Digital Electronic Meters

EIE 240 Electrical and Electronic Measurement
May 1, 2015

1

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)

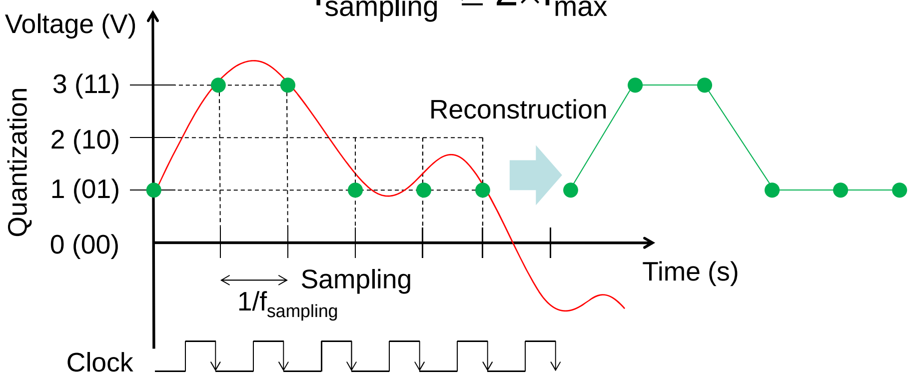
N bits

2

Shannon-Nyquist Sampling Theorem

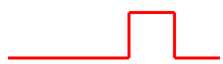
- Discrete time enough to avoid aliasing

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



Resolution

- Quantization error ➔ rounding

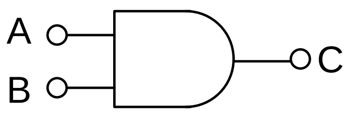
Input Voltage (V)	Binary Word (4 bits)	Digital Signal
0.0	0 0 0 0	
0.1	0 0 0 1	
0.2	0 0 1 0	

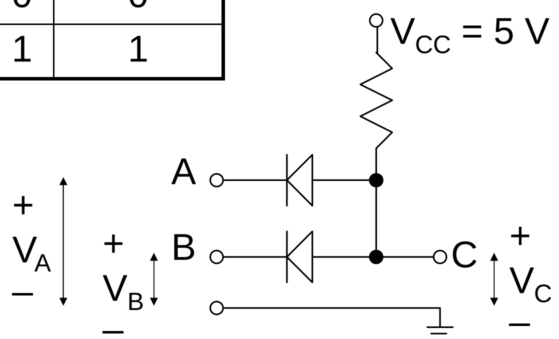
Digital Electronic Basics

- 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

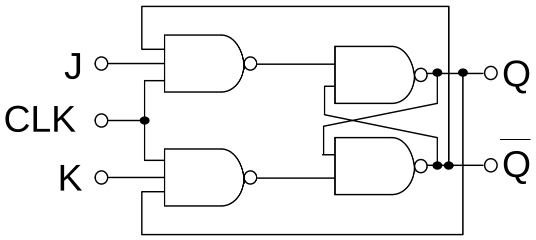




e.g. J-K Flip Flop

It is like a memory.

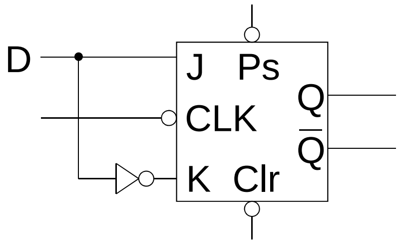
J	K	CLK	Q
0	0	1	Unchanged
0	1	1	Reset
1	0	1	Set
1	1	1	Toggle



