20EC105
Linear Integrated Circuit Applications

Core Course

(Common to: B.Tech ECE & also its splns. AIML & IOT)

by

Dr. Vijaya Gunturu

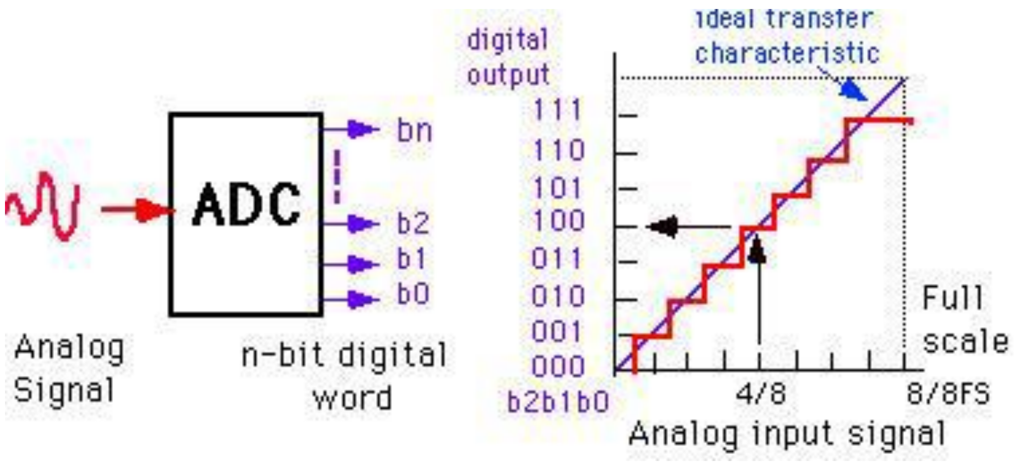
Professor in ECE, Director Extension Services

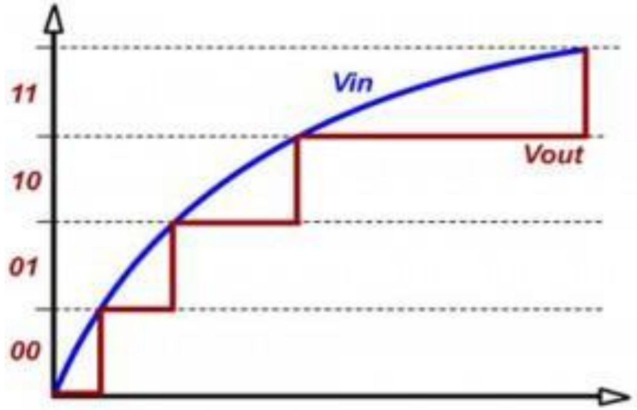
Formerly Dean School of Engg., and Dean Research & Development

Module V:D-A and A-D Converters

- DAC – basics, Weighted Resistor type, R-2R Ladder type;
- ADCs- basics, Parallel Comparator Type, Successive Approximation Register Type; ADC and DAC specifications and applications

