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Electronics for Information Technology

(Điện tử cho Công nghệ Thông tin)

IT3420E

Đỗ Công Thuần

Department of Computer Engineering

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General Information

- Course: **Electronics for Information Technology**
- ID Number: IT3420
- Credits: 2 (2-1-0-4)
- Lecture/Exercise: 32/16 hours (48 hours, 16 weeks)
- Evaluation:
  - Midterm examination and weekly assignment: **50%**
  - Final examination: **50%**
- Learning Materials:
  - Lecture slides
  - Textbooks
    - ***Introductory Circuit Analysis*** (2015), 10th – 13th ed., Robert L. Boylestad
    - ***Electronic Device and Circuit Theory*** (2013), 11th ed., Robert L. Boylestad, Louis Nashelsky
    - ***Microelectronics Circuit Analysis and Design*** (2006), 4th ed., Donald A. Neamen
    - ***Digital Electronics: Principles, Devices and Applications*** (2007), Anil K. Maini

Contact Your Instructor

- You can reach me through office in **Room 802, B1 Building**, HUST.
  - You should make an appointment by email before coming.
  - If you have urgent things, just come and meet me!
- You can also reach me at the following **email** any time. This is the best way to reach me!
  - thuandc@soict.hust.edu.vn

Course Contents

- The Concepts of Electronics for IT
- **Chapter 1**: Passive Electronic Components and Applications
- **Chapter 2**: Semiconductor Components and Applications
- **Chapter 3**: Operational Amplifiers
- **Chapter 4**: Fundamentals of Digital Circuits
- **Chapter 5**: Logic Gates
- **Chapter 6**: Combinational Logic
- **Chapter 7**: Sequential Logic

Chapter 3:
Operational Amplifiers

- Operational Amplifier
- Ideal Parameters
- Operational Amplifier Circuits
- Applications

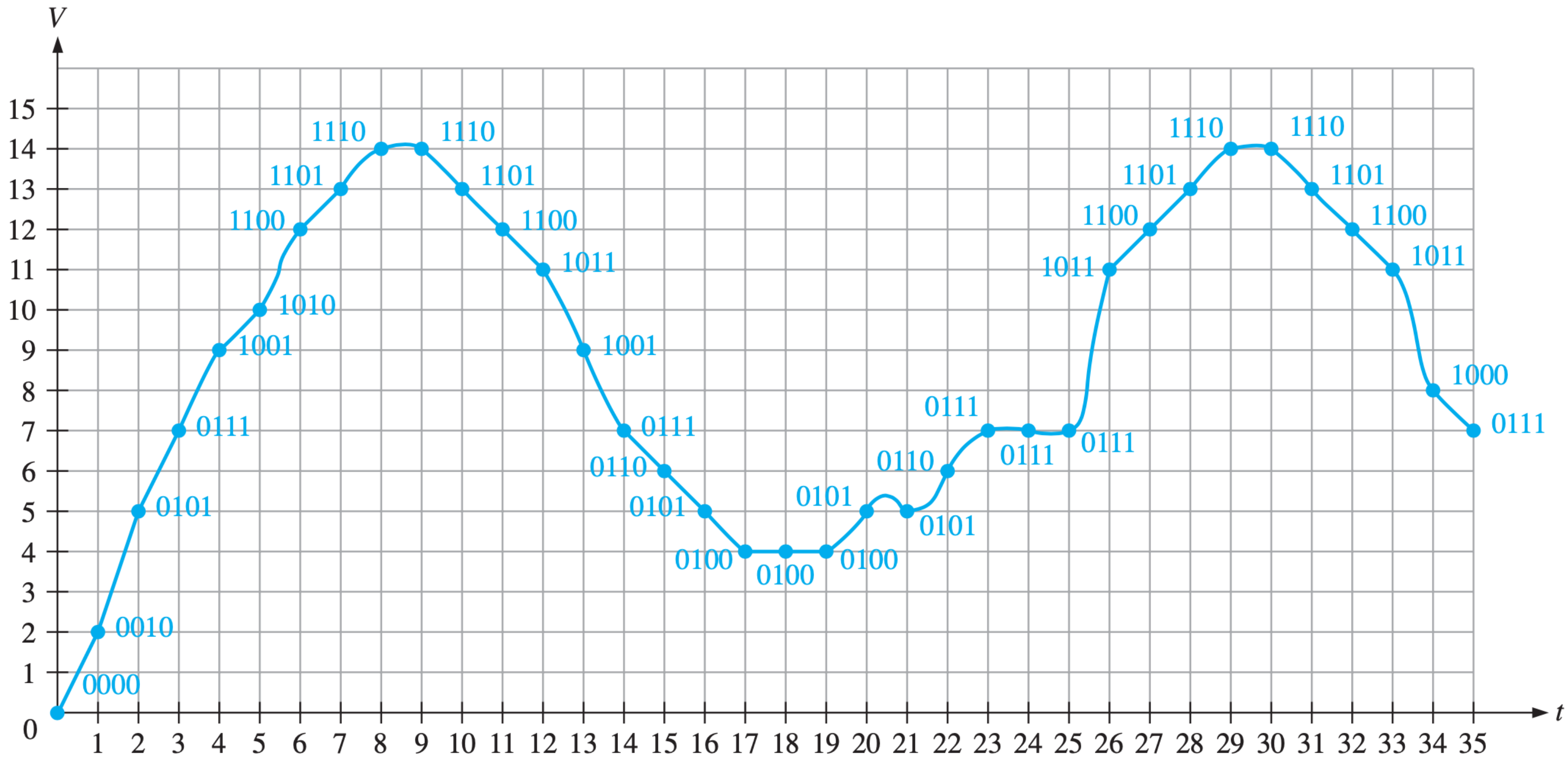
Applications of Op-amp

- Signal and A/D Conversion
- Analog-to-Digital Conversion/Converter – ADC
- Digital-to-Analog Conversion/Converter – DAC

Signal and A/D Conversion

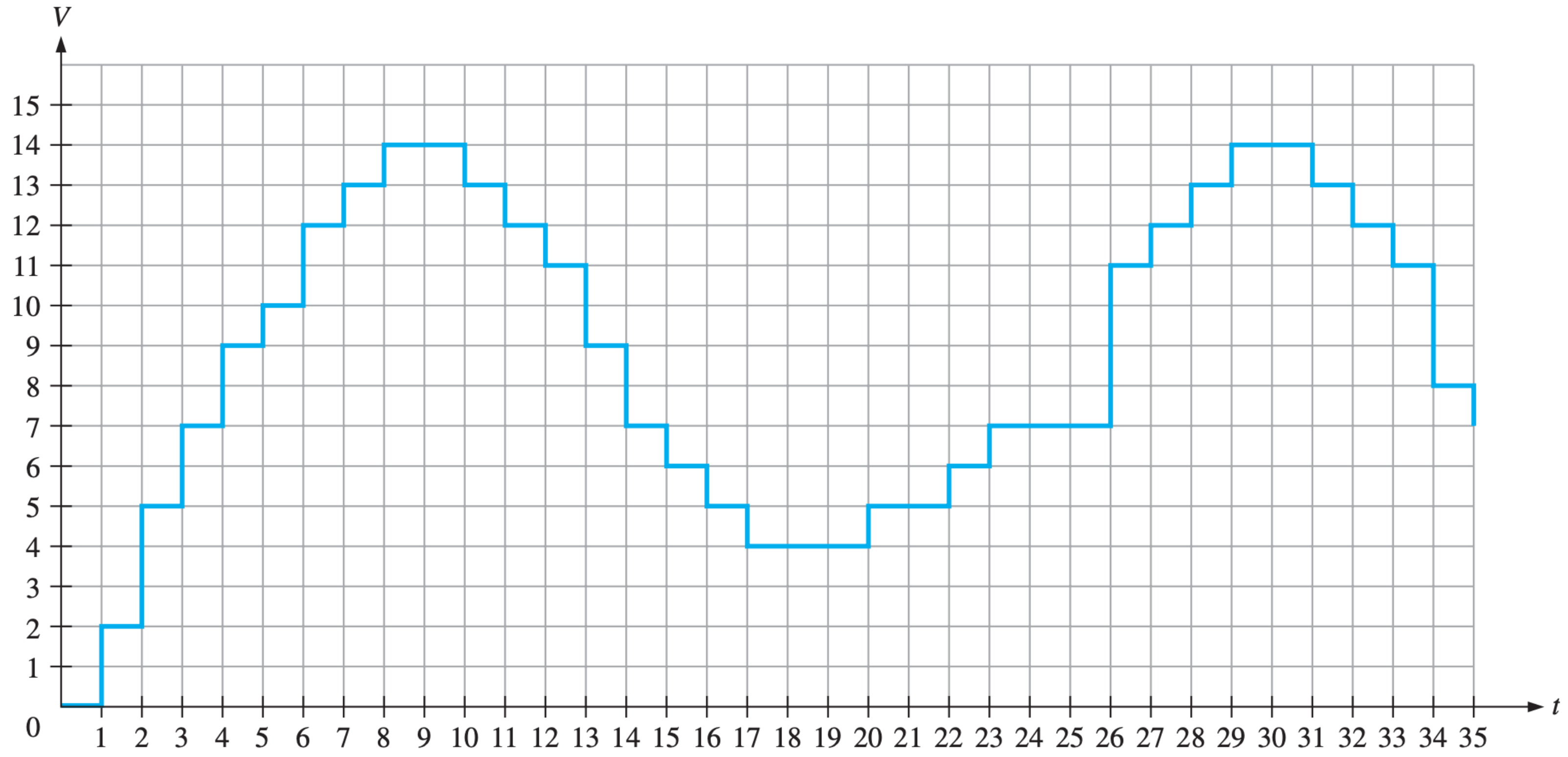
- Analog signals have continuous values, which often represent physical measurements of a time-varying quantity.
- Digital signals have a set of discrete values, which are generated by digital modulation, to represent a time-varying quantity.
- In signal processing, there are 2 important processes:
  - **Analog to Digital conversion**
  - **Digital to Analog conversion**

