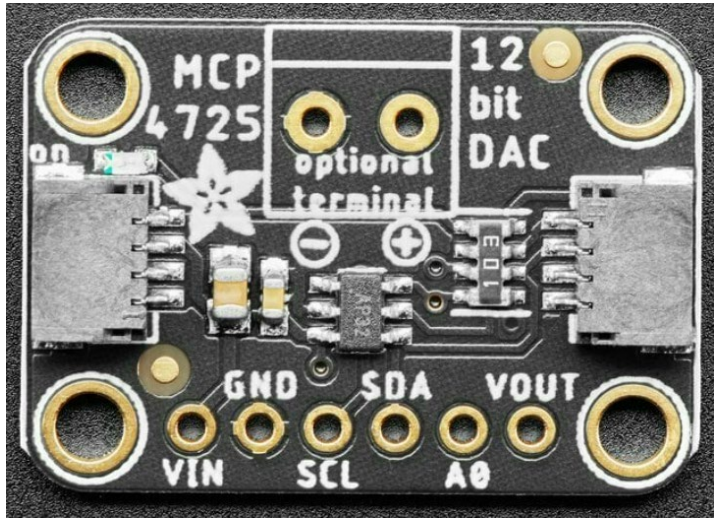
Week 11: sensors-4

Digital to Analog Converter (DAC)

makes V(t) w/ arbitrary waveform

MCP4725 12-bit DAC

- I2C communication (Addr: 0x62)
  - **A0** allow you to change the I2C address.
  - If A0 is connected to **VDD or 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 or Vin (when the DAC 'value' is the max 12-bit number: 0xFFF)

Analog to Digital Converter (ADC)

converts a voltage signal into digital number

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

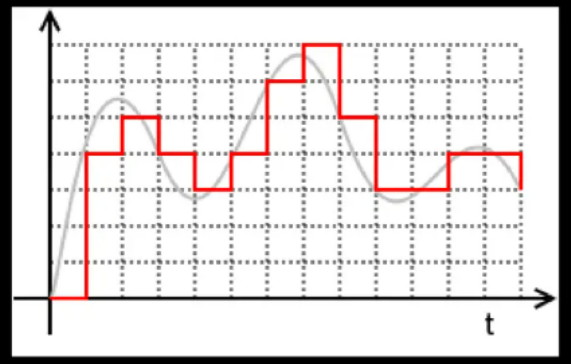


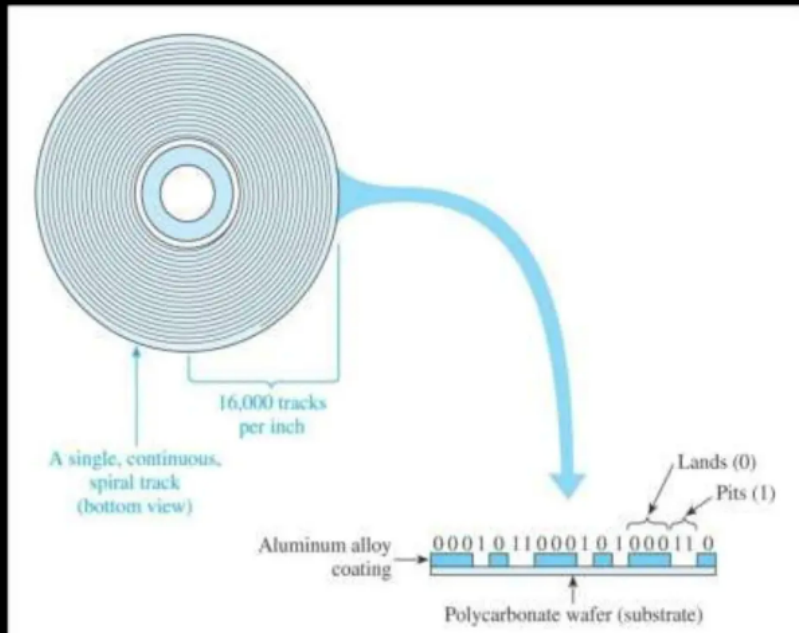


Digital electronics, e.g., CD, DVD

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.