D-A and A-D Converters Introduction

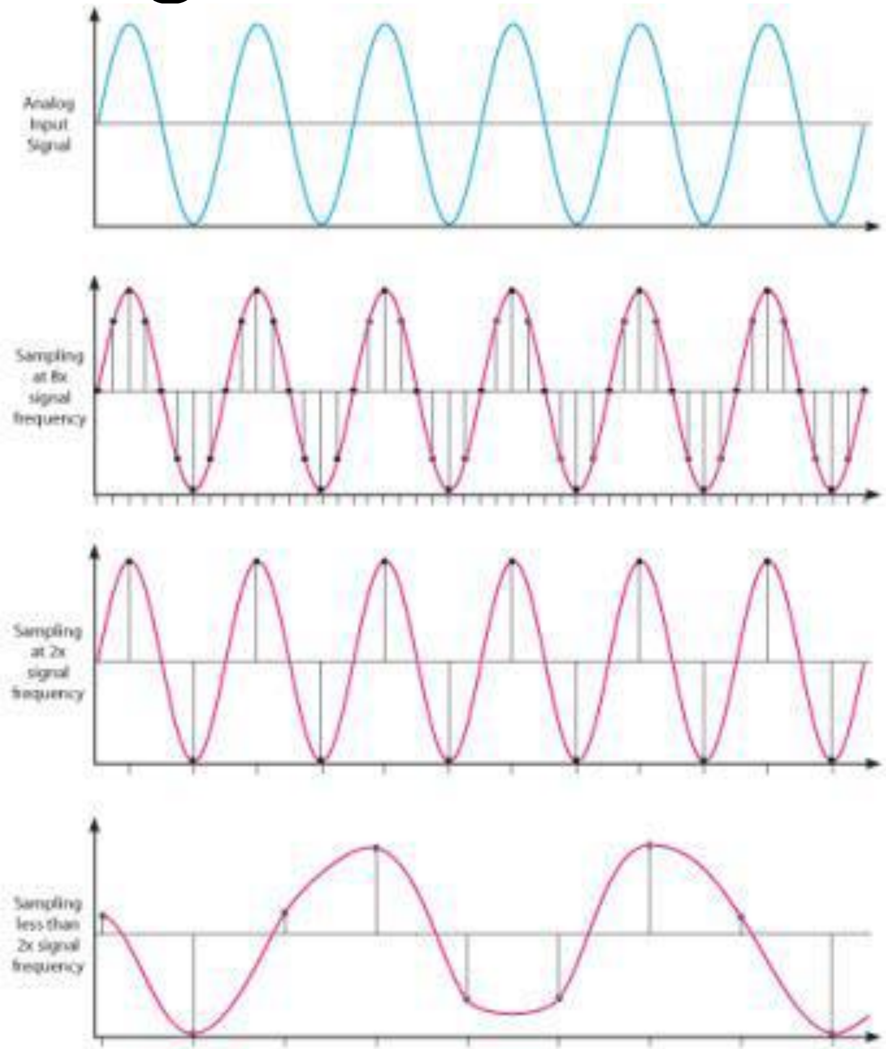




- Analog to Digital Converters
  - Signal Conversion from Analog to Digital through: Sample, Hold, Quantize, Encoding
- Digital to Analog Converters

Signal Distortion Vs Sampling Rate

- The Nyquist theorem states that the acquired signal reconstruction introduces distortion unless it is sampled at (minimum) twice the rate of the largest frequency content of the signal.
    - But this rate is 5-10 times the maximum frequency of the signal in practice.
- Factors
    - Signal to Noise Ratio
    - Bandwidth



Types of Data Converters (ADC and DAC)

- Dual Slope ADC
- Parallel comparator (Flash) A/D Converter
- Successive Approximation Register type ADC
- Sigma-Delta ADC
- Pipelined ADC
- Weighted Resistor DAC
- R-2R Ladder DAC