Analog to Digital Conversion



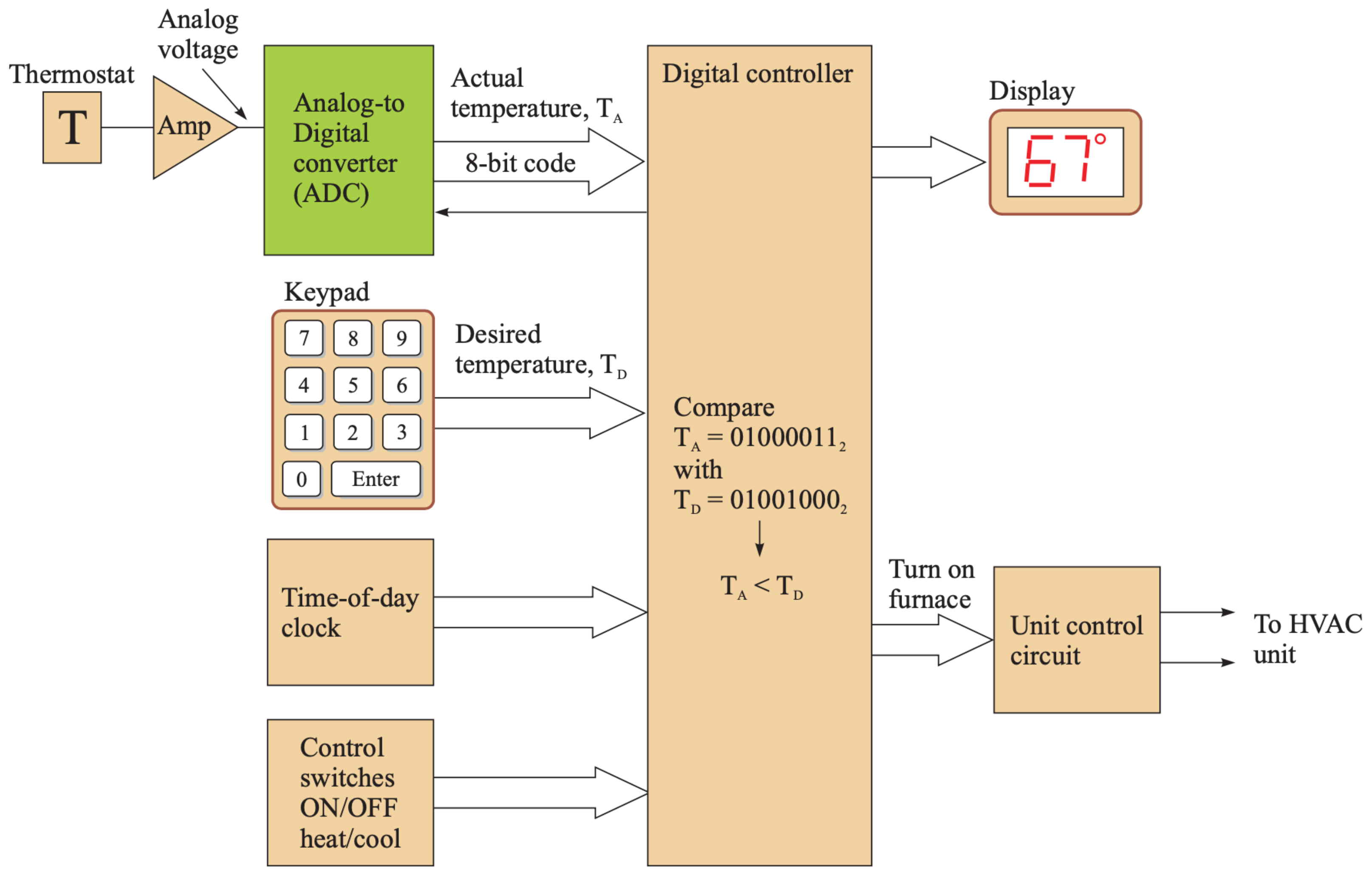
- Data acquisition: the process of taking analog information and converting it into a digital form.

Digital to Analog Conversion

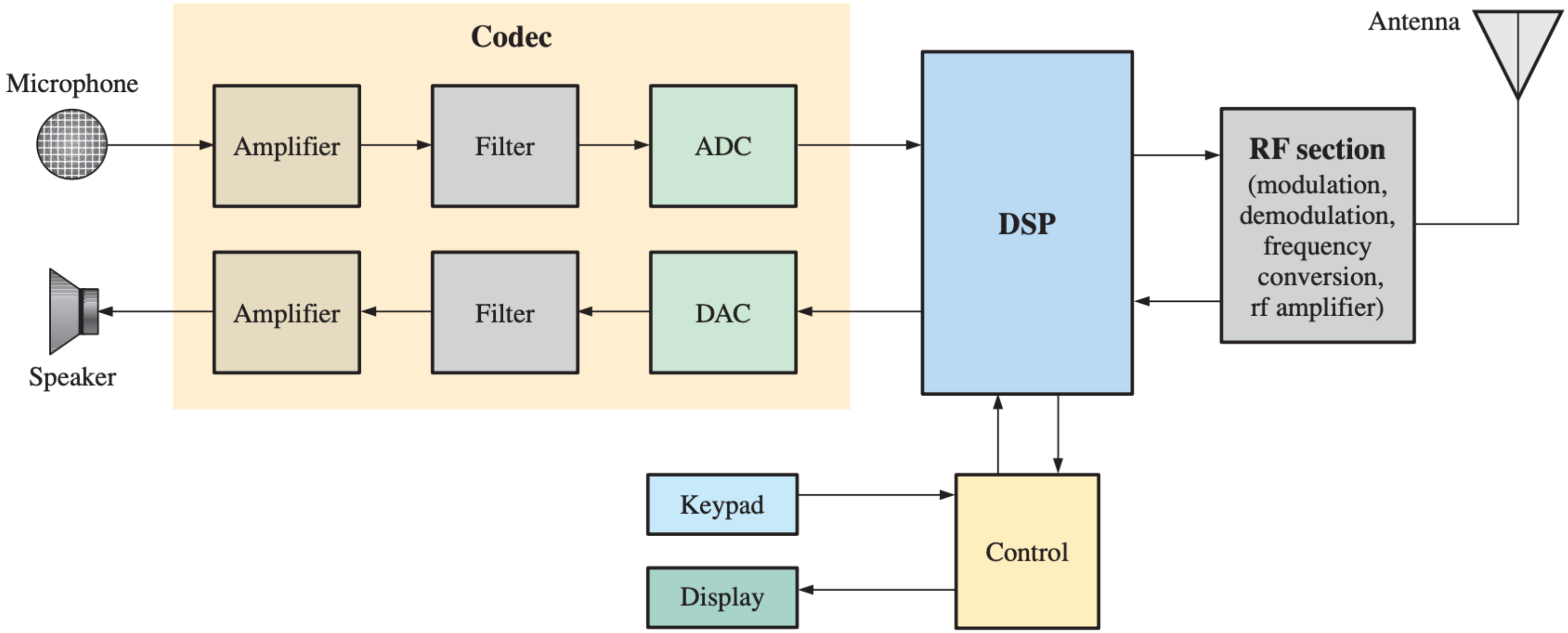


- Signal reconstruction: the process of reconstructing an analog signal from samples that have been transmitted, processed or stored.

Applications of ADC - Thermostat



Application of ADC/DAC - Telephone



Analog-to-Digital Conversion (ADC)

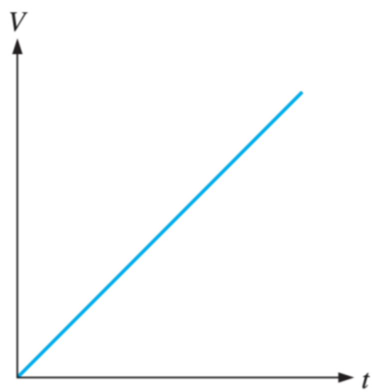
- What an ADC does
- Definition of resolution, conversion time, sampling and quantization error
- How a sample-and-hold circuit and ADC work together
- Flash ADC

Analog-to-Digital Conversion (ADC)

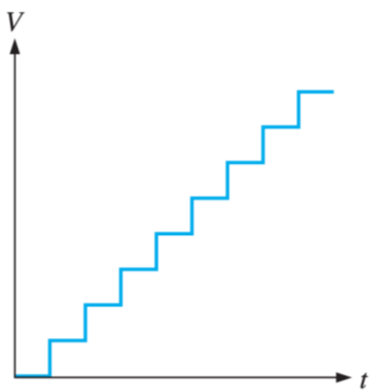
- The process of converting the sampled values of the analog signal to a series of binary codes.
- Each binary code represents the amplitude of the analog signal at each of the sample times.
- Important characteristics of ADCs:
  - Resolution
  - Conversion time
  - Sampling frequency
  - Quantization error

Resolution

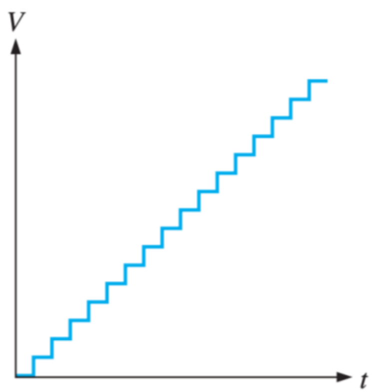
- The resolution of an ADC can be expressed as the number of bits (binary digits) used to represent each value of the analog signal.
- Example: A 3-bit ADC can represent 8 different values of an analog signal.