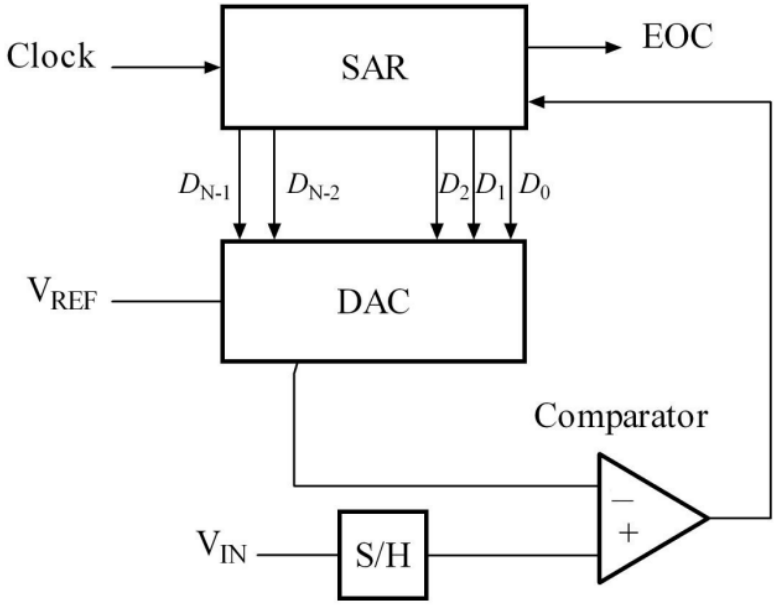
DAC: Digital to Analog Conversion

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.

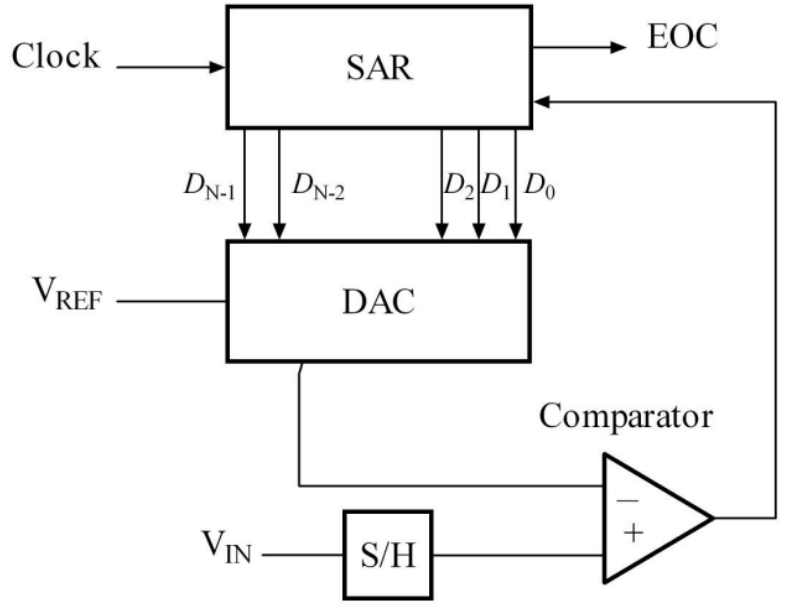
It consists of four subcircuits:

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}.

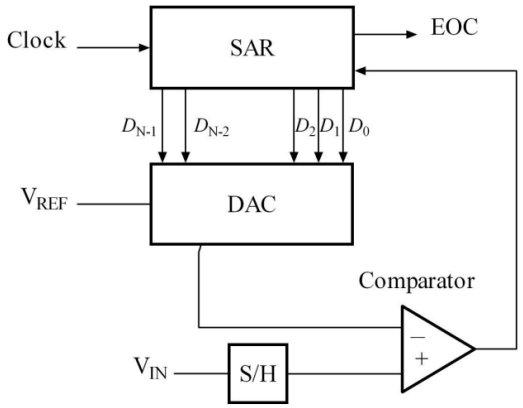


SAR ADC

- 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 SAR has been tested.



4-bit example



Range: 0 to Vcc (here 15 V)

Scale: x = (SAR out)/(Full Scale [FS])

Initial x0: MSB/FS (here 1000/1111)