- Weighted Resistor DAC
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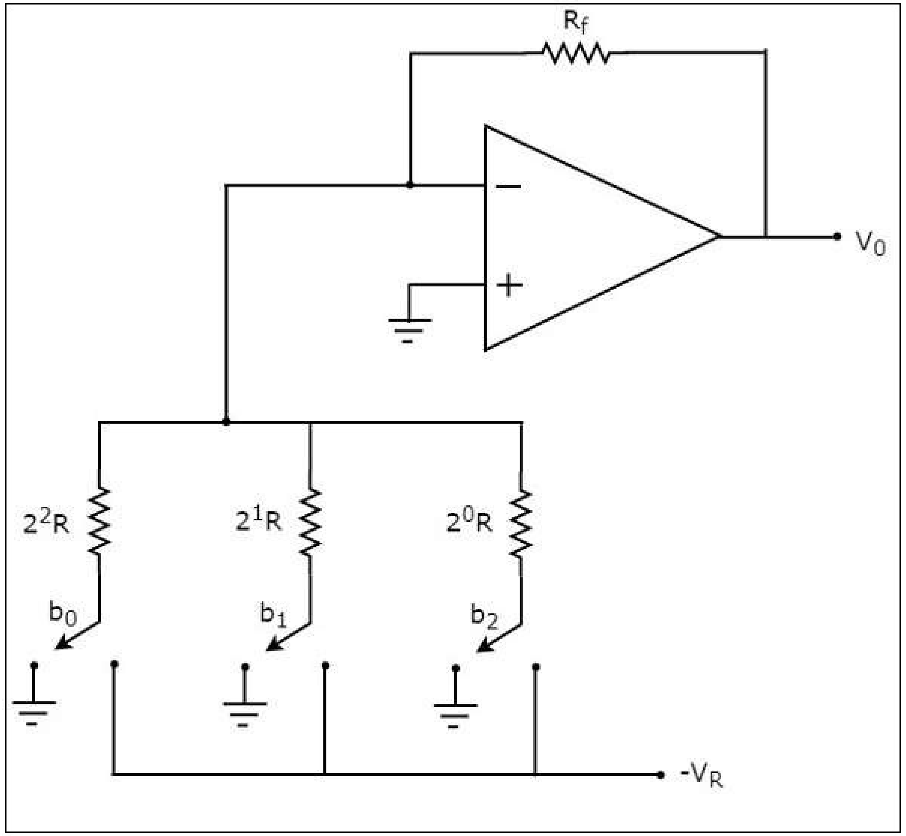
Basic Technique: Weighted Resistor DAC



$$V_0 = \frac{V_R}{2}\left\{\frac{b_{N-1}}{2^0} + \frac{b_{N-2}}{2^1} + \ldots + \frac{b_0}{2^{N-1}}\right\}$$

- Uses binary weighted resistors in the inverting adder circuit
- Switches shown connect to Ground or –VR depending on input bits equal to “0” or “1”
- Nodal equation at non-inv. terminal:

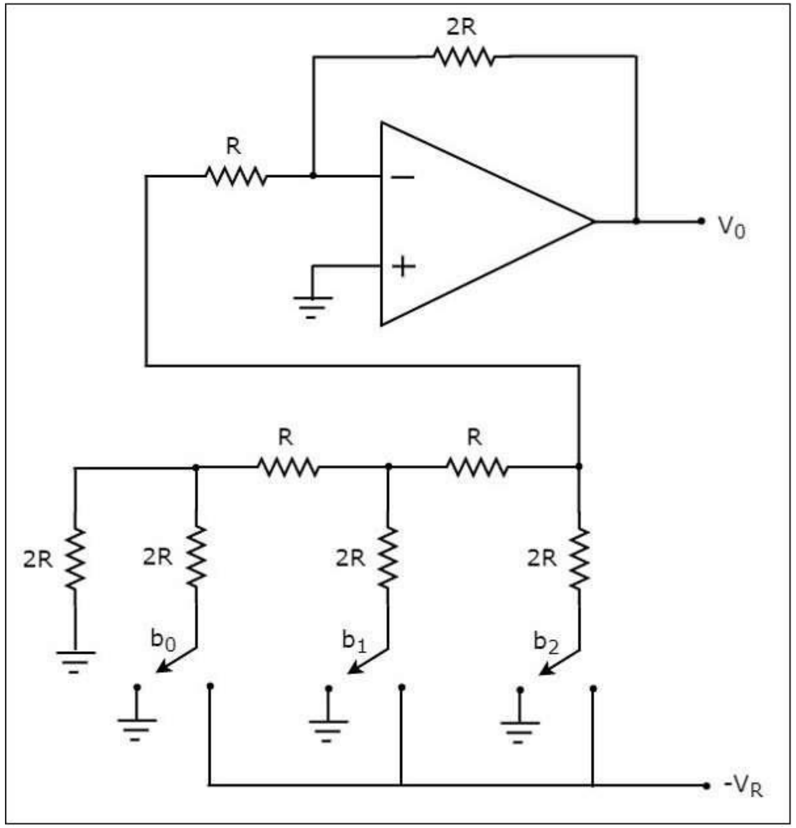
$$\frac{0+V_Rb_2}{2^0R} + \frac{0+V_Rb_1}{2^1R} + \frac{0+V_Rb_0}{2^2R} + \frac{0-V_0}{R_f} = 0$$

$$=> \frac{V_0}{R_f} = \frac{V_Rb_2}{2^0R} + \frac{V_Rb_1}{2^1R} + \frac{V_Rb_0}{2^2R}$$