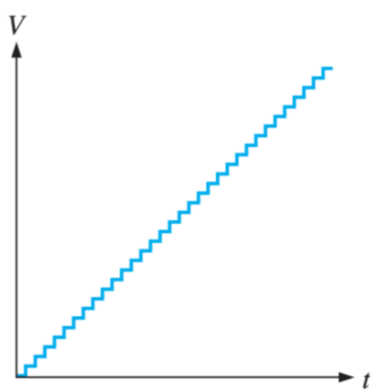
Analog signal



Digital signal with 3-bit resolution



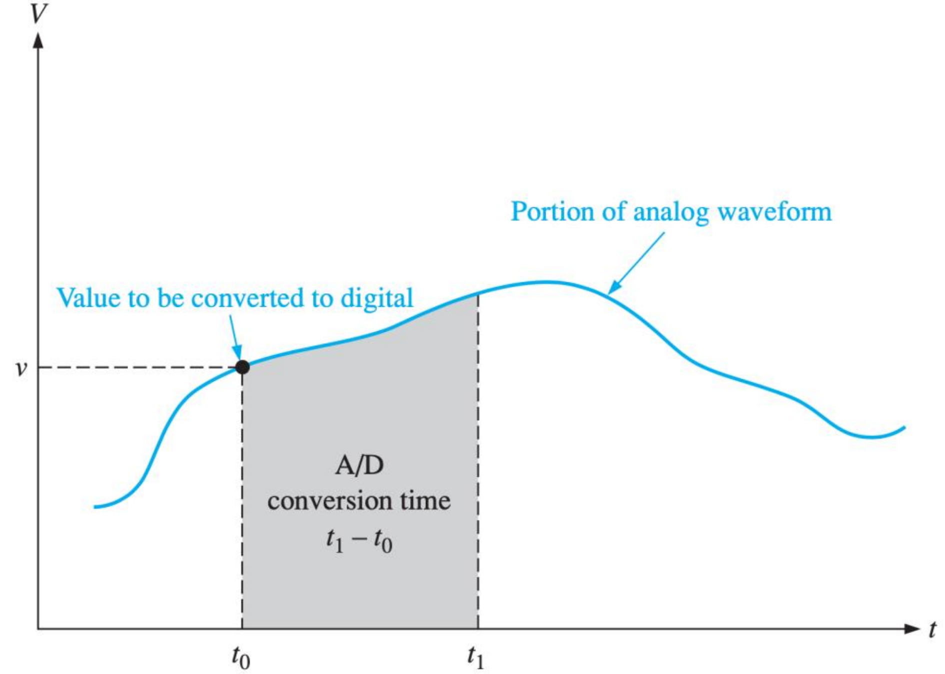
Digital signal with 4-bit resolution



Digital signal with 5-bit resolution

A/D Conversion Time

- The conversion of an analog voltage into a digital quantity is not an instantaneous event, but it is a process that takes a certain amount of time.
- The conversion time can range from microseconds (µs) for fast converters to milliseconds (ms) for slower devices.

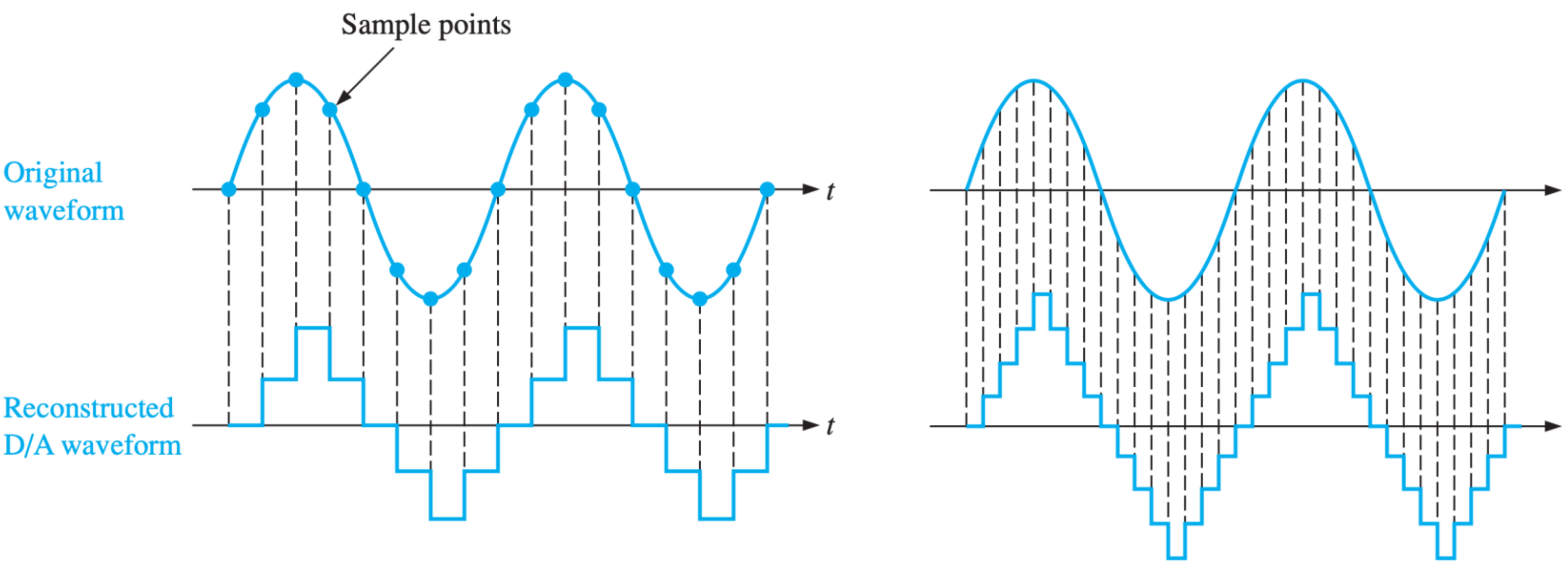


Sampling Frequency

- At a givent point, an analog waveform is sampled, and the sampled value is then converted to a binary number.
- Since it takes a certain interval of time to accomplish the conversion, the number of samples of an analog waveform during a given period of time is limited.
- The theoretical minimum limit of the sampling rate is known as the Nyquist rate or frequency: **an analog signal is sampled and converted two times per cycle**.

Sampling Frequency

- Illustration of 2 sampling rates.