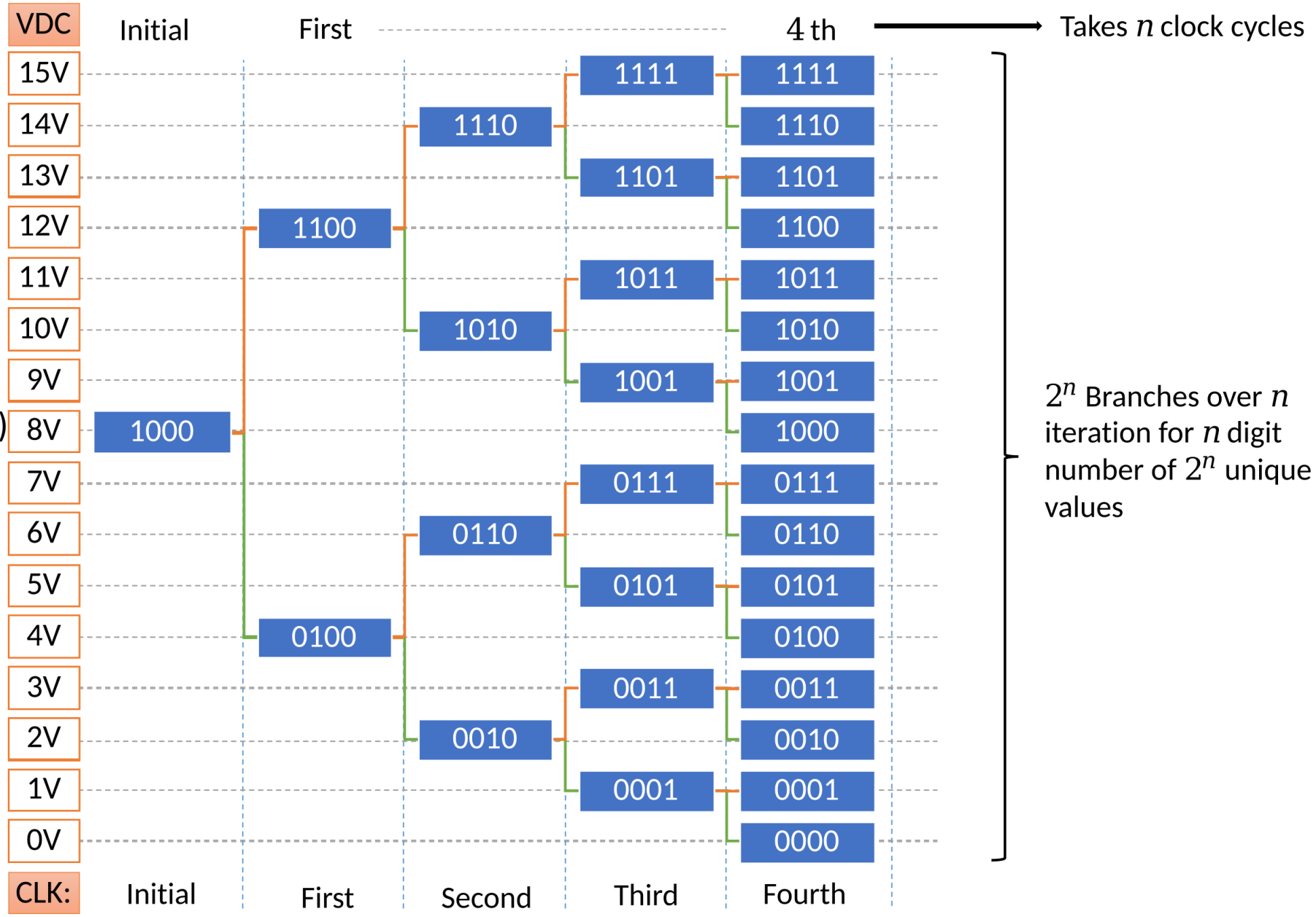
= 8/15

VREF: usually Vcc

DAC: x VREF

Amp resolution: LSB/FS = $1/2^n$

(here 1/16 x 15V = 0.93 V)