If, $R=R_f$

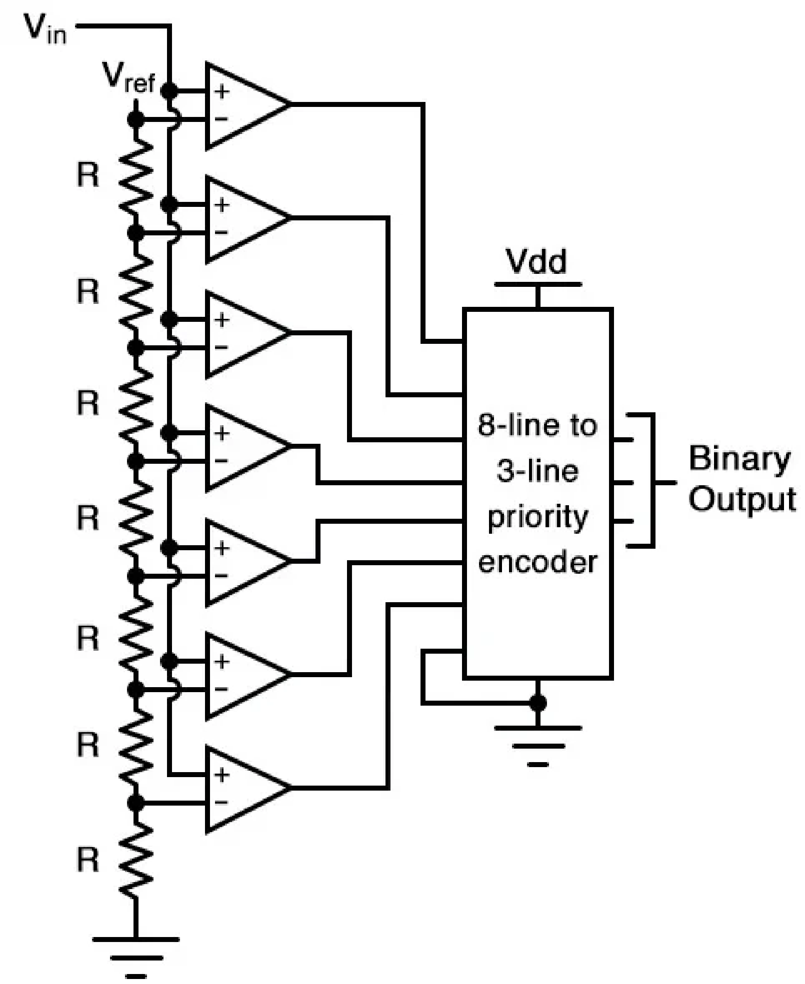
$$=> V_0 = \frac{V_R}{2}\left\{\frac{b_2}{2^0} + \frac{b_1}{2^1} + \frac{b_0}{2^2}\right\}$$