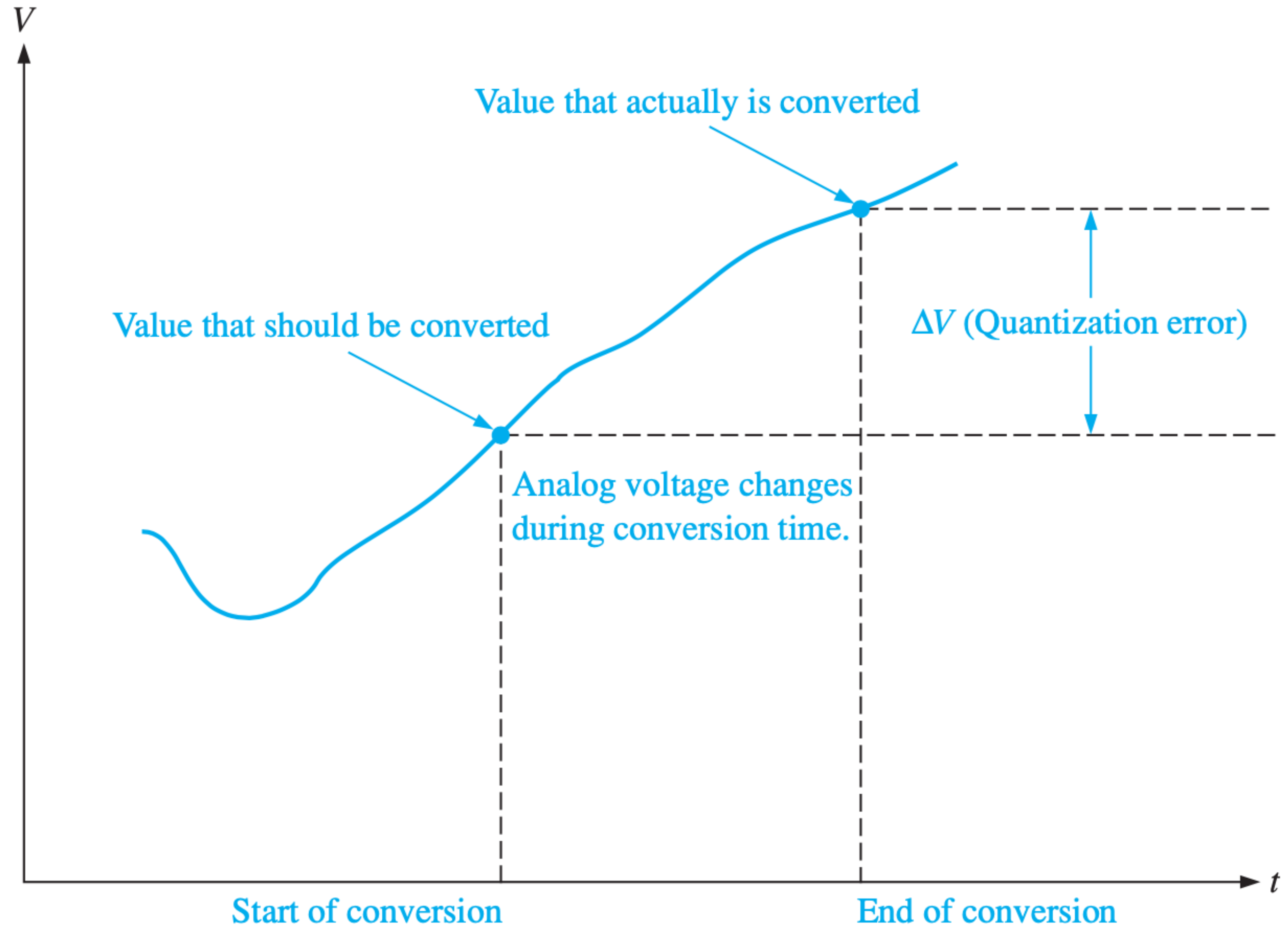
8 samples per cycles

16 samples per cycles

Quantization Error

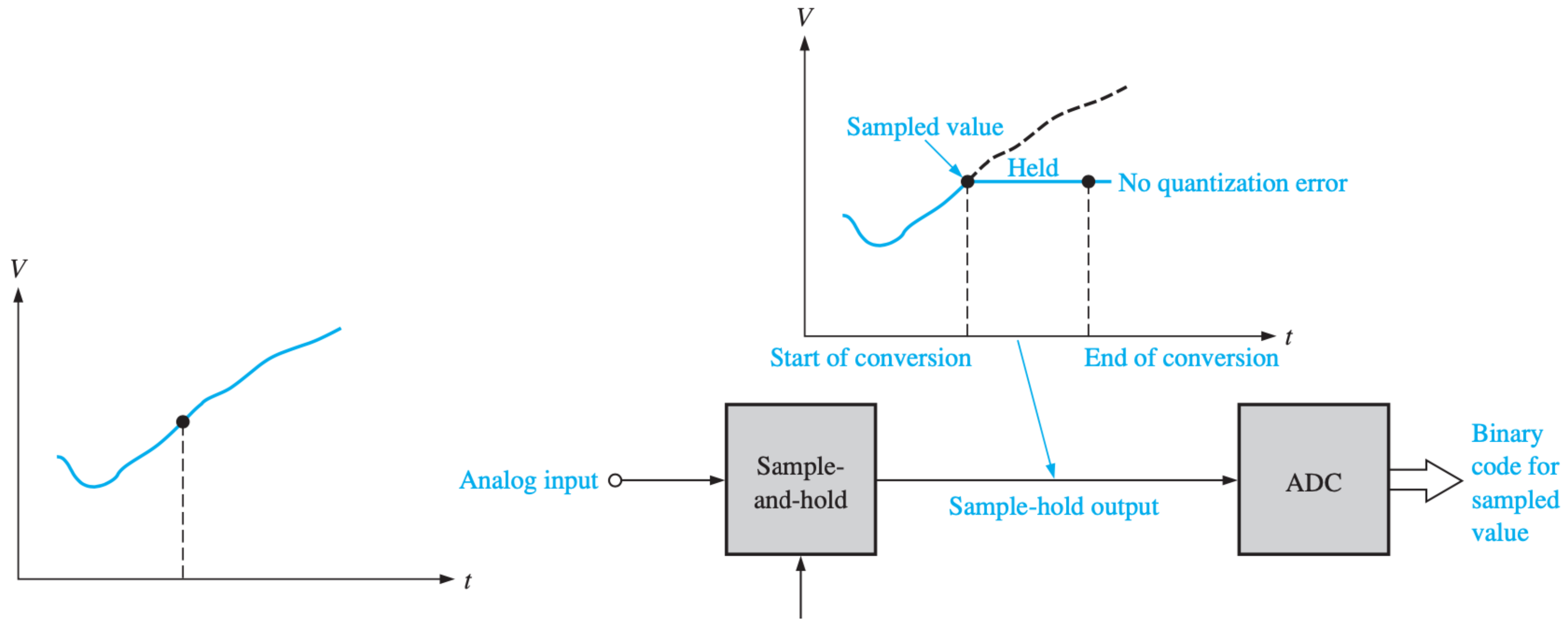
- The term quantization refers to determining a value for a changing analog voltage.
- **Ideally:** Assign a number to the voltage at a given instant and convert it <u>**immediately**</u> to digital form → impossible
- **In fact:** An analog signal may change during a conversion time → the voltage at the end of the conversion time may <u>**not be the same**</u> as it was at the beginning.
- Quantization error is the change in voltage during the conversion time.

Quantization Error



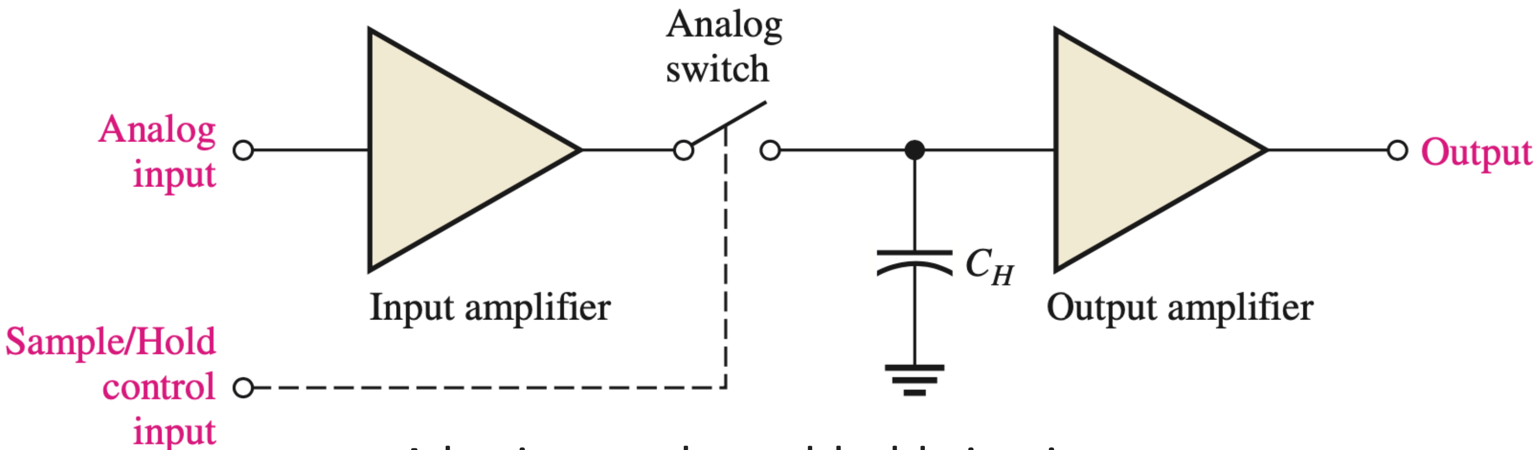
Quantization Error

- **Solution**: Using a sample-and-hold circuit to avoid quantization error at the input to the ADC.



Sample-and-Hold

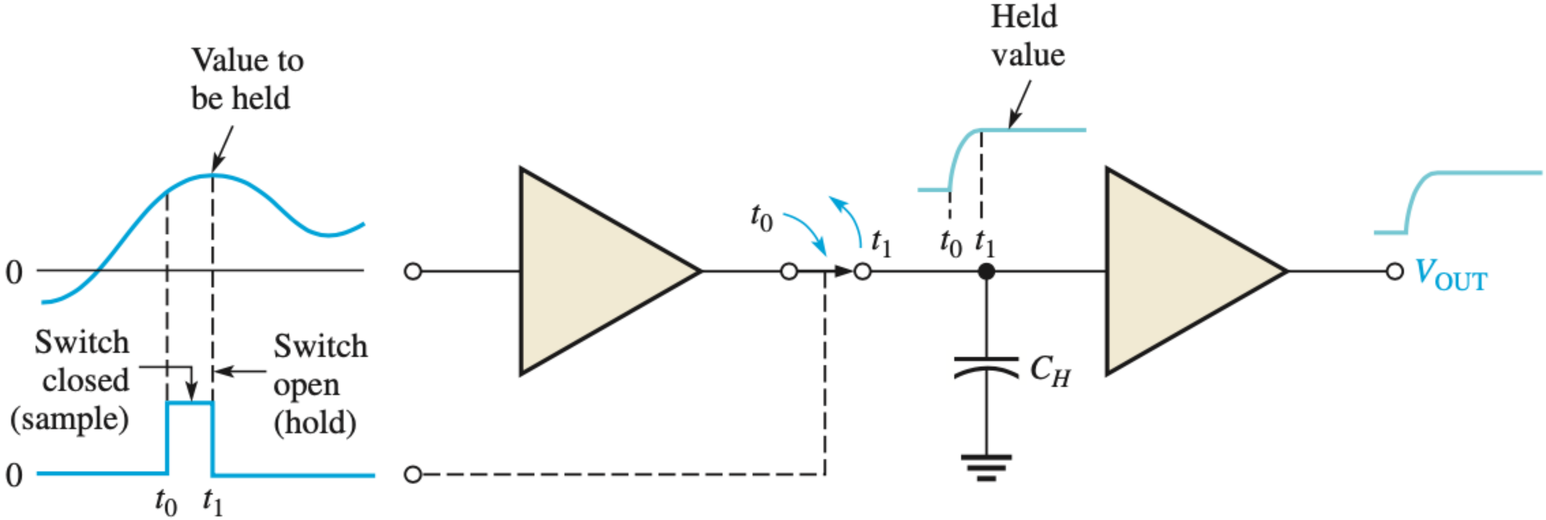
- A sample-and-hold circuit quickly samples the analog input and then holds the sampled voltage for a certain time.
- When used in conjunction with an ADC, the S&H is held constant for the duration of the conversion time.



A basic sample-and-hold circuit

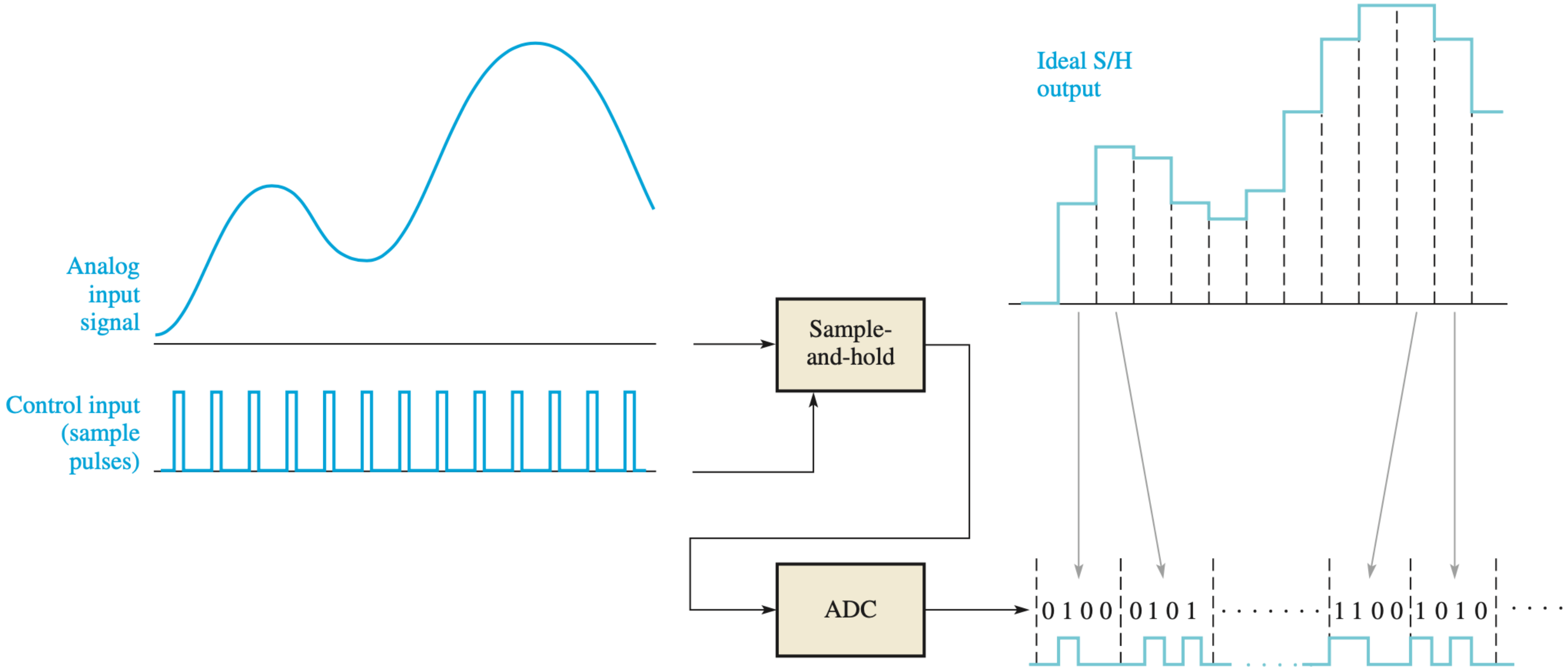
Sample-and-Hold

- A relatively narrow control voltage pulse closes the analog switch and allows the capacitor to charge to the value of the input voltage.
- The switch opens, and the capacitor holds the voltage for a long period of time (because of the very high impedance discharge path through the op-amp input).



