Digital Electronic Meters

EIE 240 Electrical and Electronic Measurement
Class 12, March 15, 2012

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Digital Signal

- Binary or two stages:
  "0" (Low voltage ➔ 0 - 3 V)
  "1" (High voltage ➔ 4 - 5 V)
- Binary digit is called "bit".
- Group of bits is called "word".
- 8-bit group is called "byte".
- For N-bit base-2 number = 2^N levels

2^{N-1} … 2^3 2^2 2^1 2^0

Most Significant Bit (MSB) → 01…000111 ← Least Significant Bit (LSB)

N bits

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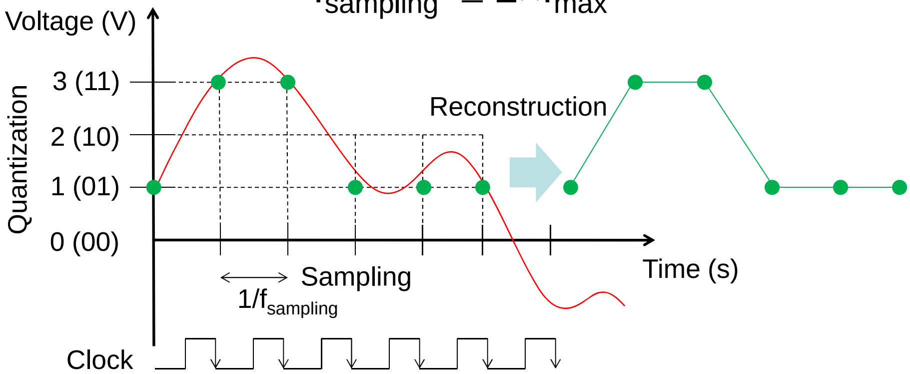
Shannon-Nyquist Sampling Theorem

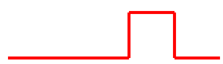
- Discrete time enough to avoid aliasing

$$f_{sampling} \geq 2 \times f_{max}$$



Resolution

- Quantization error ➔ rounding

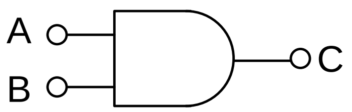
Input Voltage (V)	Binary Word (4 bits)	Digital Signal
0.0	0 0 0 0	
0.1	0 0 0 1	
0.2	0 0 1 0	

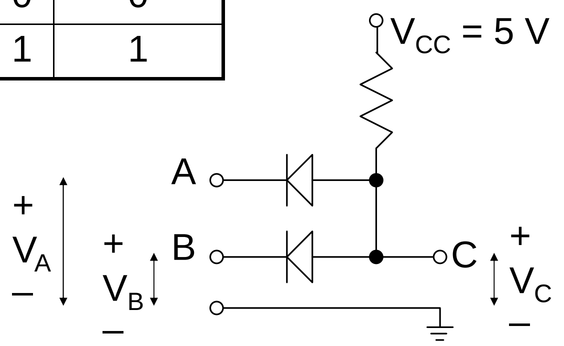
Digital Electronic Basics

- Logic gate, e.g. AND, OR, NAND, NOR, NOT, XOR
- Adder and Subtractor
- Flip-Flop, e.g. RS-FF, JK-FF
- Shift Register
- Counter
- Digital display, e.g. LED, 7-Segment, LCD

e.g. AND Gate

A	B	C = A·B
0	0	0
0	1	0
1	0	0
1	1	1

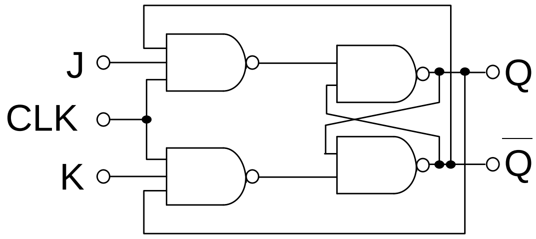




e.g. J-K Flip Flop

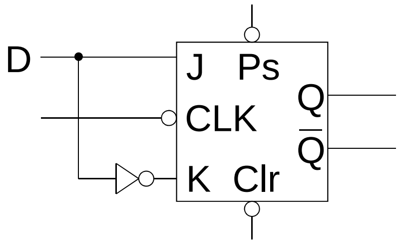
It is like a memory.