Basic DAC Technique: R-2R Ladder Type



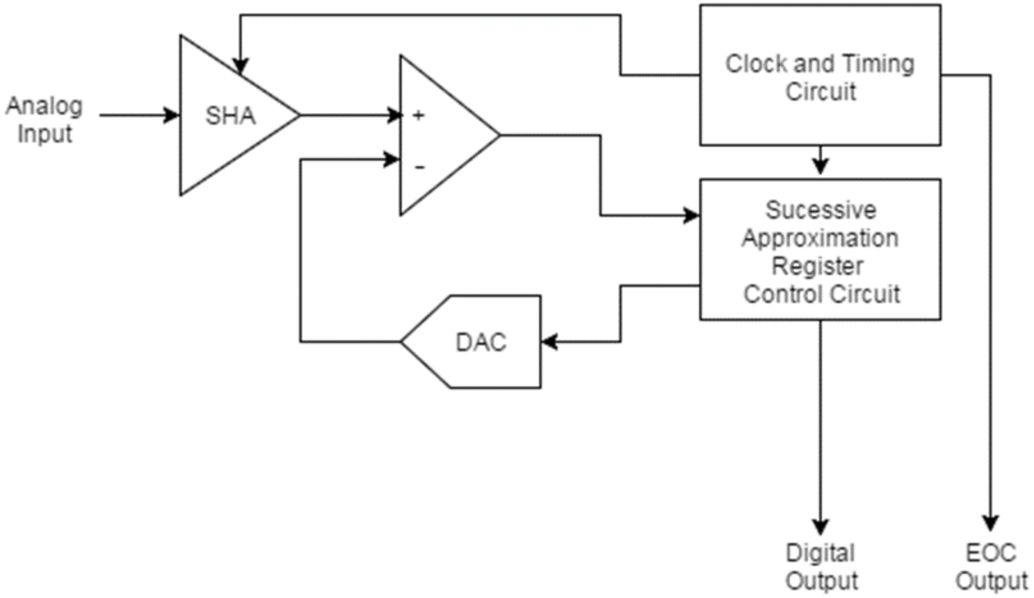
- R-2R Ladder type

ADCs: Parallel Comparator Type (Flash) ADC



- Circuit has a series of comparators, each one comparing the input signal to a unique reference voltage.
- The comparator outputs connect to the inputs of a priority encoder circuit, which then produces a binary output.

Successive Approximation Register (SAR) ADC



- The SAR ADC does the following things for each sample:

1. The analog signal is sampled and held.
2. For each bit, the SAR logic outputs a binary code to the DAC that is dependent on the current bit under scrutiny and the previous bits already approximated. The comparator is used to determine the state of the current bit.
3. Once all bits have been approximated, the digital approximation is output at the end of the conversion (EOC).

Data Converter (ADC/DAC) Specifications

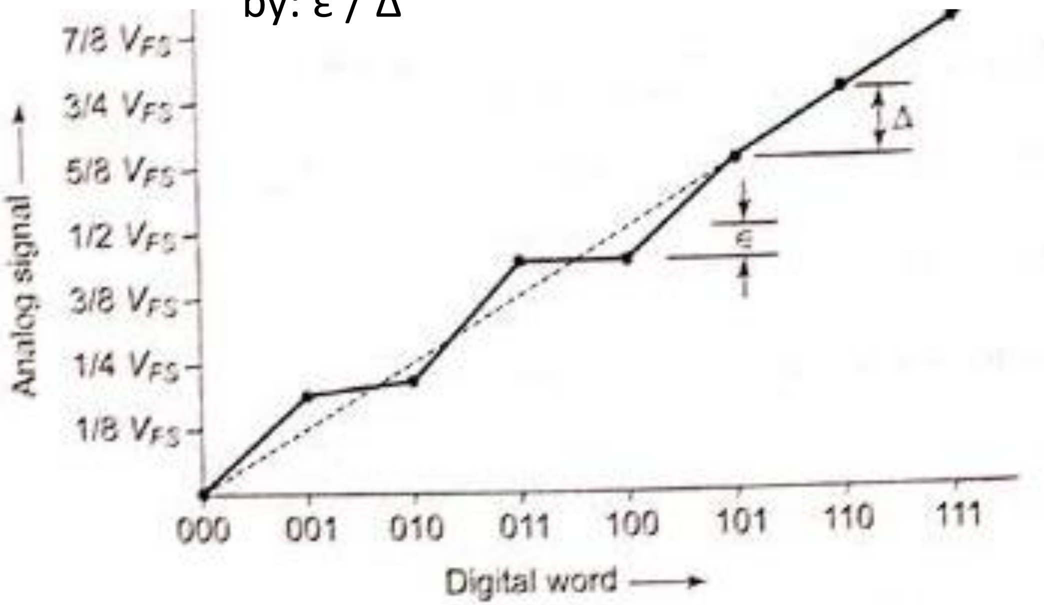
- Resolution
  - The resolution of a D/A converter is the smallest change in voltage which may be produced at the output (or input) of the converter. => (VFS/[2^n-1]) -1LSB increment
    - For example, an 8-bit D/A converter has 2^8-1=255 equal intervals.
    - Hence the smallest change in output voltage is (1/255) of the full scale output range
  - The resolution of an A/D converter is defined as the smallest change in analog input for a one bit change at the output.
    - Example, the input range of an 8-bit A/D converter is divided into 255 intervals

Bits	Intervals	LSB Size (% of FS)	LSB size for 10V FS
6	63	1.588	158.8 mV
8	255	0.392	39.2 mV
10	1023	0.0978	9.78 mV
12	4095	0.0244	2.44 mV

Data Converter (ADC/DAC) Specifications

- Linearity
  - The linearity of an A/D or D/A converter is an important measure of its accuracy.
  - In an ideal DAC, equal increment in the digital input should produce equal increment in the analog output and the transfer curve should be linear.
  - In an actual DAC, output voltages do not fall on a straight line because of gain and offset errors as shown by the solid line curve.
  - The static performance of a DAC is determined by fitting a straight line through the measured output points.
  - Linearity error of a 3-bit D/A converter is shown in figure
  - A good converter exhibits a linearity error of less than ±(1/2)LSB

The linearity error measures the deviation of the actual output from the fitted line and is given by: ε / Δ



The error is usually expressed as a fraction of LSB increment or percentage of full scale voltage (V_{FS}).

Data Converter (ADC/DAC) Specifications

- Accuracy
  - Absolute accuracy is the maximum deviation between the actual converter output and the ideal converter output.
  - Relative accuracy is the maximum deviation after gain and offset errors have been removed
- Monotonicity
  - A monotonic DAC is the one whose analog output increases for an increase in digital input.
  - A monotonic characteristics is essential in control applications, otherwise oscillations can result.
  - If a DAC has to be monotonic, the error should be less than ±(1/2) LSB at each output level
- Conversion time
  - It is the total time required for a converter to convert (say, an analog signal to digital
  - output) and it depends on (i)the conversion technique and (ii) propagation delay of the circuit components

Data Converter (ADC/DAC) Specifications

- Settling Time
  - Settling time represents the time it takes for the output to settle within a specified band ±(1/2) LSB of its final value, after the change in digital input.
  - It should be as small as possible.
  - Settling time ranges from 100 ns to 10 μs depending on word length and type of circuit used
- Stability
  - The performance of converter changes with temperature, age and power supply variations.
  - So all the relevant parameters such as offset, gain, linearity error and monotonicity must be specified over the full temperature and power supply ranges

ADC Applications

- Microphones - Take your voice varying pressure waves in the air and convert
- them into varying electrical signals
- Strain Gages - Determines the amount of strain (change in dimensions) when a
- stress is applied
- Thermocouple – Temperature measuring device converts thermal energy to electric energy
- Voltmeters
- Digital Multimeters

Flash ADC Advantages and Disadvantages

- Advantages
  - Simplest in terms of operational theory
  - Most efficient in terms of speed, very fast
  - limited only in terms of comparator and gate propagation delays
- Disadvantages
  - Lower resolution
  - Expensive
  - Large Power Consumption
  - For each additional output bit, the number of comparators is doubled

SAR ADC Advantages and Disadvantages

- Advantages
  - Capable of high speed and reliable
  - Medium accuracy compared to other ADC types
  - Good tradeoff between speed and cost
  - Capable of output the binary number in serial (one bit at a time) format.
  - High resolution
  - No precision external components needed
- Disadvantages
  - Higher resolution successive approximation ADC’s will be slower
  - Speed limited to ~5Msps