S&H Circuit and ADC Working Together

- Illustrating the basic function of an ADC
- The output of the S&H goes to the ADC → Minimizing quantization errors.



Flash ADC

- The flash ADC uses several comparators to compare reference voltages with the analog input from a S&H circuit.
- When the analog voltage exceeds the reference level for a given comparator, a high-level output is produced by the comparator.
- 2^n-1 comparators are required for conversion to an n-bit binary code.
- **Main disadvantage**: large number of comparators necessary for a practical size binary code.

3-bit flash ADC

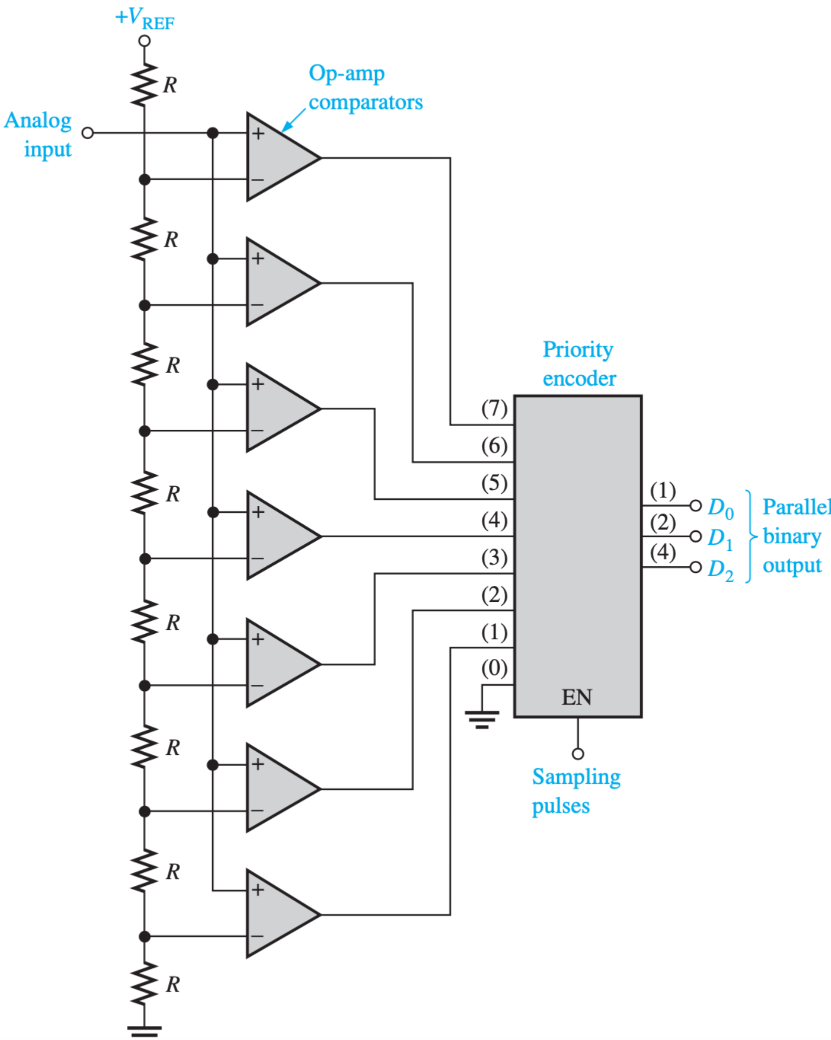
- 7 comparators for a conversion to 3 binary bits.
- The resistive voltage-divider sets the reference voltage for each comparator.

$$(7) = \frac{7}{8}V_{\mathrm{ref}} \quad (3) = \frac{3}{8}V_{\mathrm{ref}}$$

$$(6) = \frac{6}{8}V_{\mathrm{ref}} \quad (2) = \frac{2}{8}V_{\mathrm{ref}}$$

$$(5) = \frac{5}{8}V_{\mathrm{ref}} \quad (1) = \frac{1}{8}V_{\mathrm{ref}}$$

$$(4) = \frac{4}{8}V_{\mathrm{ref}} \quad (0) = \frac{0}{8}V_{\mathrm{ref}}$$

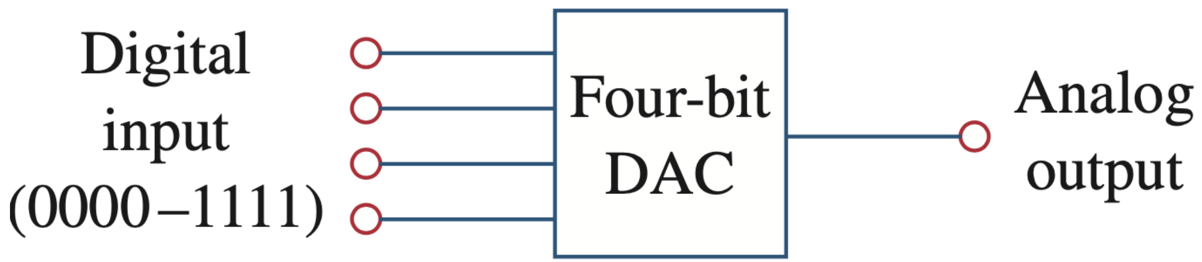


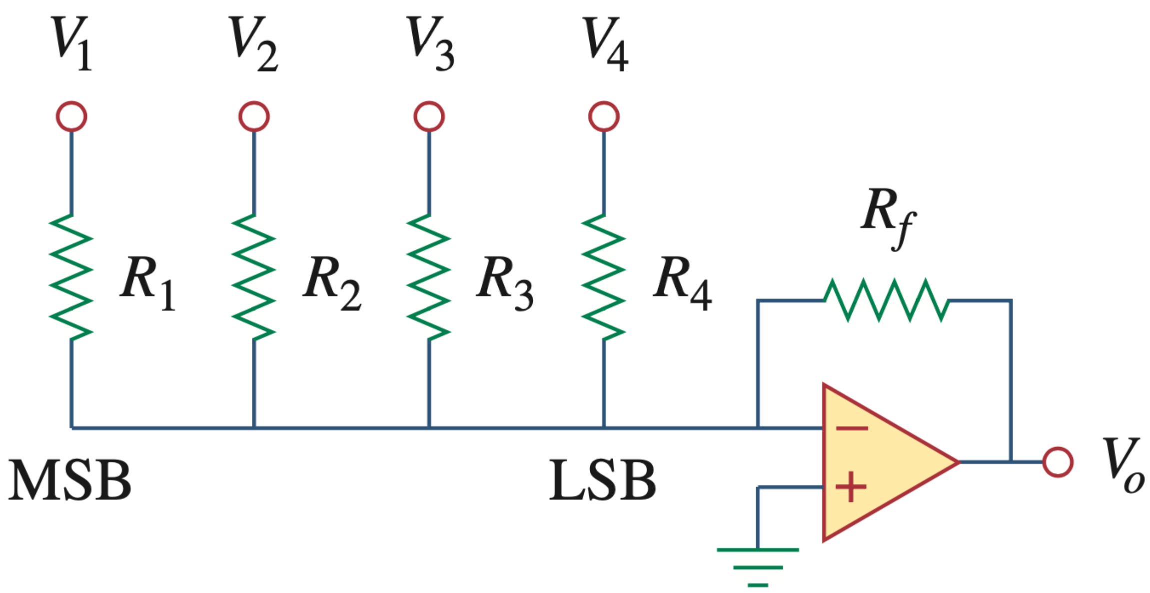
Digital-to-Analog Converter (DAC)

- Transforming digital signals into analog form.
- Input: digital signal
- Output: analog signal

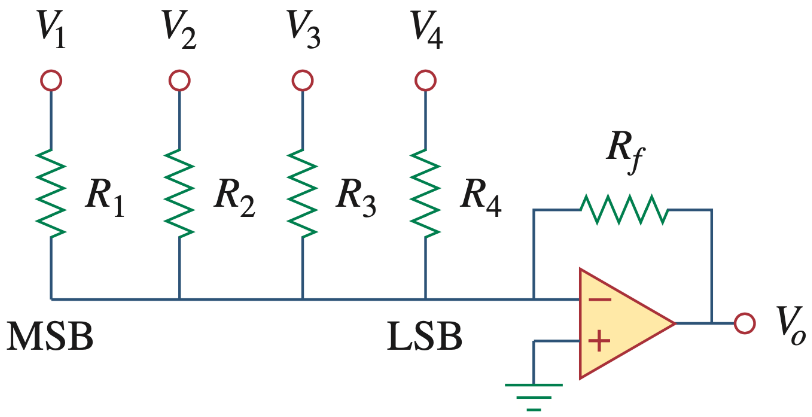
4-bit DAC: Binary Weighted Ladder

- Assuming only 2 voltage levels for inputs: +5V and 0V.