J	K	CLK	Q
0	0	1	Unchanged
0	1	1	Reset
1	0	1	Set
1	1	1	Toggle



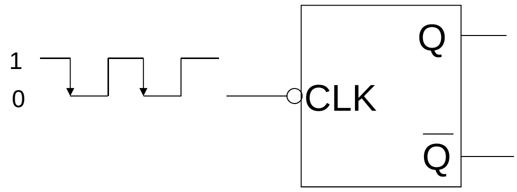
e.g. D Flip-Flop

CLK	D	Q	$\overline{Q}$
↓	1	1	0
↓	0	0	1



e.g. Toggle Flip-Flop

CLK	Q	$\overline{Q}$
↓	$\overline{Q}$	Q



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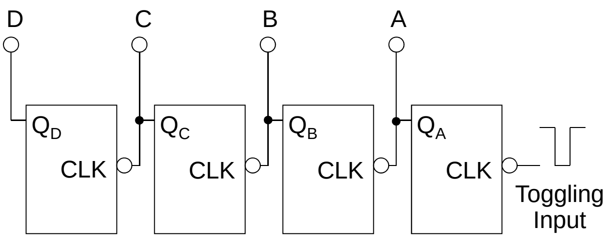
e.g. 16-Counter

Input Pulses	Q_D	Q_C	Q_B	Q_A
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1



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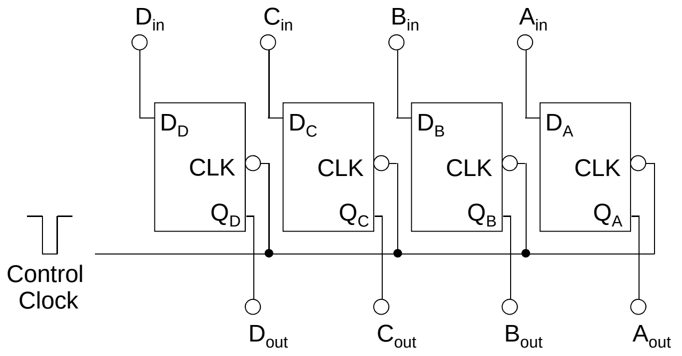
e.g. Parallel-In Parallel-Out Shift Register



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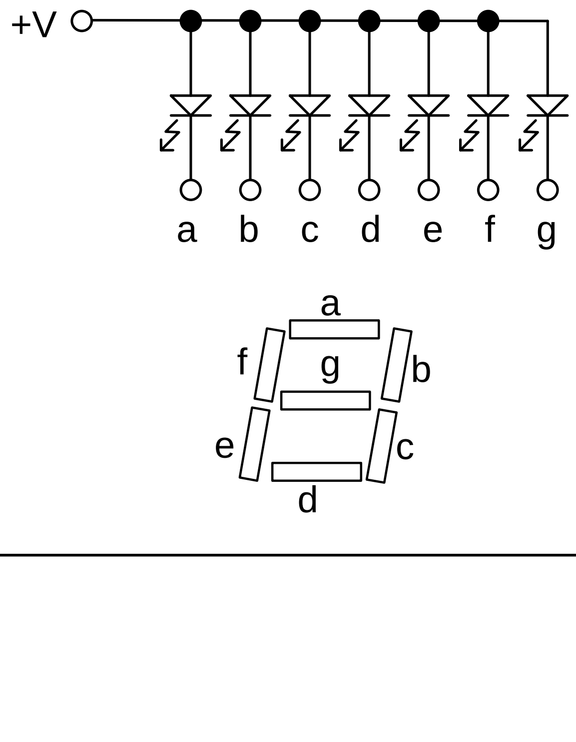
e.g. Common-Anode 7-Segment



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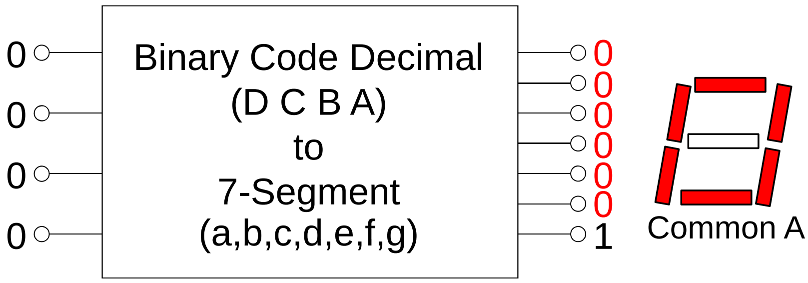
e.g. BCD to 7-Segment