Vin = 10.4 V

x0: MSB/FS = 1000/1111 = 8/15

VREF = 15.0 V

DAC0 = (8/15) 15 V = 8.0 V

DAC0 > Vin? No: keep MSB = 1

x1: nSB/FS = 1100/1111 = 12/15

DAC1 = (12/15) 15 V = 12.0 V

DAC1 > Vin? Yes: set nSB = 0

x2: nSB/FS = 1010/1111 = 10/15

DAC2 = (10/15) 15 V = 10.0 V

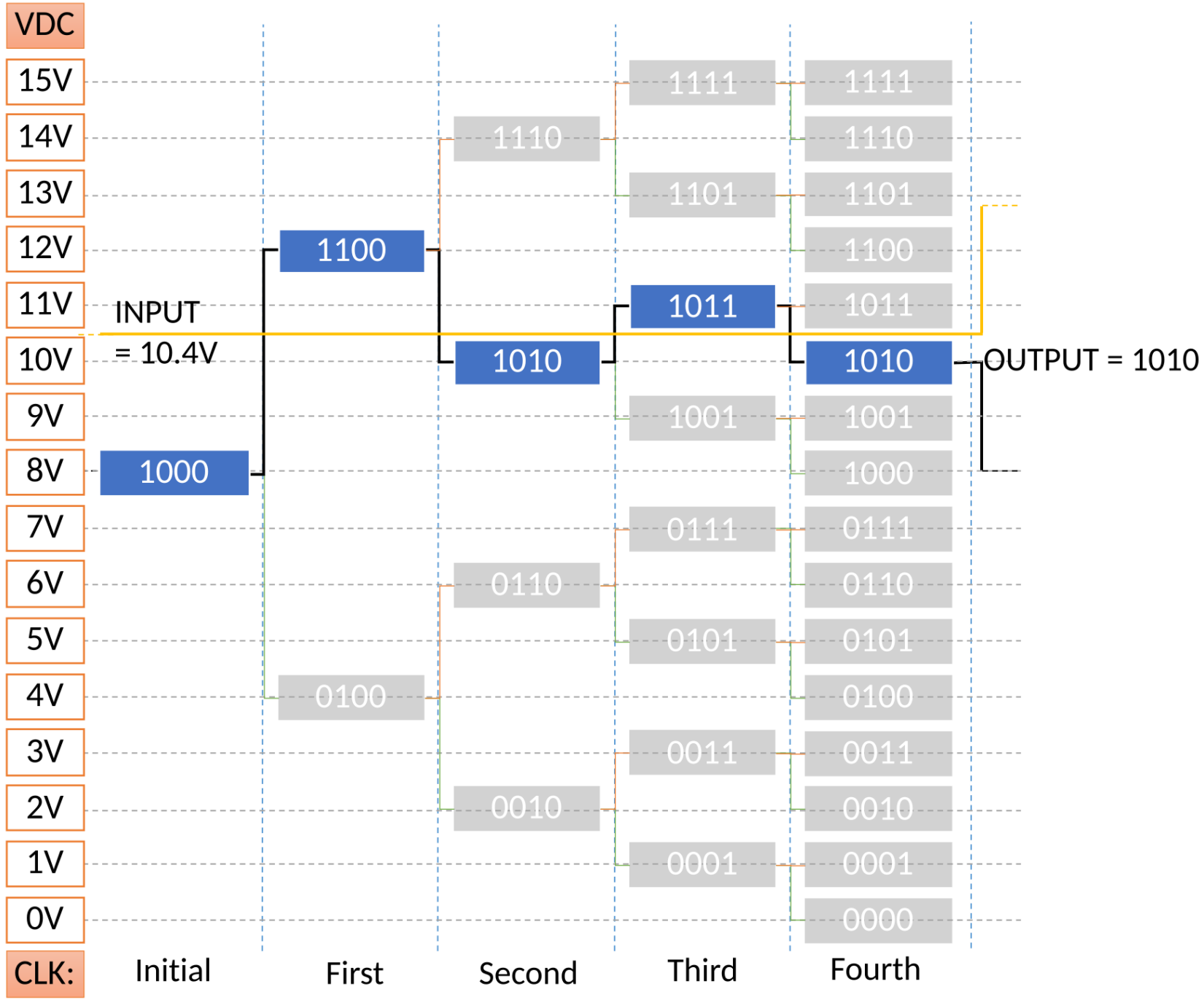
DAC2 > Vin? No: keep nSB = 1

x3: nSB/FS = 1011/1111 = 11/15

DAC2 = (11/15) 15 V = 11.0 V

DAC2 > Vin? Yes: set nSB = 0

Result = 1010 = 10



Vin = 9.4 V

x0: MSB/FS = 1000/1111 = 8/15

VREF = 15.0 V

DAC0 = (8/15) 15 V = 8.0 V

DAC0 > Vin? No: keep MSB = 1

x1: nSB/FS = 1100/1111 = 12/15

DAC1 = (12/15) 15 V = 12.0 V

DAC1 > Vin? Yes: set nSB = 0