4-bit DAC: Binary Weighted Ladder



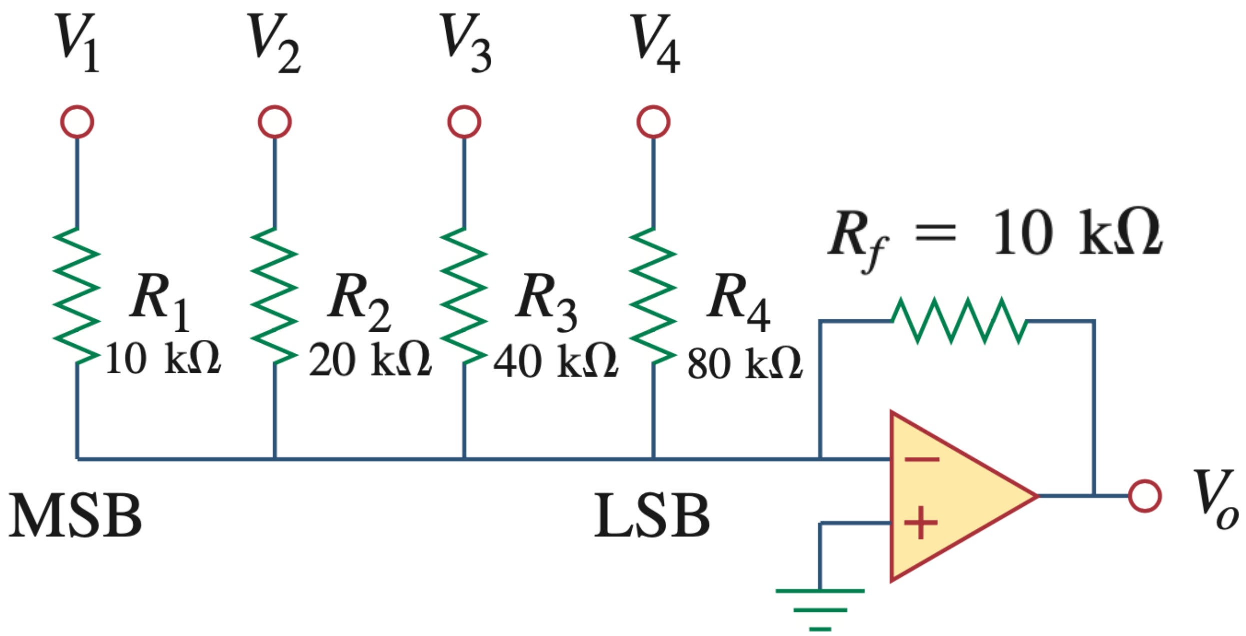
- The output is related to the inputs as:

$$-V_o = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4$$

- By using the proper input and feedback resistor values, the DAC provides a single output that is proportional to the inputs.

Example 4.9

- For a 4-bit DAC shown in the figure, determine the analog output V_O for binary inputs $V_1V_2V_3V_4$ from 0000 to 1111.



Example 4.9

- The analog output:

$$-V_o = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4$$

$$= V_1 + 0.5V_2 + 0.25V_3 + 0.125V_4$$

- For each digital input, we have:

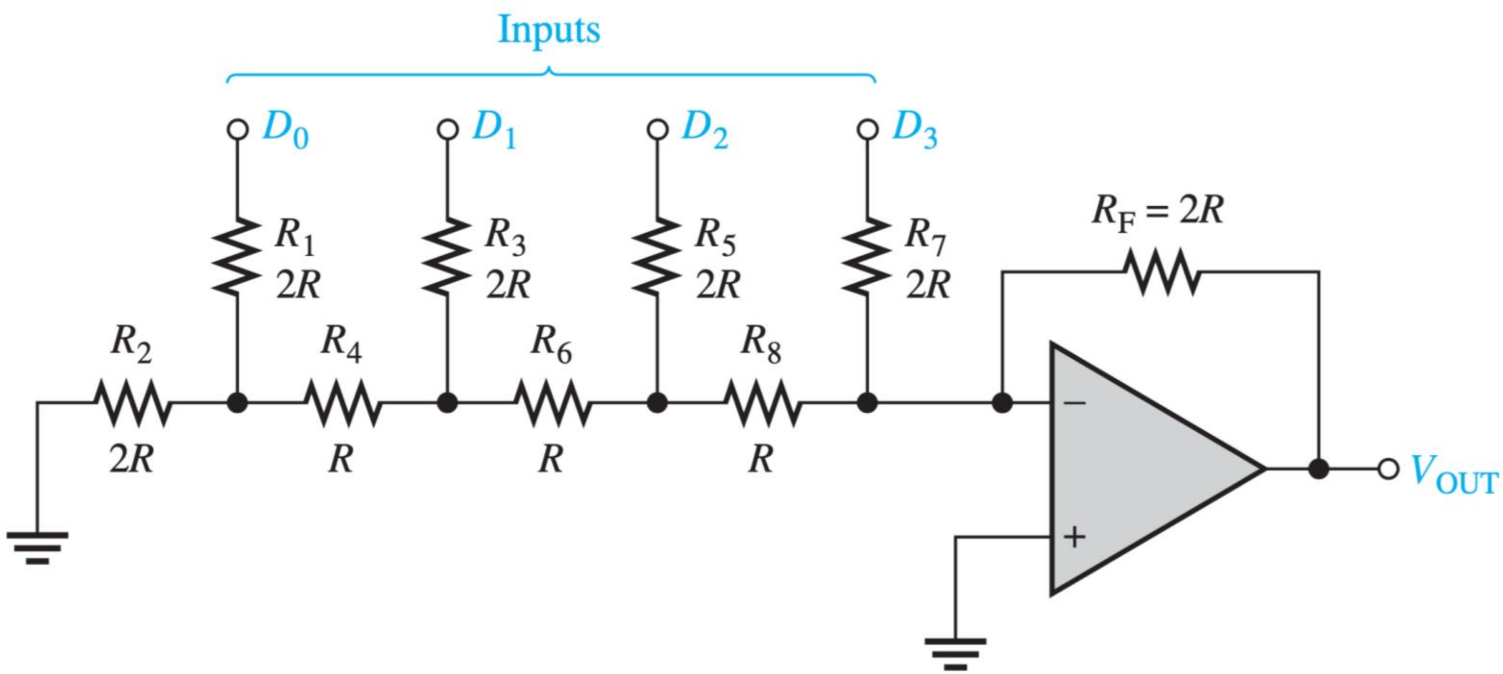
$$\begin{aligned}
[V_1 V_2 V_3 V_4] &= [0010] && \Rightarrow && -V_o = 0.25\text{ V} \\
[V_1 V_2 V_3 V_4] &= [0011] && \Rightarrow && -V_o = 0.25 + 0.125 = 0.375\text{ V} \\
[V_1 V_2 V_3 V_4] &= [0100] && \Rightarrow && -V_o = 0.5\text{ V} \\
&\vdots \\
[V_1 V_2 V_3 V_4] &= [1111] && \Rightarrow && -V_o = 1 + 0.5 + 0.25 + 0.125 \\
&&&&& = 1.875\text{ V}
\end{aligned}$$

Example 4.9

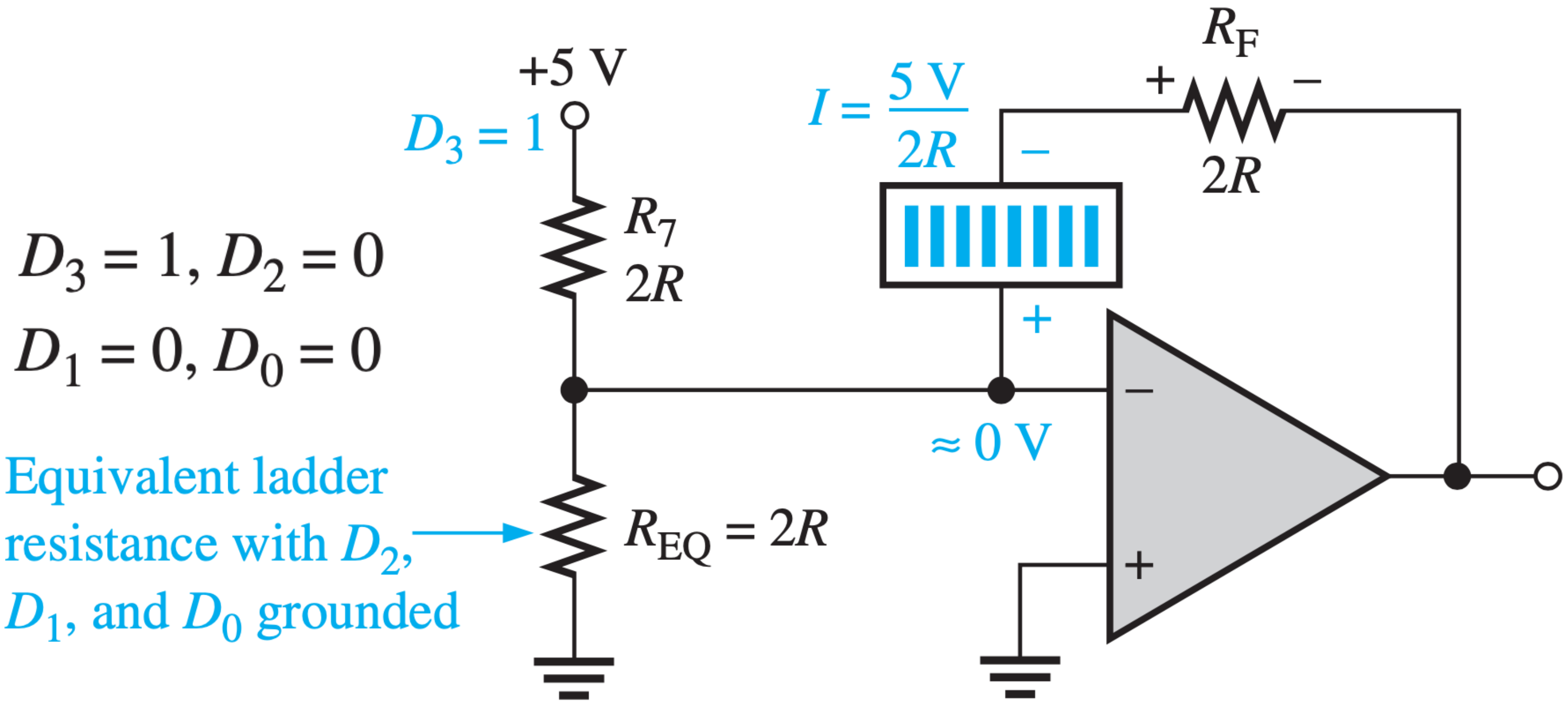
$[V_1V_2V_3V_4]$	Decimal value	$-V_o$
0000	0	0
0001	1	0.125
0010	2	0.25
0011	3	0.375
0100	4	0.5
0101	5	0.625
0110	6	0.75
0111	7	0.875
1000	8	1.0
1001	9	1.125
1010	10	1.25
1011	11	1.375
1100	12	1.5
1101	13	1.625
1110	14	1.75
1111	15	1.875

R-2R DAC

- Assuming only 2 voltage levels for inputs: +5V and 0V.