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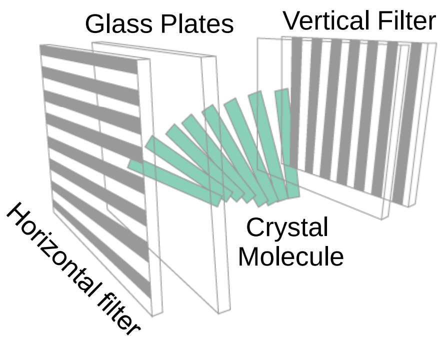
Liquid Crystal Display

- There is a set of two 90°-polarlized transparent panels with a liquid crystal solution between them.
- Light is shined from behind the panels.



- When electricity is applied to one of the segments, the crystals line up in such a way as to make the light twists through the panels and is visible on the other side.

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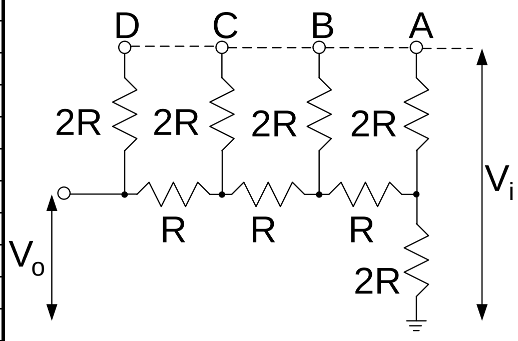
e.g. R/2R Network

V_i at each input				Analog Output (V_o)
D	C	B	A	
0	0	0	0	0
0	0	0	1	V_i / 16
0	0	1	0	2 (V_i / 16)
0	0	1	1	3 (V_i / 16)
0	1	0	0	4 (V_i / 16)
0	1	0	1	5 (V_i / 16)
0	1	1	0	6 (V_i / 16)
0	1	1	1	7 (V_i / 16)
1	0	0	0	8 (V_i / 16)
1	0	0	1	9 (V_i / 16)
1	0	1	0	10 (V_i / 16)
1	0	1	1	11 (V_i / 16)
1	1	0	0	12 (V_i / 16)
1	1	0	1	13 (V_i / 16)
1	1	1	0	14 (V_i / 16)
1	1	1	1	15 (V_i / 16)

Digital-to-analog converter



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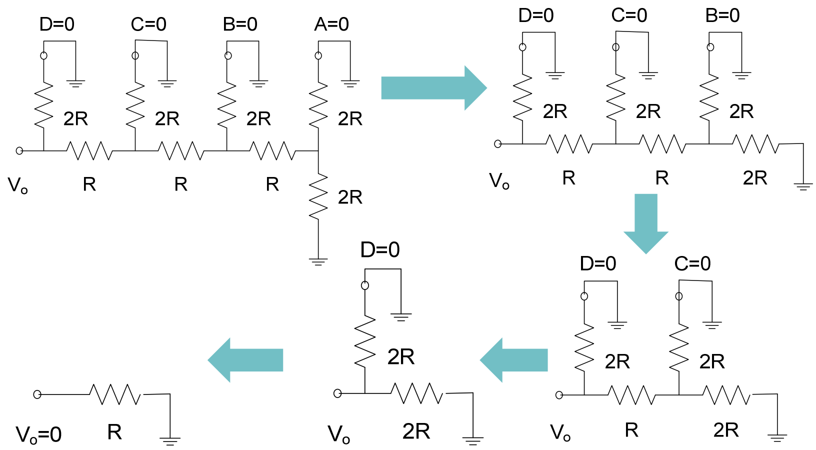
R/2R Network (Cont'd)