7

e.g. D Flip-Flop

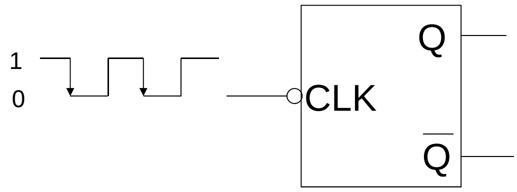
CLK	D	Q	$\overline{Q}$
↓	1	1	0
↓	0	0	1



8

e.g. Toggle Flip-Flop

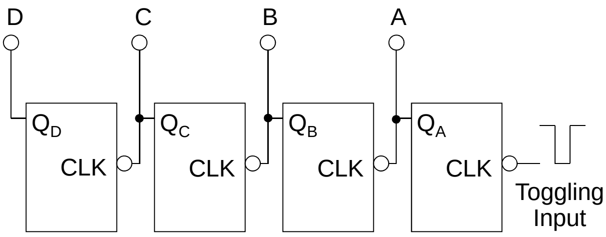
CLK	Q	$\overline{Q}$
↓	$\overline{Q}$	Q



9

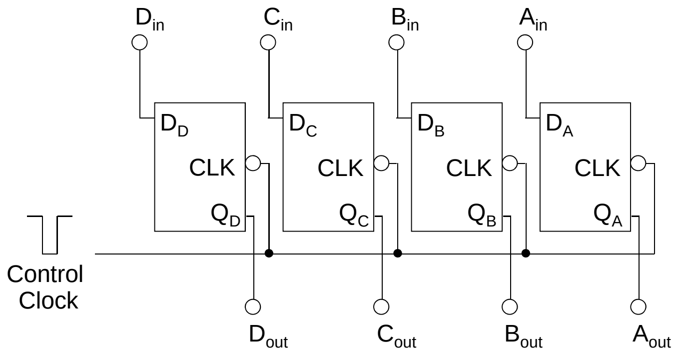
e.g. 16-Counter

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



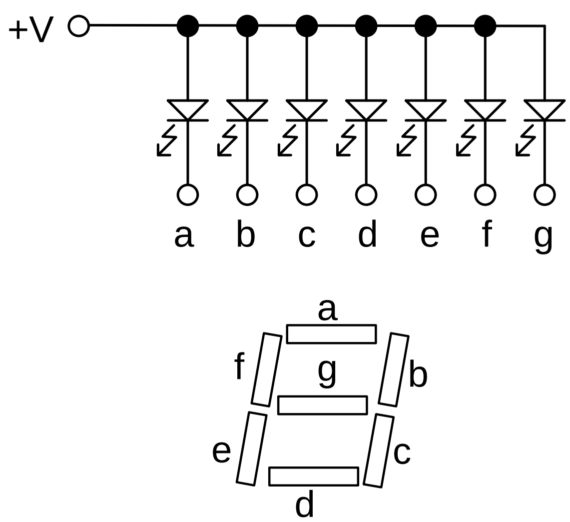
10

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



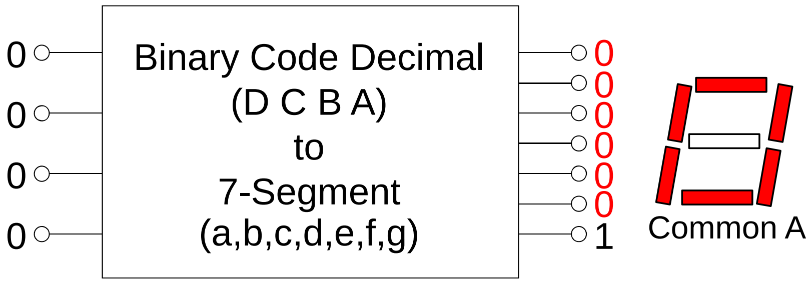
11

e.g. Common-Anode 7-Segment



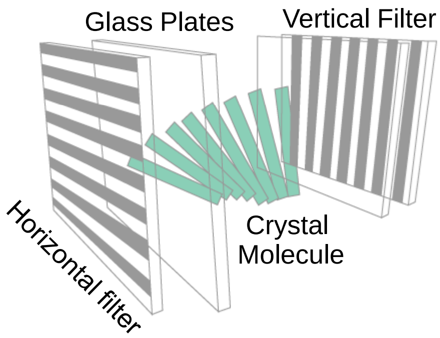
12

e.g. BCD to 7-Segment



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.

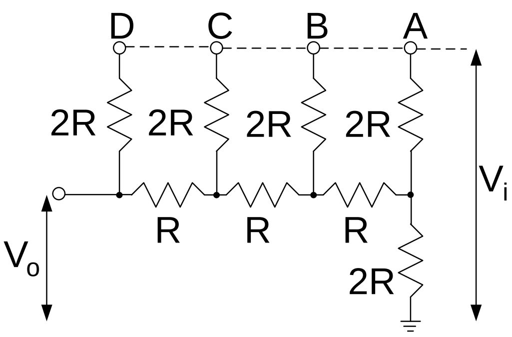


- When electricity is applied to one of the segments, the crystals line up in such a way as to make the light twists through the panels and is visible on the other side.

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)

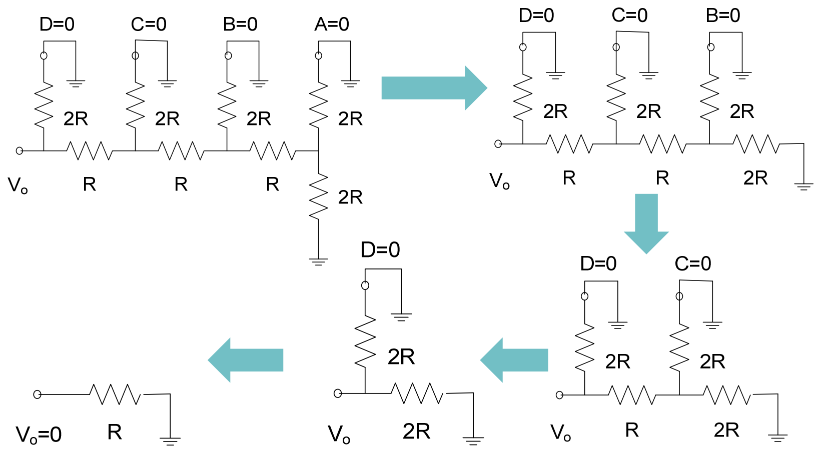
Digital-to-analog converter



15

R/2R Network (Cont'd)

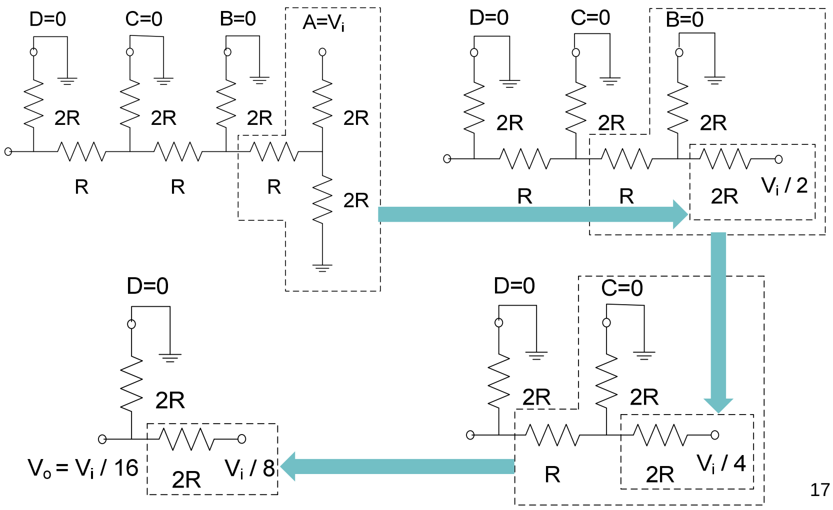
- 0000 ➔ $V_o = 0$



16

R/2R Network (Cont'd)

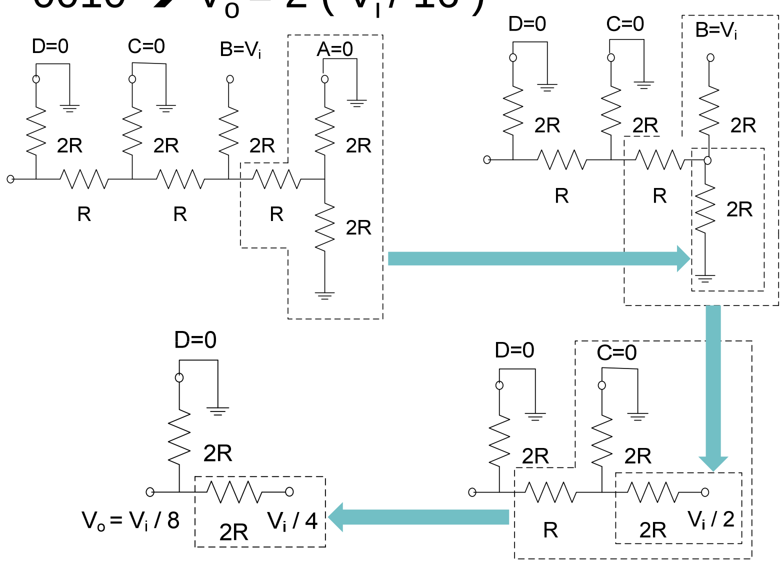
- 0001 ➔ $V_o = V_i/16$ using Thévenin's theorem



17

R/2R Network (Cont'd)

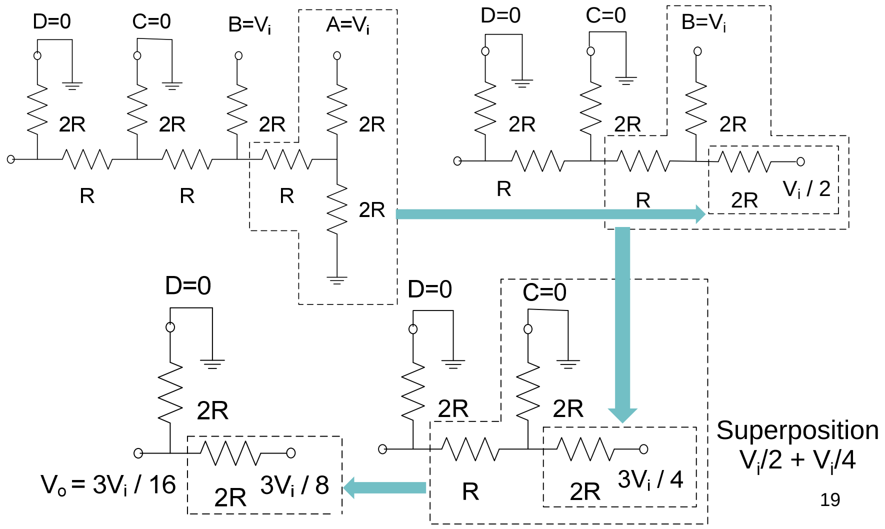
- 0010 ➔ $V_o = 2\ (\ V_i / 16\ )$



18

R/2R Network (Cont'd)

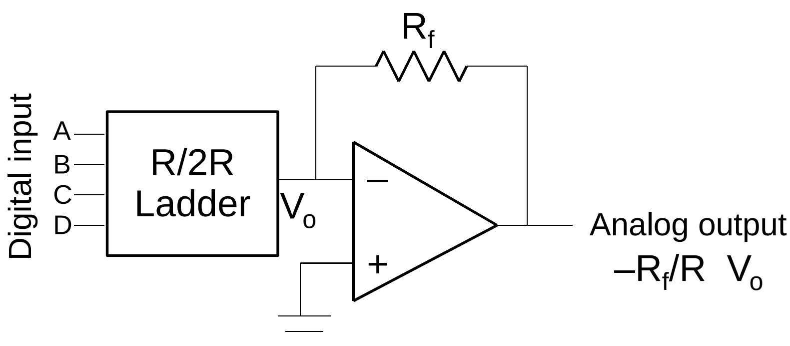
- 0011 ➔ $V_o = 3 (V_i / 16)$



19

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).

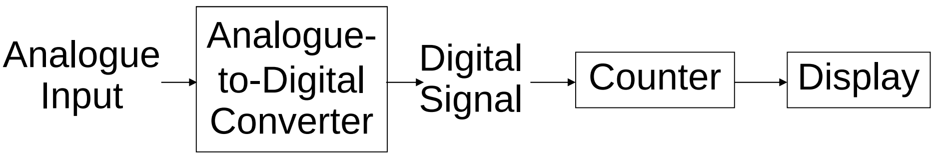


Inverting Amplifier

20

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.



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.

23

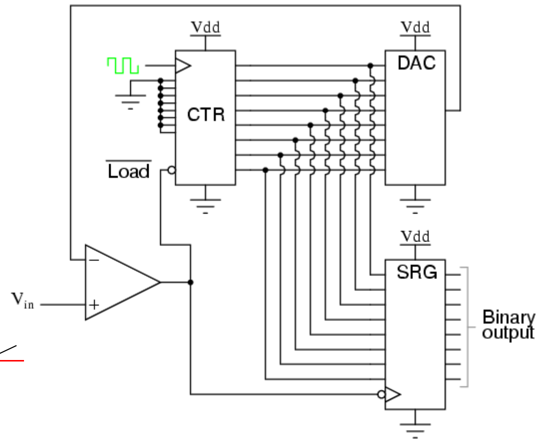
Analogue-to-Digital Converter

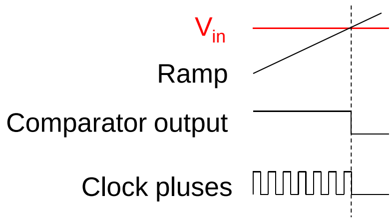
1. Ramp converter
2. Successive approximation
3. Flash converter
4. Voltage-to-frequency converter

24

Ramp Converter

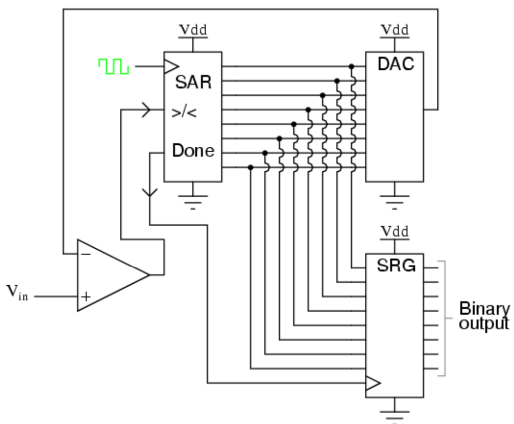
- Ramp voltage climbs from 0 V to the input voltage.
- Counting the clock pulses during no “load” (Active-low).





Successive Approximation

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



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

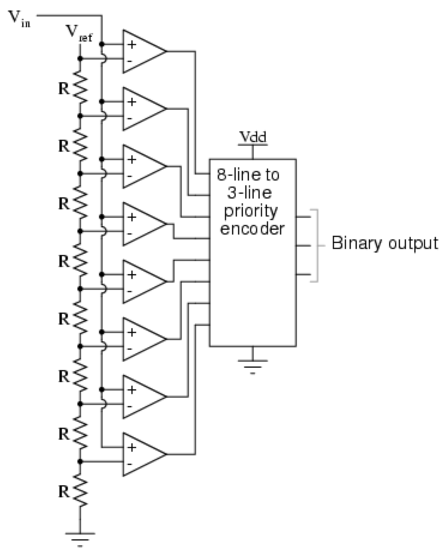
e.g. V_{in} = 9 V

- V_{ref1} = 8 V (**<u>1</u>**000)
  if $V_{in} > V_{ref1}$ ➔ D = "1"
- V_{ref2} = 12 V (**1<u>1</u>**00)
  if $V_{in} < V_{ref2}$ ➔ C = "0"
- V_{ref3} = 10 V (**10<u>1</u>**0)
  if $V_{in} < V_{ref3}$ ➔ B = "0"
- V_{ref4} = 9 V (**100<u>1</u>**)
  if $V_{in} = V_{ref4}$ ➔ A = "1"
  V_{in} = **1001**

27

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 $\Rightarrow$ 001
  00000011 $\Rightarrow$ 010
  00000111 $\Rightarrow$ 011



Voltage-to-Frequency Converter

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

29

Digital AC Voltmeter

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

30

Digital Ammeter

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

31

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)

32

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"

33

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)

34

Accuracy

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

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

35