R-2R DAC

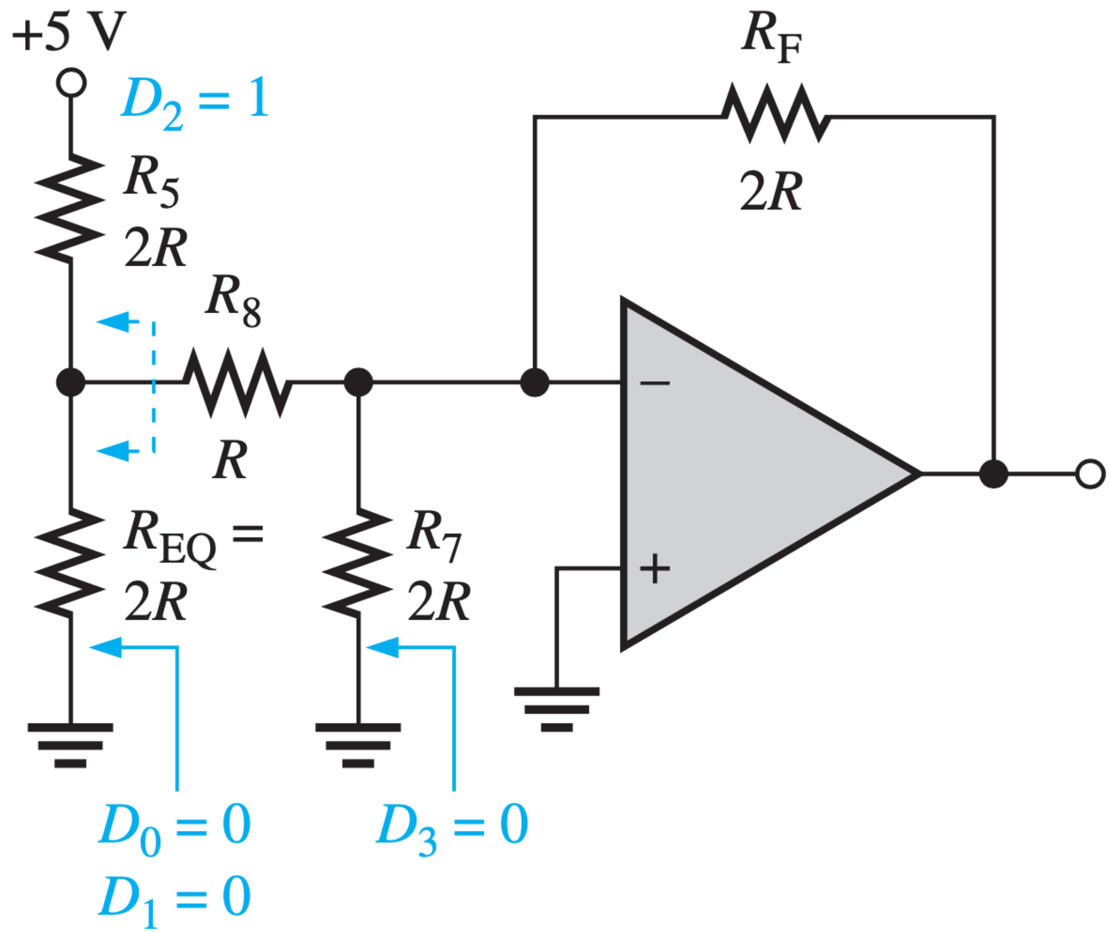


$$V_{OUT} = -IR_F = -\left(\frac{5\text{ V}}{2R}\right)2R = -5\text{ V}$$

R-2R DAC

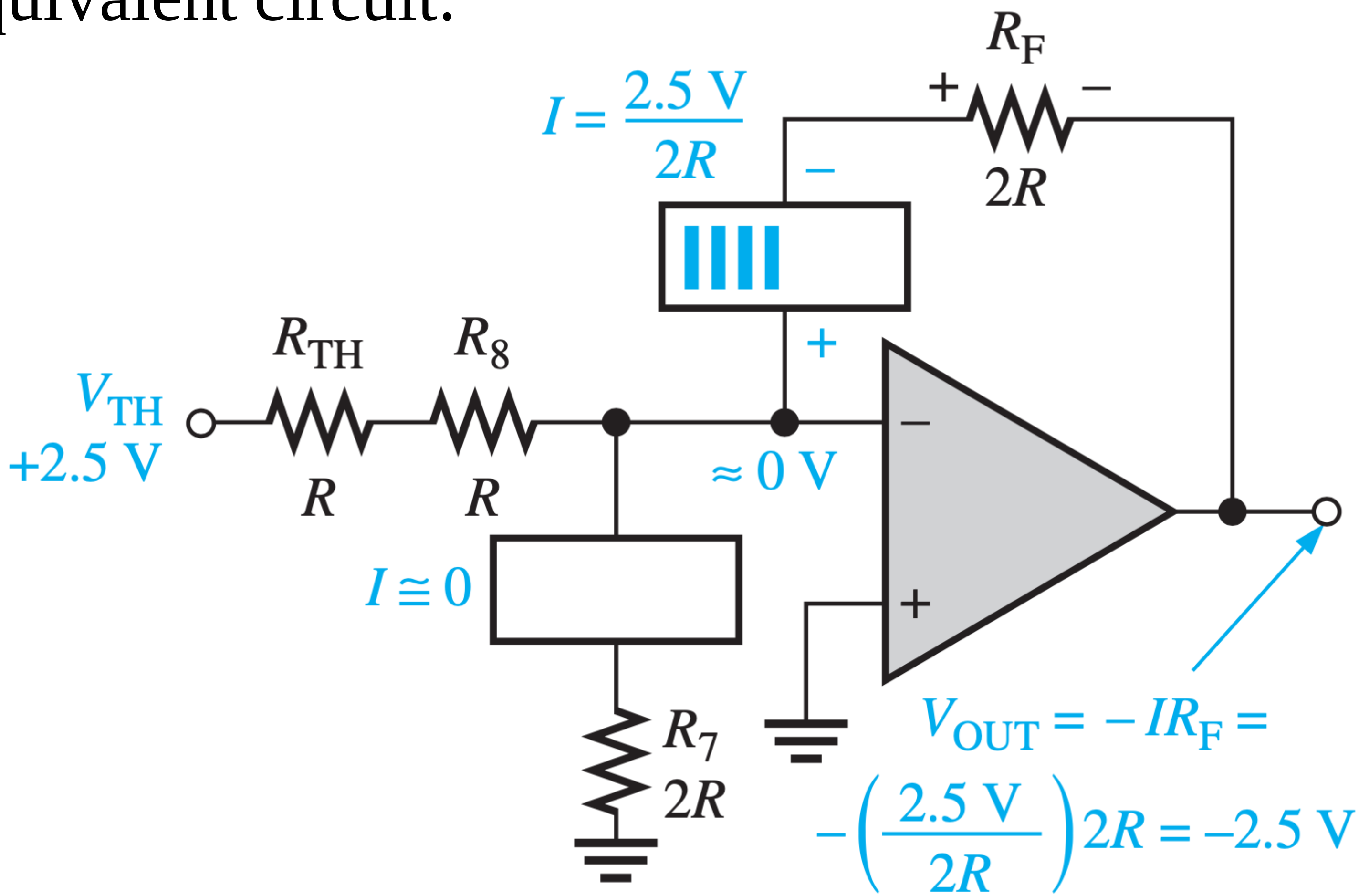
$D_3 = 0, D_2 = 1$

$D_1 = 0, D_0 = 0$



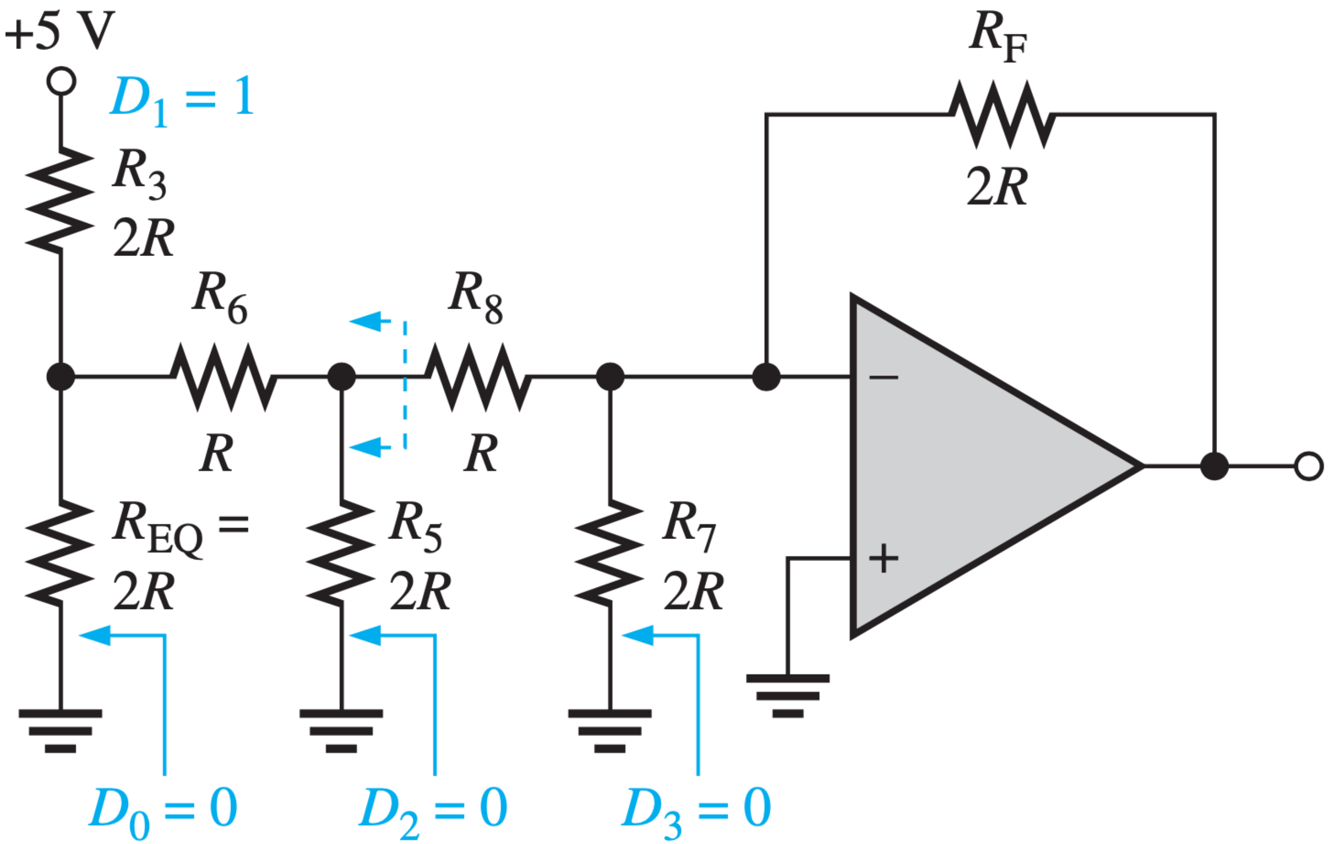
R-2R DAC