- 0000 ➔ $V_o = 0$



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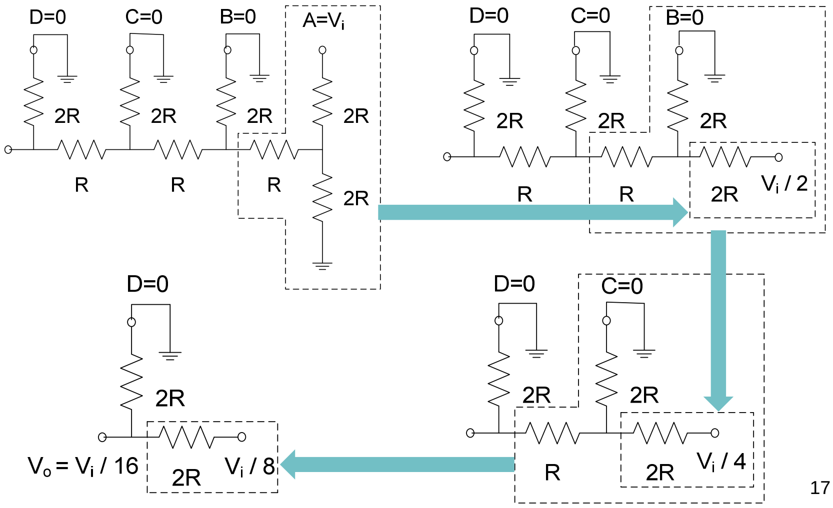
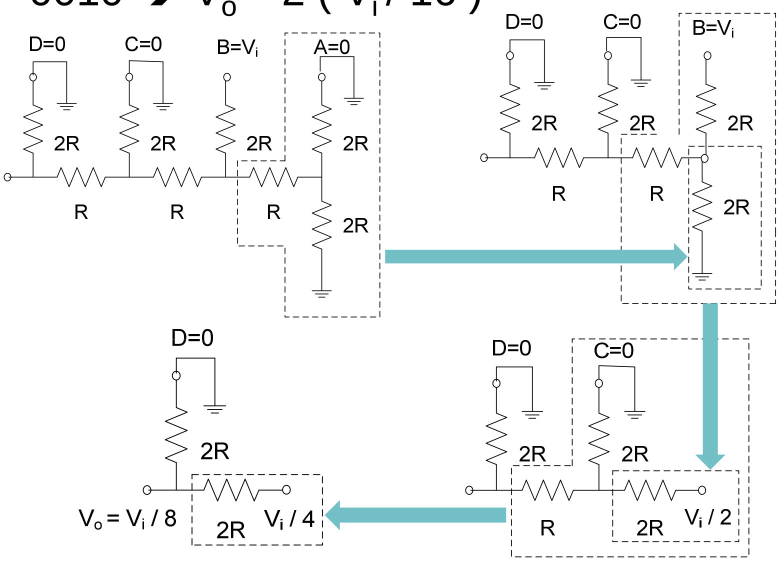
R/2R Network (Cont'd)

- 0001 ➔ $V_o = V_i/16$ using Thévenin's theorem



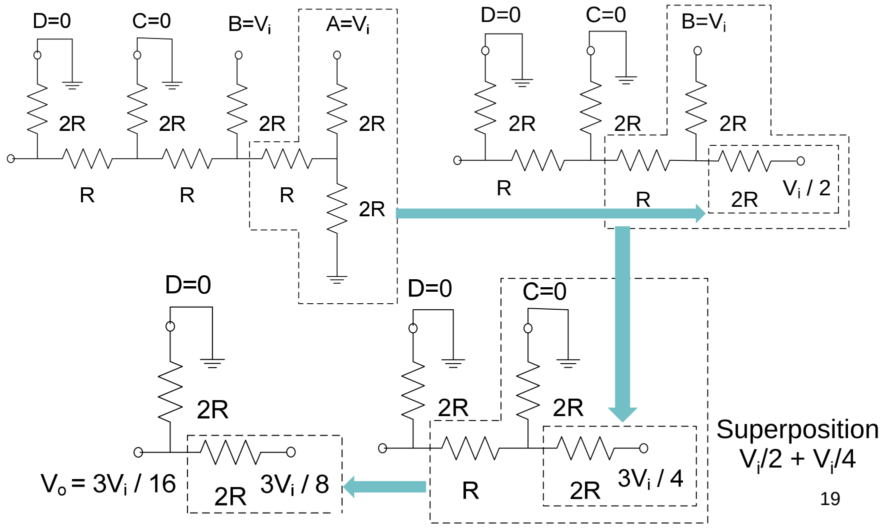
R/2R Network (Cont'd)

- 0010 ➔ $V_o = 2\ (V_i / 16)$



R/2R Network (Cont'd)

- 0011 ➔ $V_o = 3\ (V_i / 16)$



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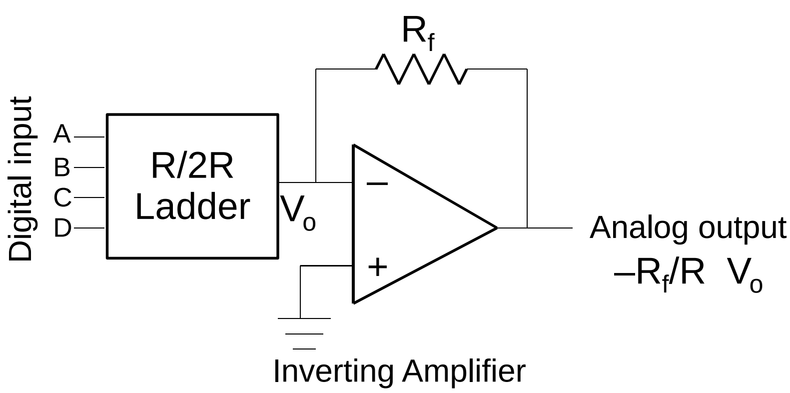
R/2R Network (Cont'd)

- The speed of the converter is limited by the output amplifier slew rate (the maximum rate of change of the output voltage).



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Digital Voltmeter (DVM)

- Analogue voltage is sampled at some instant of time (sampled and hold) and converted to digital signals (series of pulses).
- Number of pulses related to the voltage is counted and displayed as digits.

Analogue Input → Analogue-to-Digital Converter → Digital Signal → Counter → Display

Advantages over Analog Meters

- The numerical readout reduces the human reading error, many readers read the same value, and makes no parallax error
- Faster reading
- The accuracy is much higher e.g. the best tolerance of analog meters is about ±0.5%, while it is about ±0.005% for digital meters
- Higher precision (repeatability) and also contain automatic ranging
- No moving part, life will be long
- Digital signal processing is possible e.g. hold, max, min, polarity or peak

Disadvantages

- Battery needed for electronic circuits
- Cannot show trend and continuous changing number not easy to be interpreted (bar graph may be optional added)
- Cannot measure very high frequency signals (not more than Nyquist rate of sampling)

In spite of above mentioned disadvantages, the digital meters are gaining popularity and are most widely used.

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Analogue-to-Digital Converter

1. Ramp converter
2. Successive approximation
3. Flash converter
4. Voltage-to-frequency converter

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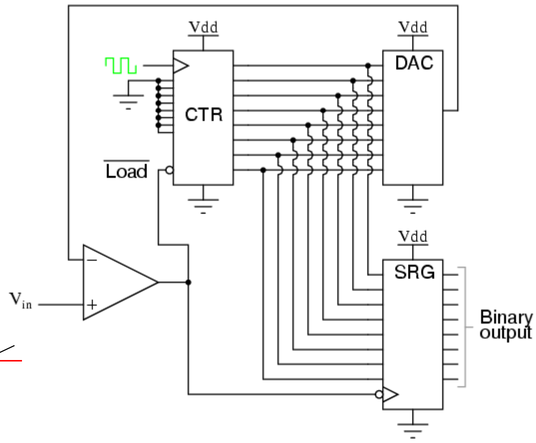
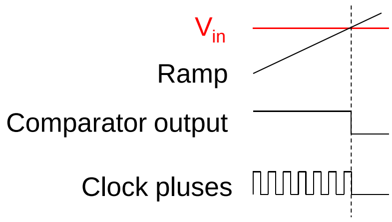
Ramp Converter

- Ramp voltage climbs from 0 V to the input voltage.
- Counting the clock pulses during no "load" (Active-low).





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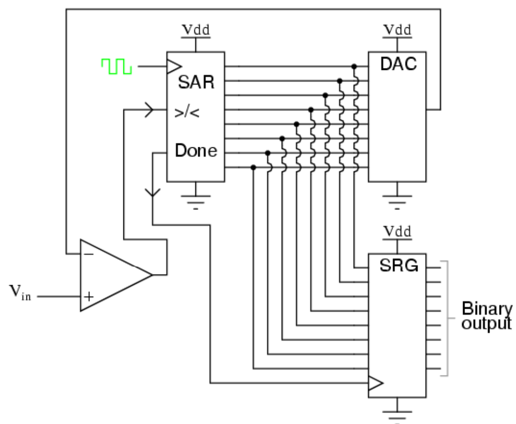
Successive Approximation

- Input voltage is compared to the voltage increased until it reaches the input voltage.
- Trying all values starting with MSB to LSB.



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Successive Approximation (Cont'd)

D (MSB)	C	B	A (LSB)	V_{ref}
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

e.g. V_{in} = 9 V

- V_{ref1} = 8 V (**1**000)
  if $V_{in} > V_{ref1}$ ➔ D = "1"
- V_{ref2} = 12 V (**11**00)
  if $V_{in} < V_{ref2}$ ➔ C = "0"
- V_{ref3} = 10 V (**101**0)
  if $V_{in} < V_{ref3}$ ➔ B = "0"
- V_{ref4} = 9 V (**1001**)
  if $V_{in} = V_{ref4}$ ➔ A = "1"
  V_{in} = **1001**

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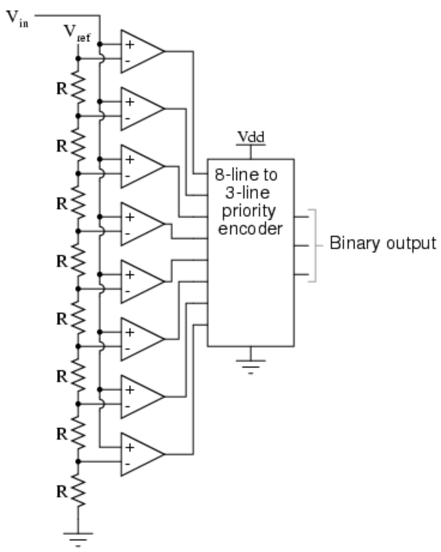
Flash Converter

- Simultaneous comparison between the analogue input and the reference signals.
- N-bit conversion needs 2^{N-1} comparators.
- 8-line to 3-line priority encoder, e.g.
  00000001 ⇒ 001
  00000011 ⇒ 010
  00000111 ⇒ 011



Voltage-to-Frequency Converter

- Input voltage is converted into a set of pulses whose frequency is proportional to the input voltage.

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Digital AC Voltmeter

- Using rectifier in a similar way to analogue meter.
- The average value from rectifier is scaled to RMS value.

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Digital Ammeter

- Current can be measured by using digital voltmeter to measure the potential difference across a standard resistor.

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Reading Resolution

- For the fixed resolution of .001 V (step size)
  Range 0 - 1 V ➔ 3 digits (.999) 1,000 steps
  Range 0 - 10 V ➔ 4 digits (9.999) 10,000 steps
  Range 0 - 100 V ➔ 5 digits (99.999) 100,000 steps
  Number of digit = log(step)

- How many digit for the range 0 - 3 V ?
  It is 3½ digits (log(3000) $\approx$ 3.477 digits)

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Reading Resolution (Cont'd)

- 3½ digit display 0000 ➔ 1999
  (e.g. full scale 2 V if enable the 1st decimal point, 0.000 ➔ 1.999)
- MSB can only be "0" or "1" (usually not visible when the reading is less than 999), whereas all the other can be "0", "1", "2", "3", …, "9"
- e.g. 1V range, resolution is 1V/1999 ≈ 0.001 V (0.000, 0.001, 0.002, …, 0.999)
- For 3¾ digit for the range 5 V, MSB can be "0" to "4"

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Range Changing

Auto ranging by using frequency divider circuit to change clock frequency.

- e.g. 3½ digit display (fixed digit),
  change step size
  Range 1V (0.999) ➔
  1/1999 ≈ 0.001 V/step (1,000 steps)
  Range 10V (09.99) ➔
  10/1999 ≈ 00.01 V/step (1,000 steps)
  Range 100V (099.9) ➔
  100/1999 ≈ 000.1 V/step (1,000 steps)

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Accuracy

- $\pm$ (0.5% Reading + 1 Digit LSB)
- e.g. when you read a voltage 1.8 V

$$\text{error} = \pm (0.5\% \text{ of } 1.8V \quad + \quad 0.001V)$$
$$= \pm 0.01V$$
$$\approx \pm 0.56\% \text{ of reading}$$

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