x2: nSB/FS = 1010/1111 = 10/15

DAC2 = (10/15) 15 V = 10.0 V

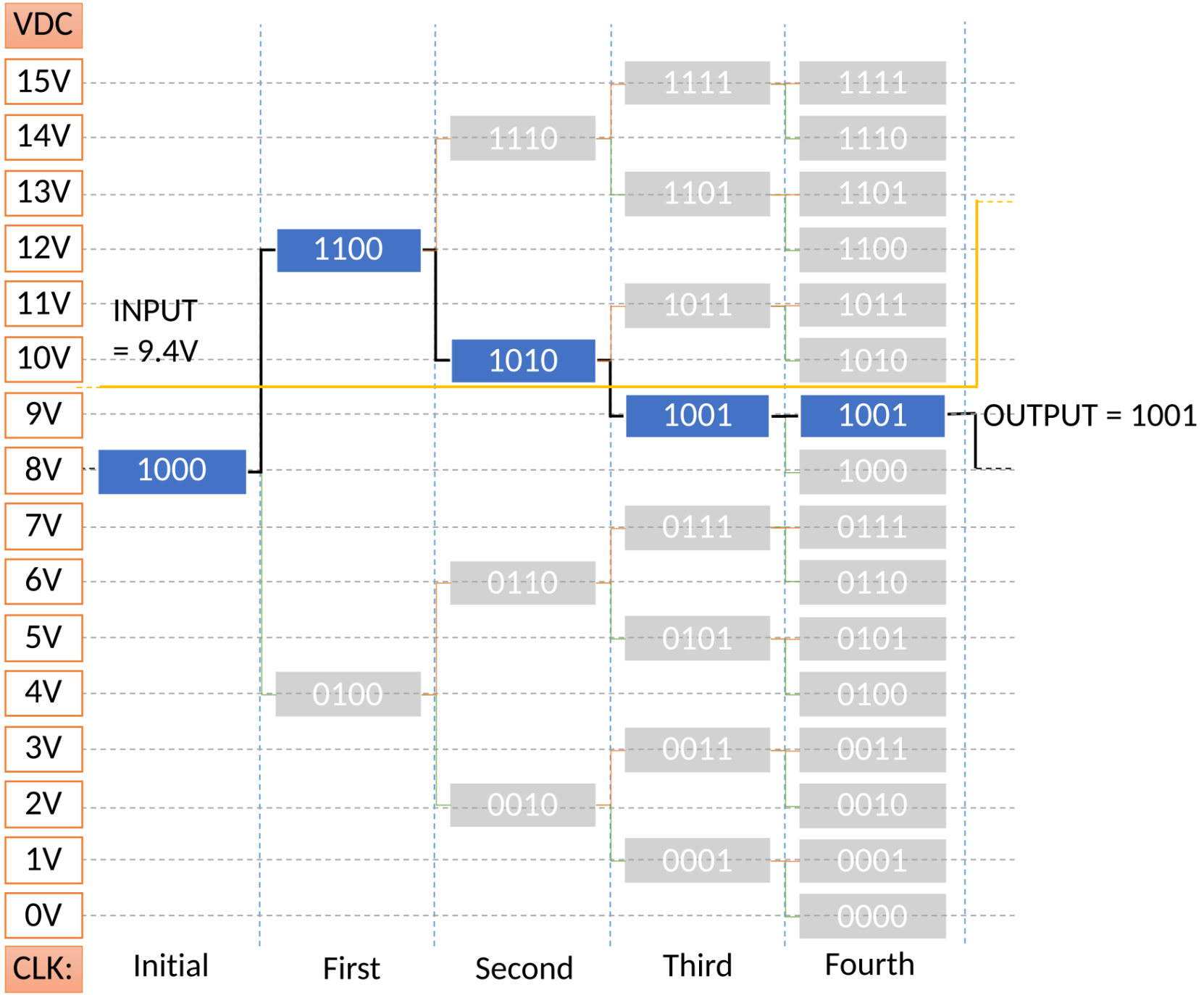
DAC2 > Vin? Yes: set nSB = 0

x3: nSB/FS = 1001/1111 = 9/15

DAC2 = (9/15) 15 V = 9.0 V

DAC2 > Vin? No: keep nSB = 1

Result = 1001 = 9



In-class exercise: DAC, ADC

1. Wire up the circuit in the unit 4d write-up. Connect an MCP4725 DAC to an Adalogger, and write (or modify) 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 (due 11/19(!)) : SAR Emulator

12-bit SAR ADC 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, and setting or clearing various bits as you hunt for the DAC voltage that's closest to the voltage on the trimpot center pin.