- Equivalent circuit:



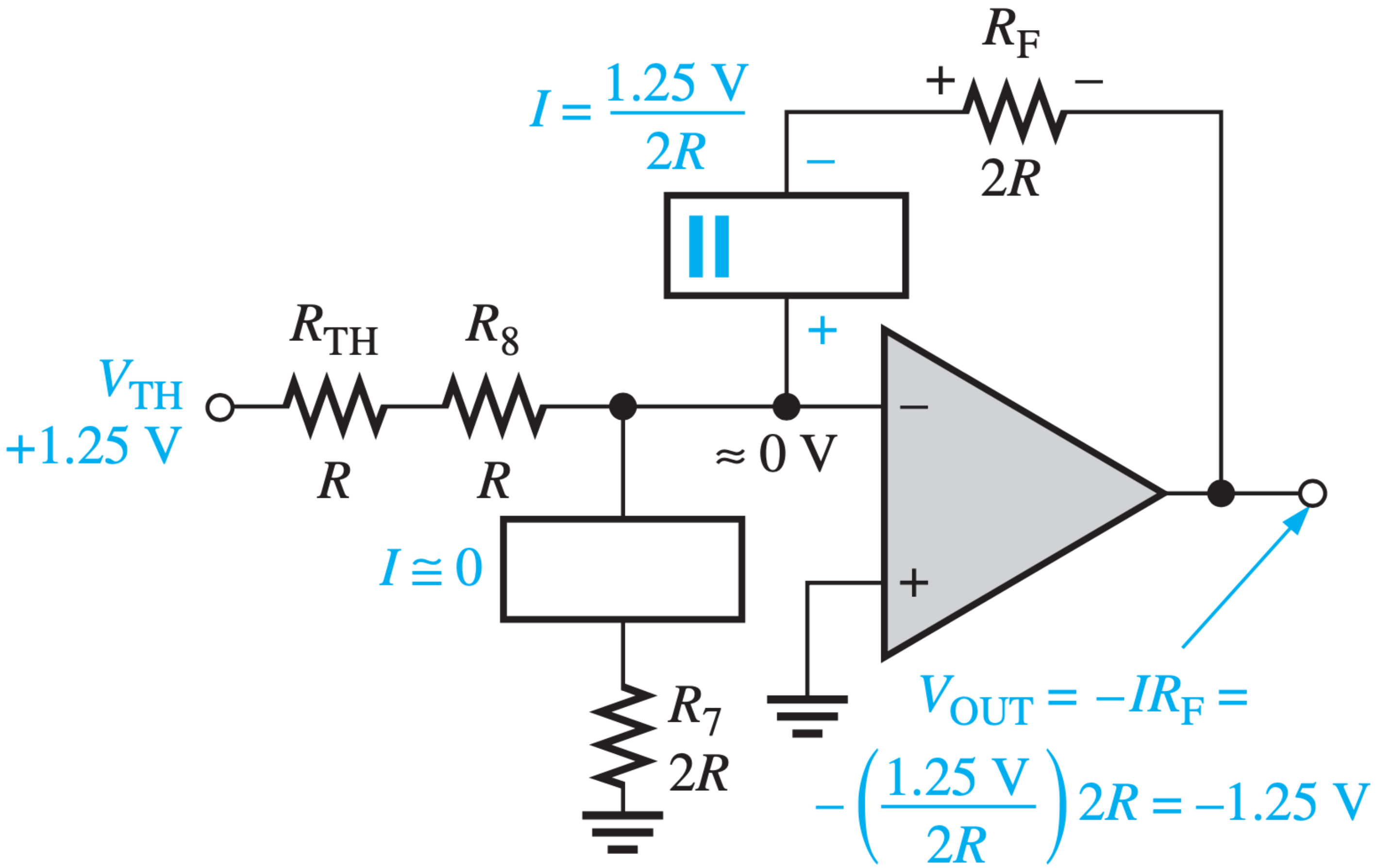
R-2R DAC

$$D_3 = 0, D_2 = 0, D_1 = 1, D_0 = 0$$



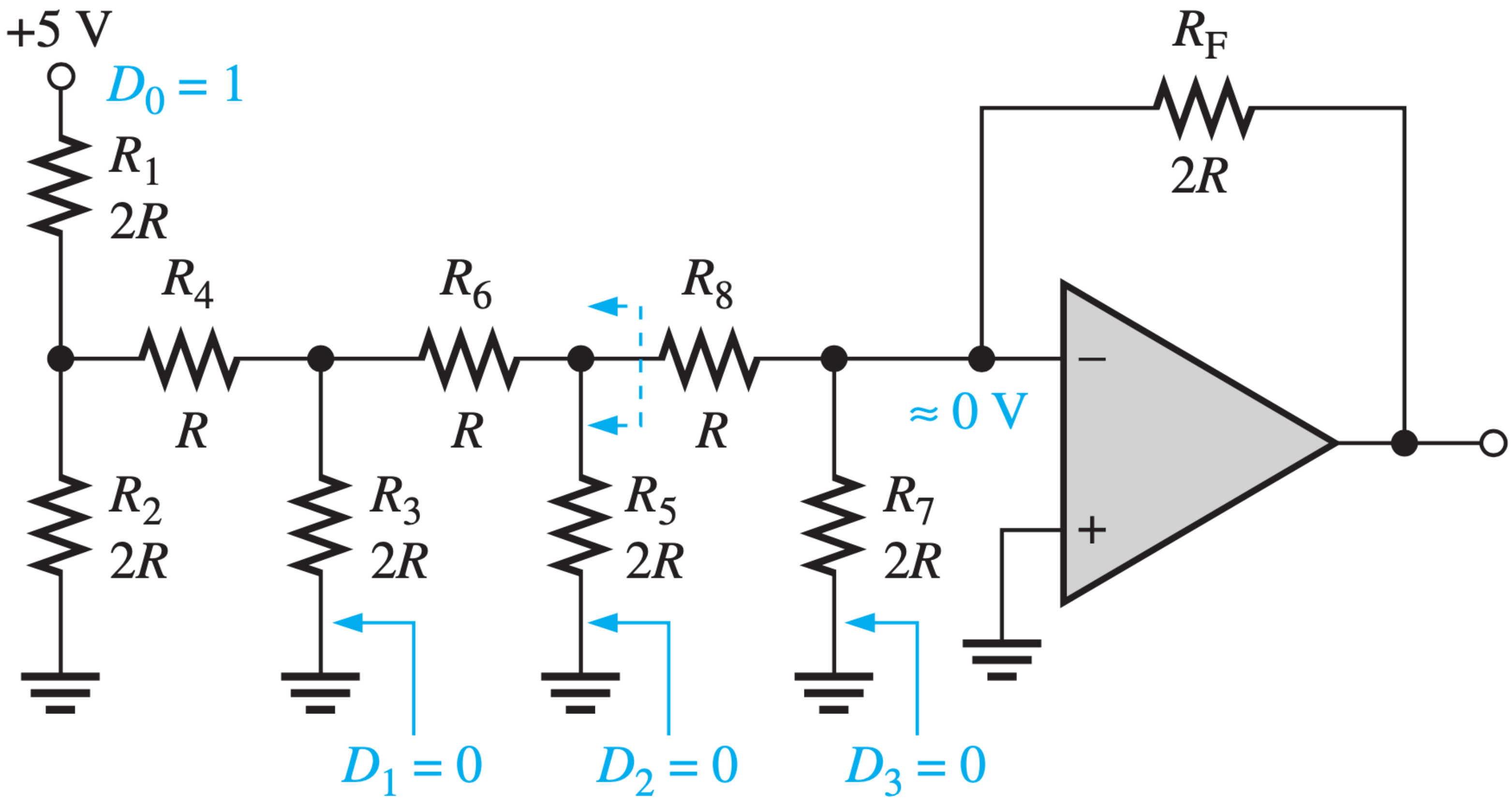
R-2R DAC

- Equivalent circuit:



R-2R DAC

$$D_3 = 0, D_2 = 0, D_1 = 0, D_0 = 1$$



R-2R DAC

- Equivalent circuit: