Microcontroller Applications
Department of Instrumentation Engineering

Analogue (ADC & DAC) Interfacing

In this Lecture ….

Interface 8051 with the following Input/Output Devices

- Transducer/Sensors
- Analogue-to-Digital Conversion (ADC)
- Digital-to-Analogue Conversion (DAC)

Analog-to-digital converter (ADC)

- ADC convert analogue voltage to digital numbers so that microcontrollers can handle and process the data.
- Used for data acquisition
- n-bit resolution, where n = 8, 12, 16 or even 24 bits.
- Higher-resolution ADC provides a smaller *step size*.
- Step size is the smallest change that can be recognized by ADC.

Analog-to-digital converter (ADC)

- An ADC has a resolution of 8 bits, the range is divided into 2^8=256 steps (from 0 – 255). But there are 255 quantization levels.

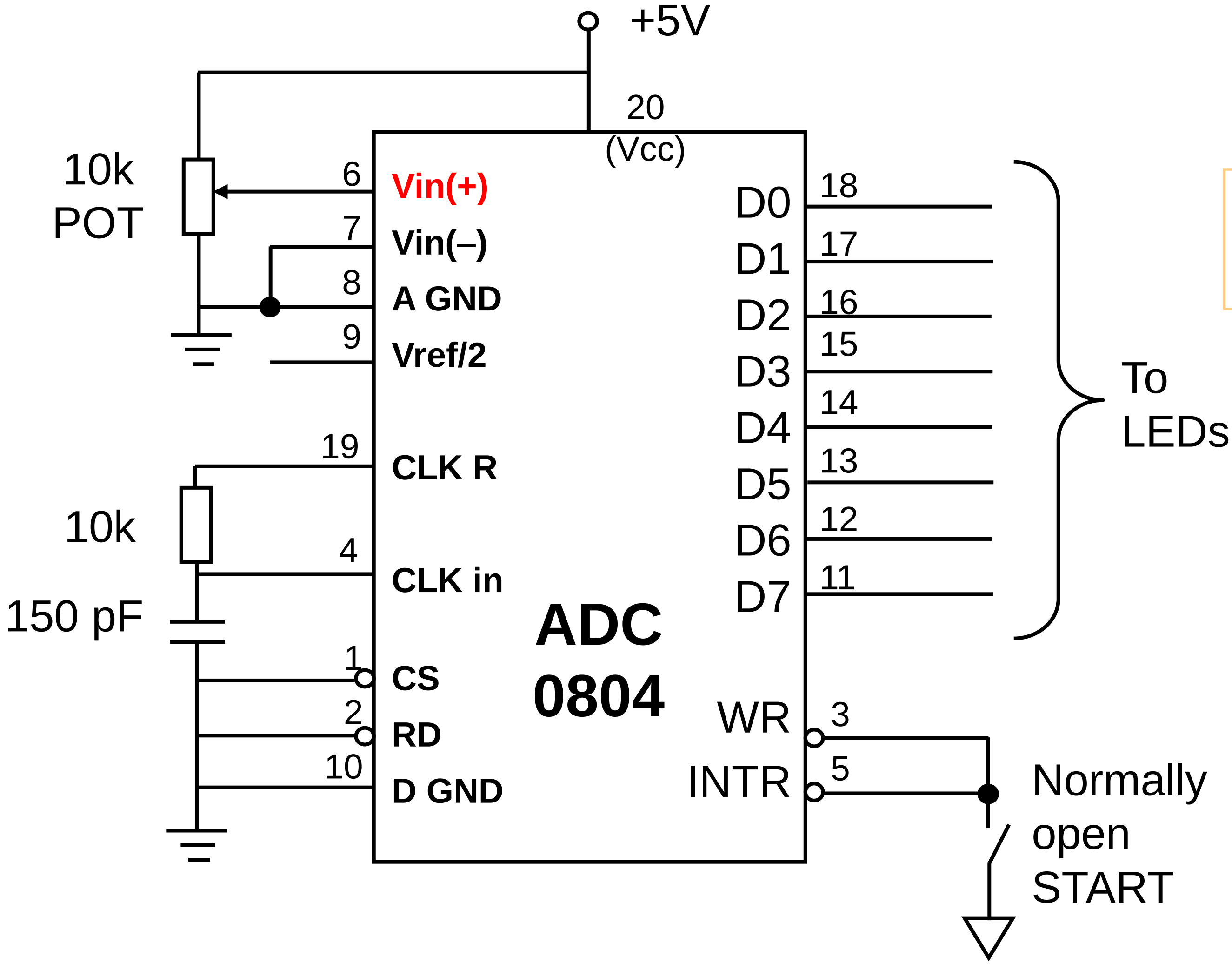
$$Step\ Size = \frac{V_{cc}}{2^n}$$

- Vcc is the reference voltage of ADC with n-bit resolution

Table 10.3 : Resolution versus Step Size for ADC (if Vcc = 5V)

n-bit	Number of steps	Step Size (mV)
8	2^8 = 256	5/256 = 19.53
10	2^10 = 1024	5/1024 = 4.88
12	2^12 = 4096	5/4096= 1.2
16	2^16 = 65536	5/65536= 0.076

ADC0804 Chip (Free Running Mode)



Port of
8-bit uC

ADC0804 Chip

$$step\ size = \frac{2 \times \frac{V_{REF}}{2}}{2^8} = \frac{V_{REF}}{256}$$

V_{CC}

This is the +5V power supply. It is also used as a reference voltage when the Vref/2 (pin 9) input is open.

Vref/2

Input voltage pin used for the reference voltage. If this pin is open, the analog input voltage for the the ADC is ranged from 0 to 5 volts.

ADC0804 has resolution of 8 bits

Vref/2 (V)	Vin (V)	Step Size (mV)
Not connected	0 to 5	5/256 = 19.53
2.0	0 to 4	4/256 = 15.62
1.5	0 to 3	3/256 = 11.71
1.28	0 to 2.56	2.56/256 = 10
1.0	0 to 2	2/256 = 7.81
0.5	0 to 1	1/256 = 3.90

Pin Vref/2 is open, Step size =19.53 mV

ADC0804 Chip

D0 – D7

D0 – D7 are the digital data output pins. These are the tri-state buffered and the converted data is accessed only when CS = 0 and RD is forced low. The output voltage:

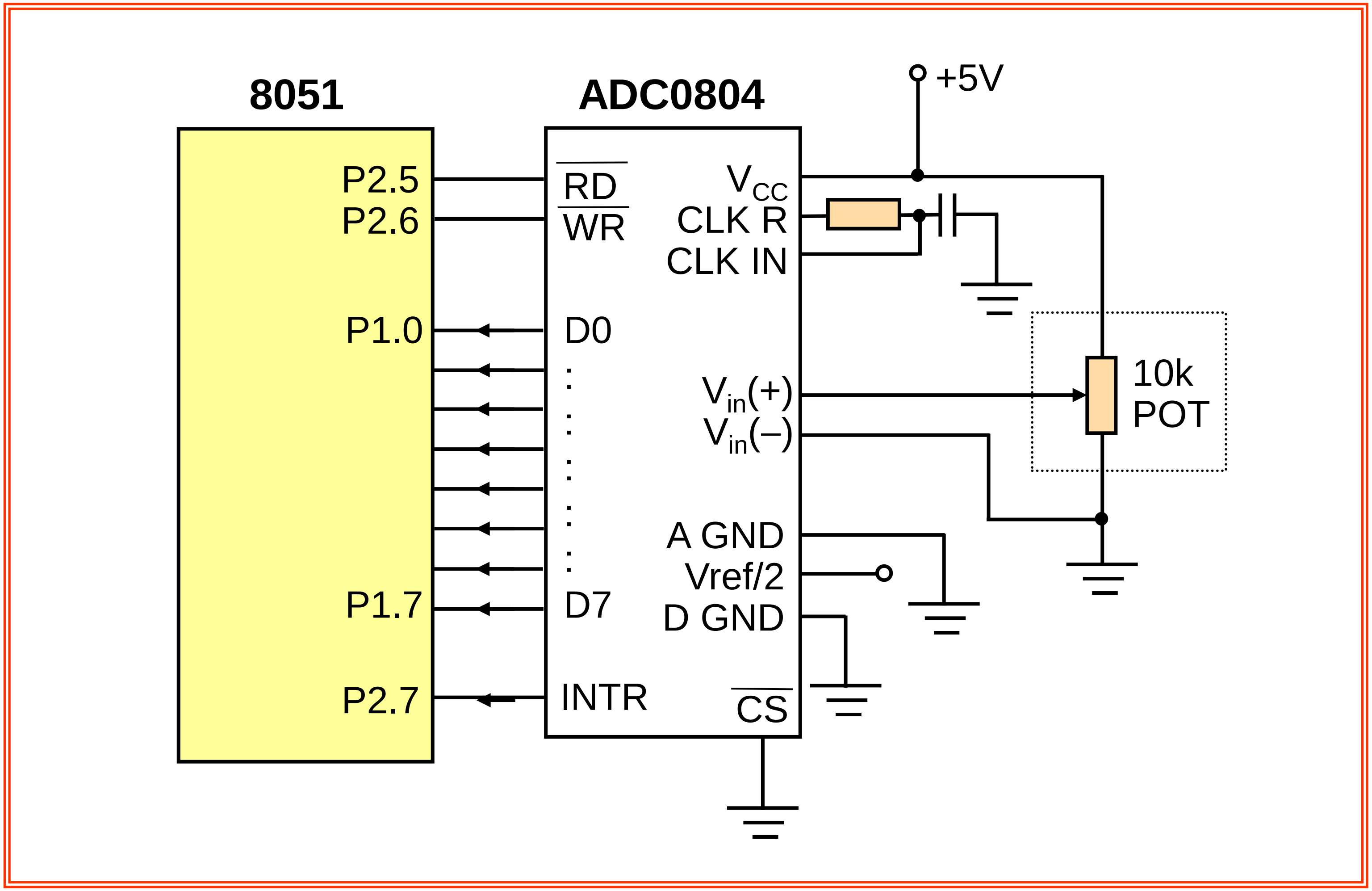
$$D_{out} = \frac{V_{in}}{\text{Step size}}$$

Analog Ground and Digital Ground

Analog ground is connected to the ground of the analog signal while digital ground is connected to the ground of the Vcc pin.

Question: An analog input voltage of 3.5V, Pin Vref/2 is open.
Solution:
Dout = 3.5V / 19.53 mV = 179 (depends on accuracy of ADC)

Testing the ADC0804

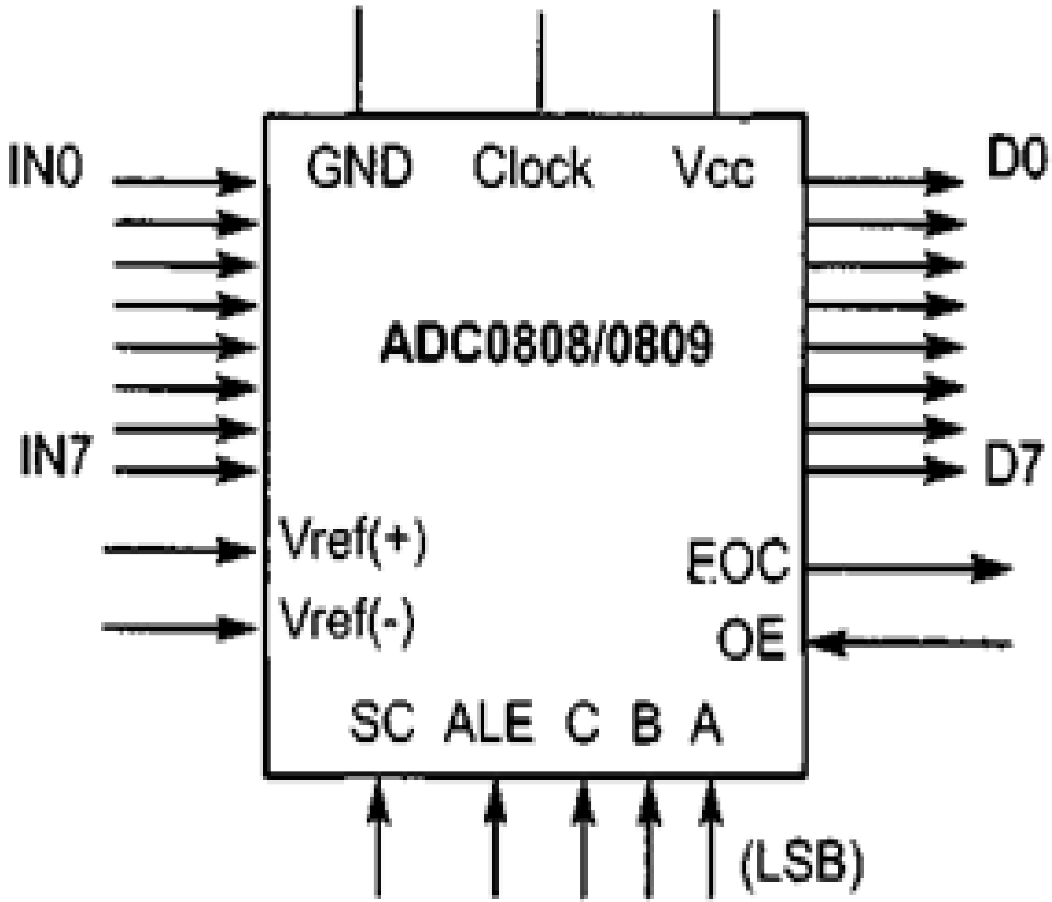


Example of ADC Application

- Temperature detection
- A temperature sensor (LM34 or LM35) is interfaced to the 8051 via an ADC (ADC0804)
- The output voltage from the LM34/LM35 is linearly proportional to the measuring temperature
- The ADC0804 converts the output voltages from the LM34/LM35 into digital signals, which correspond to the measured temperature.

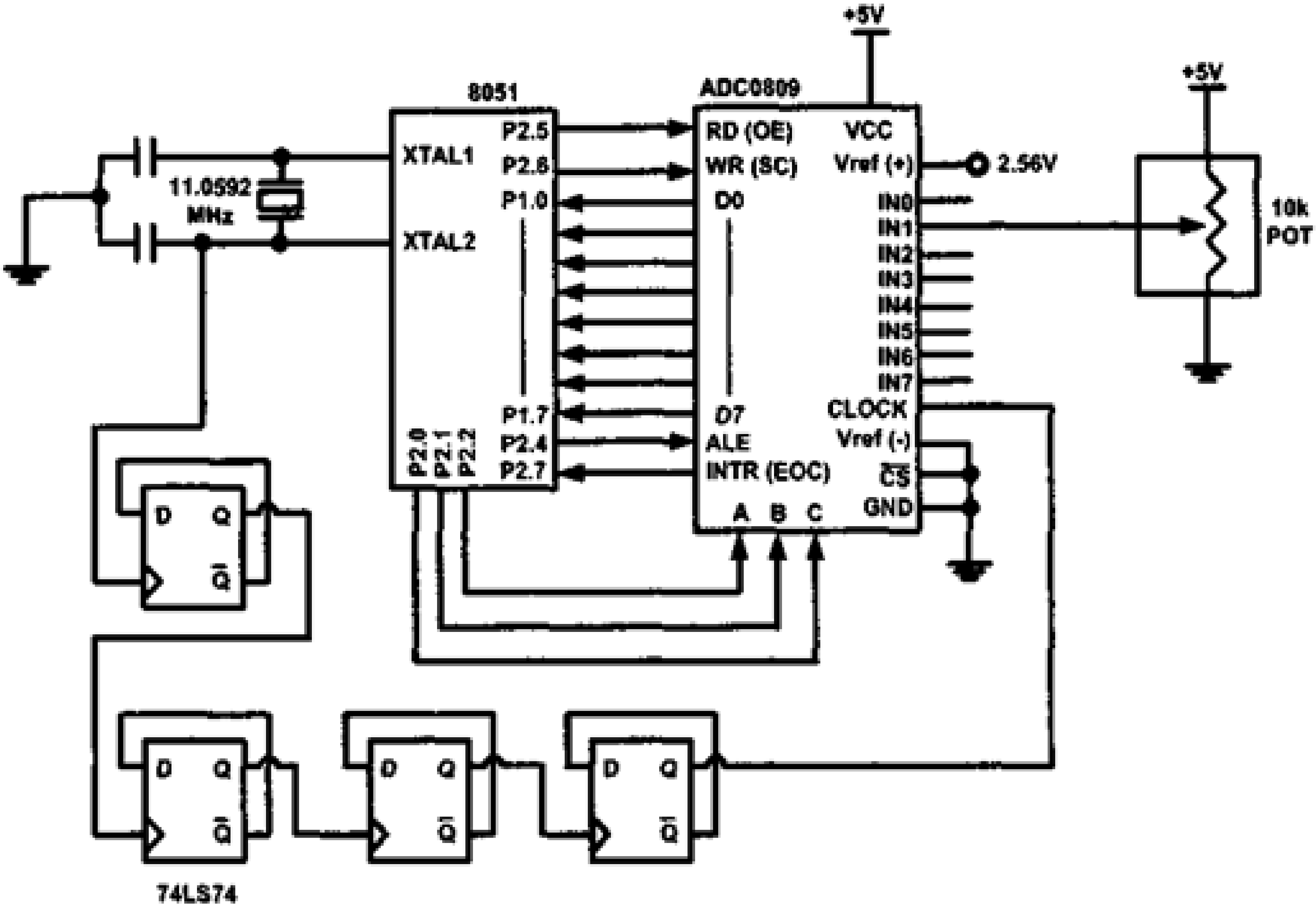
Features of ADC 0808

1. Inbuilt 8 analog channels with multiplexer.
2. Zero or full scale adjustment is not required.
3. 0 to 5 V input voltage range with a single polarity 5 V supply.
4. Output is TTL compatible.
5. High speed.
6. Low conversion time(100 μs).
7. High accuracy.
8. 8-bit resolution.
9. Low power consumption (less then 15 mW).
10. Easy to interface with all microcontroller.
11. Minimum temperature dependence.


IN0
IN7
GND
Clock
Vcc
ADC0808/0809
Vref(+)
Vref(-)
EOC
OE
SC ALE C B A
D0
D7
(LSB)

ADC0808/0809 ANALOG CHANNEL SELECTION

Analog Channel	ADDRESS LINES		
	C	B	A
IN0	0	0	0
IN1	0	0	1
IN2	0	1	0
IN3	0	1	1
IN4	1	0	0
IN5	1	0	1
IN6	1	1	0
IN7	1	1	1



8051
ADC0809
+5V
+5V
XTAL1
XTAL2
11.0592
MHz
P2.5
P2.6
P1.0
P1.7
P2.4
P2.7
P2.0
P2.1
P2.2
RD (OE)
WR (SC)
D0
D7
ALE
INTR (EOC)
A
B
C
VCC
Vref (+)
2.56V
IN0
IN1
IN2
IN3
IN4
IN5
IN6
IN7
CLOCK
Vref (-)
CS
GND
10k
POT
D
Q
Q
74LS74

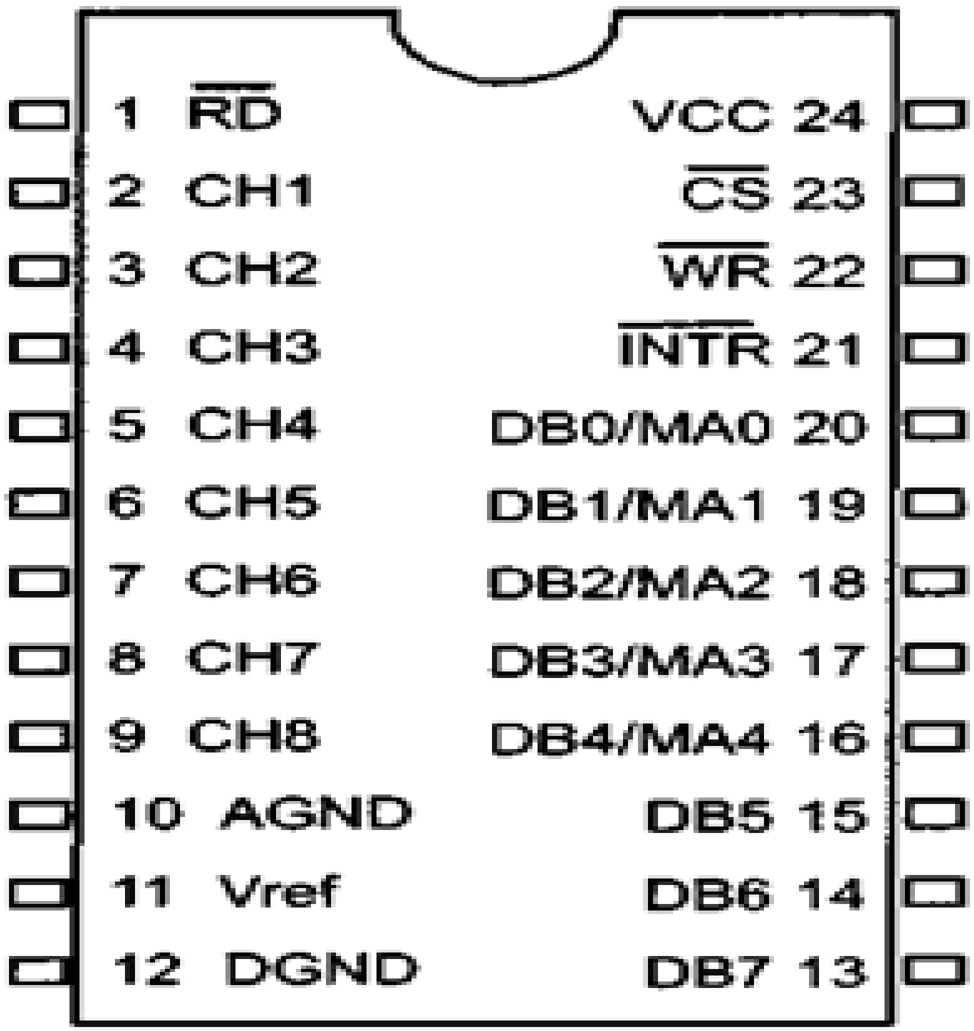
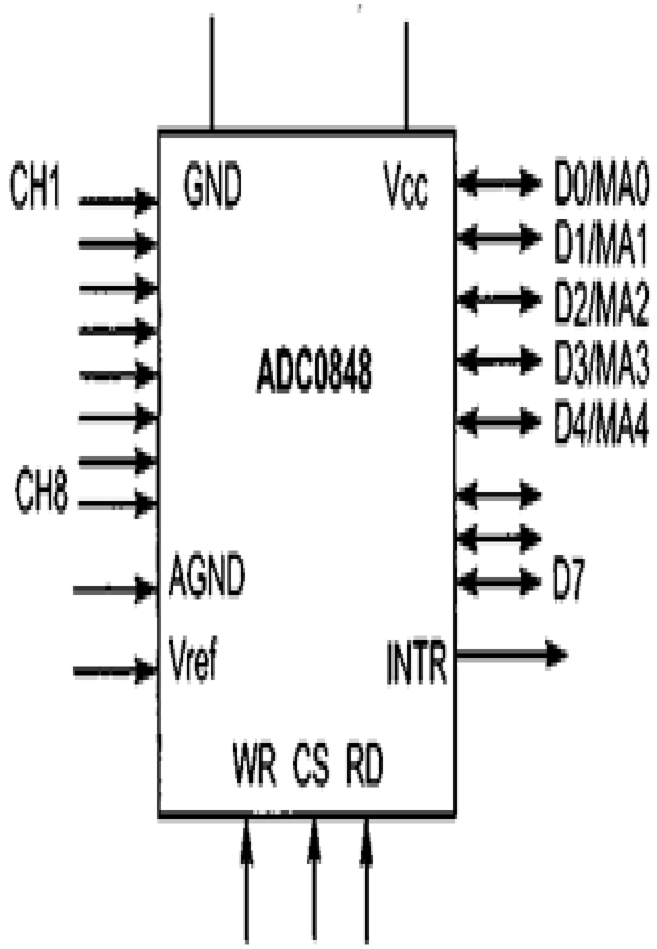
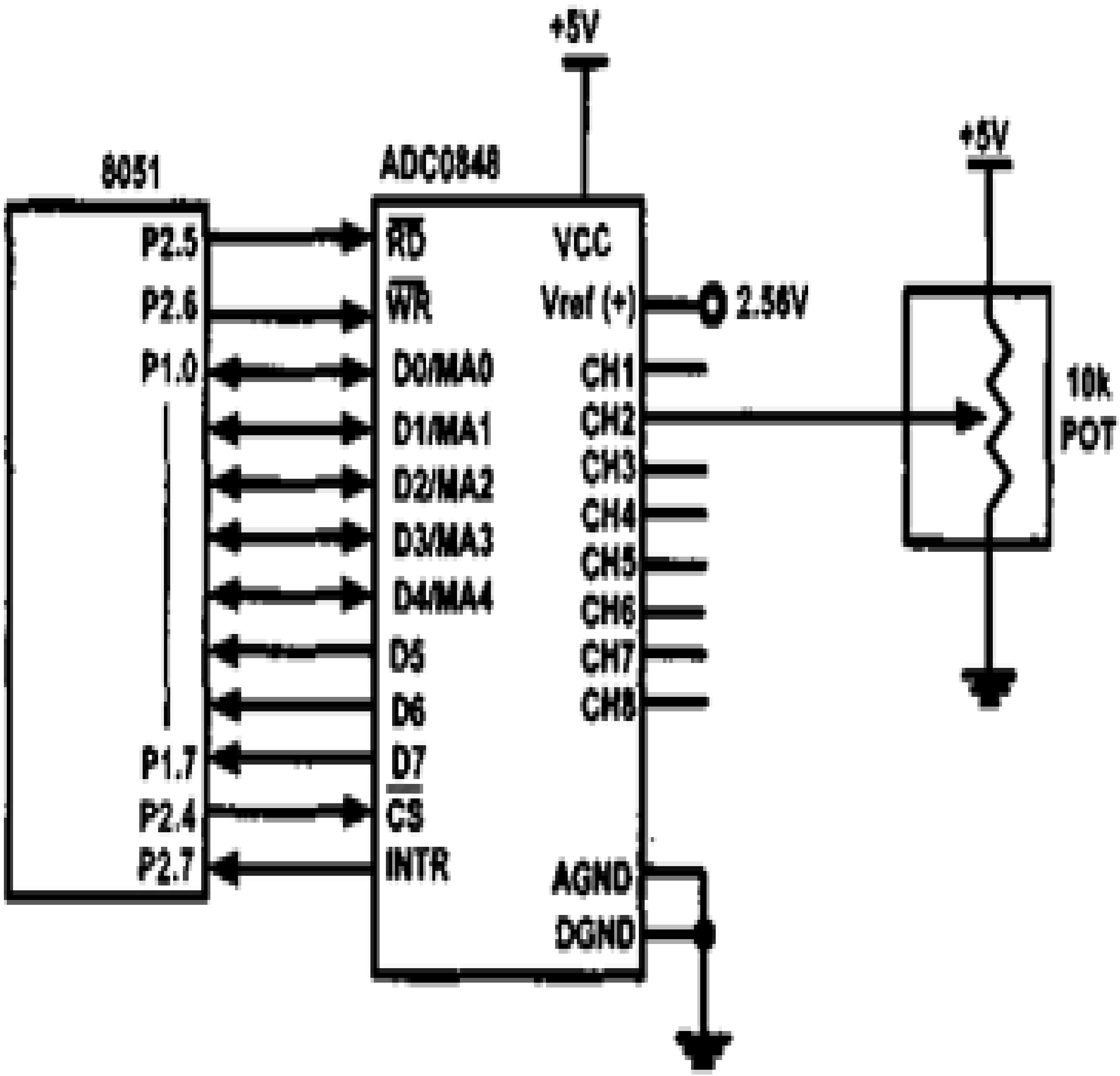


Figure 13-8. ADC0848 Chip


CH1
CH8
GND
Vcc
ADC0848
AGND
Vref
INTR
WR CS RD
D0/MA0
D1/MA1
D2/MA2
D3/MA3
D4/MA4
D7

Selected Analog Channel	MA4	MA3	MA2	MA1	MA0
CH1	0	1	0	0	0
CH2	0	1	0	0	1
CH3	0	1	0	1	0
CH4	0	1	0	1	1
CH5	0	1	1	0	0
CH6	0	1	1	0	1
CH7	0	1	1	1	0
CH8	0	1	1	1	1


+5V
8051
ADC0848
P2.5
P2.6
P1.0
P1.7
P2.4
P2.7
RD
WR
D0/MA0
D1/MA1
D2/MA2
D3/MA3
D4/MA4
D5
D6
D7
CS
INTR
VCC
Vref (+)
2.56V
CH1
CH2
CH3
CH4
CH5
CH6
CH7
CH8
AGND
DGND
+5V
10k
POT

Serial ADC chips

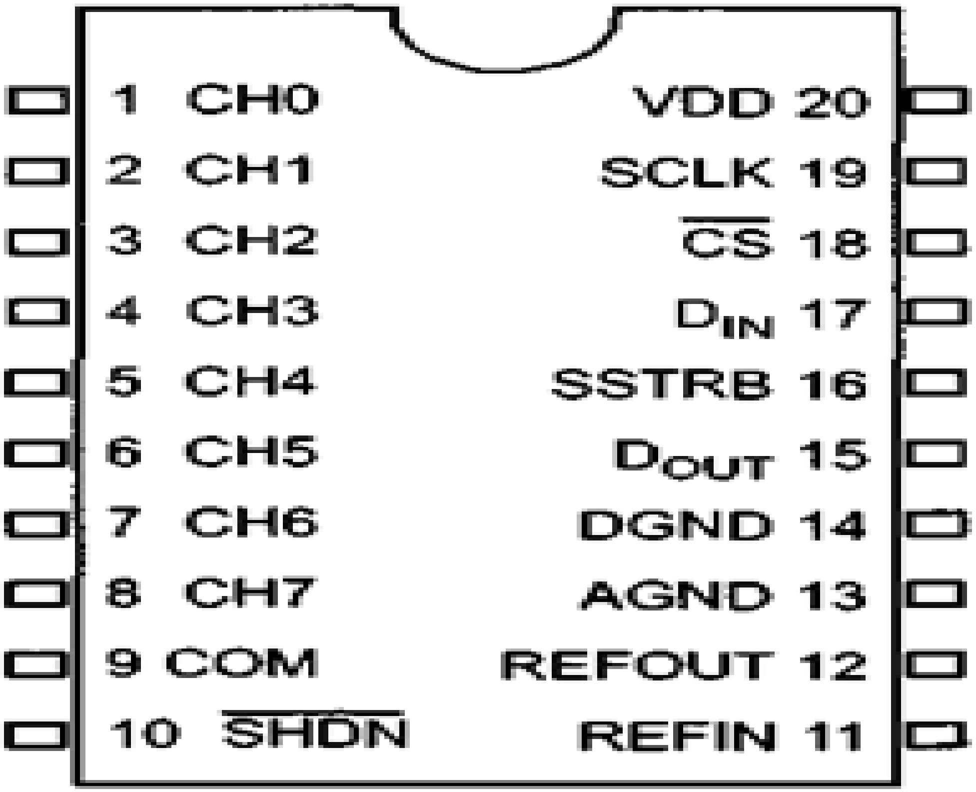


Figure 13-12. MAX1112 Chip

Digital-to-Analog (DAC) Conversion

- The digital-to-analog converter (DAC) is a device widely used to convert digital values to analog signals.
- It does the reverse operation of an ADC
- The resolution of DAC depends on the no. of binary bits input to it.
- The common ones are 8, 10 and 12 bits.
- An 8-input DAC provides 256 discrete voltages (or current) levels of output. (The 12-bit DAC gives 4096 discrete levels).

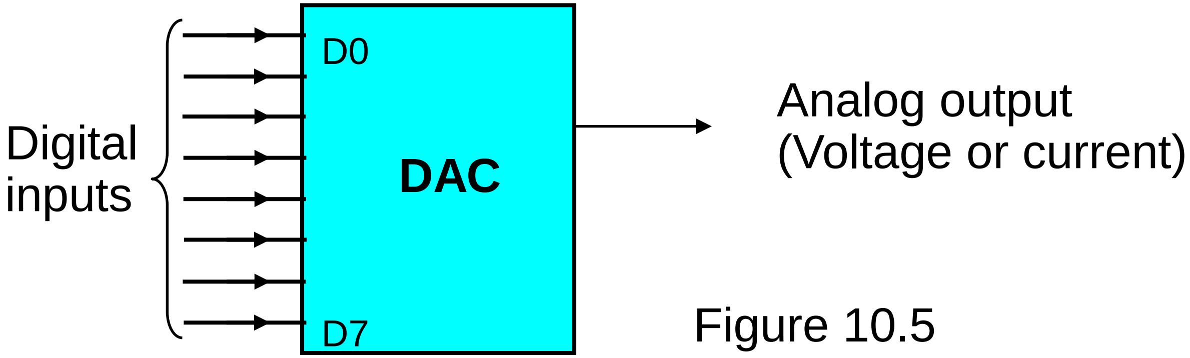


Figure 10.5

DAC0808 Chip (MC1408)

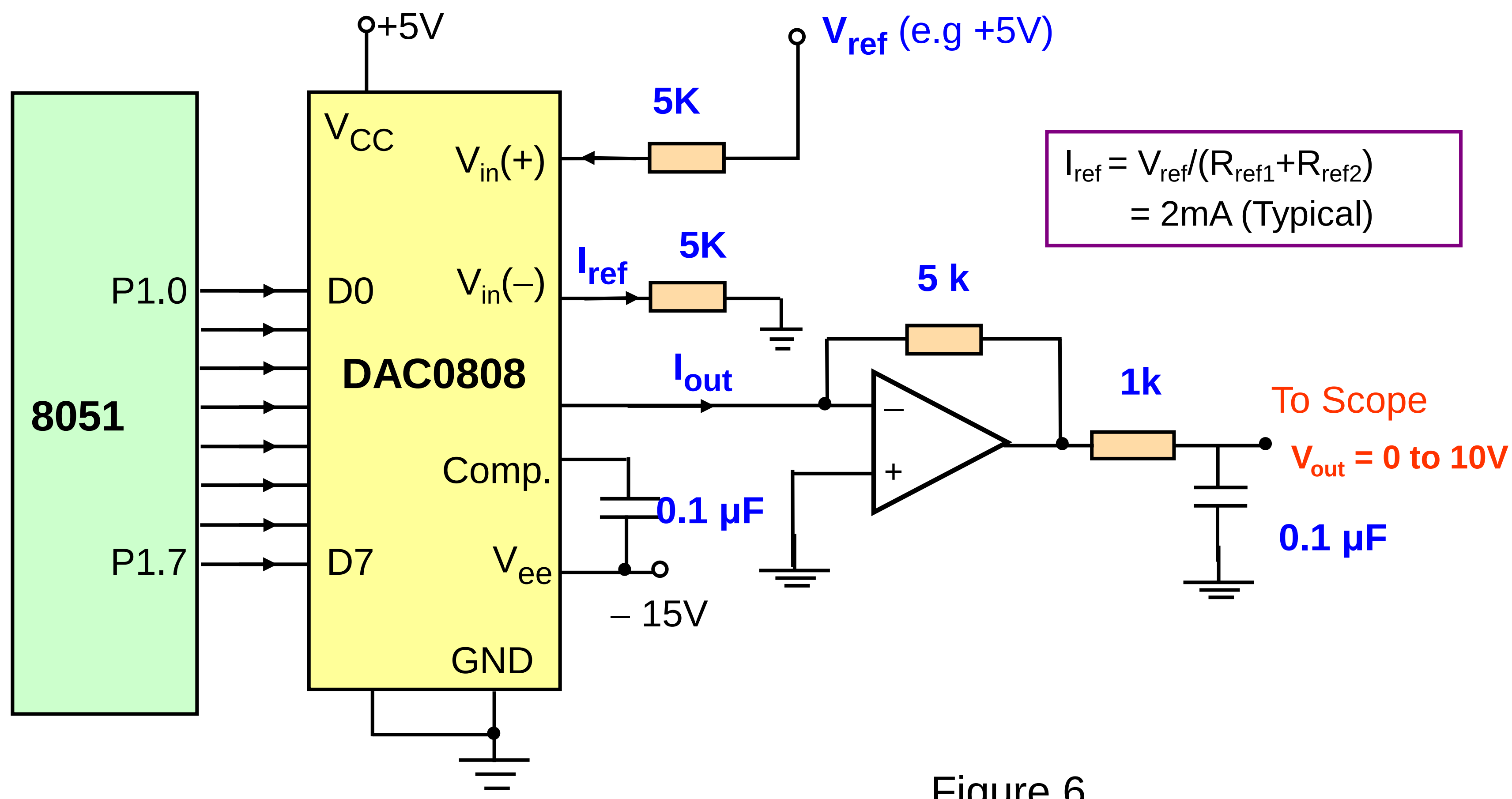


Figure 6

DAC0808 Chip (MC1408)

Operating Principle

- In the DAC0808, the digital inputs are converted to corresponding current (I_{out}).
- Then by connecting a resistor to the I_{out} pin, the current will further convert to voltage level.
- The total current provided by the output I_{out} pin is a function of the reference current (I_{ref}) and is follows:

$$I_{out} = I_{ref}\left(\frac{D_7}{2}+\frac{D_6}{4}+\frac{D_5}{8}+\frac{D_4}{16}+\frac{D_3}{32}+\frac{D_2}{64}+\frac{D_1}{128}+\frac{D_0}{256}\right)$$

Converting I_{out} to voltage (V_{out})

Connect the output pin I_{out} to a output standard resistor and hence convert this current to a voltage.

Output voltage, $V_{out} = I_{out} \times R_o$

Example 3

Assume that Ro = 5kΩ, R_{ref1} = 1k Ω, R_{ref2} = 1.5k Ω and using a standard 5V supply connected to $V_{ref(+)}$, calculate V_{out} for the following binary inputs.

(a) 1001 1001 (99H) (b) 1100 1000 (C8H)

Solution:

$$I_{ref} = \frac{5}{1000+1500} = 2mA$$

(a) 99H = 153_{10}

$$I_{out} = (2mA)\frac{153}{256} = 1.195mA$$

$$V_{out} = (1.195mA)(5000k\Omega) = 5.975V$$

(b) C8H = 200_{10}

$$I_{out} = (2mA)\frac{200}{256} = 1.562mA$$

$$V_{out} = (1.562mA)(5000k\Omega) = 7.8125V$$

Example 4

In order to generate a stair-step ramp, set up the circuit as in Figure 6 and connect the output to an oscilloscope. Then write a program to send data to the DAC at port 1 to generate a stair-step ramp.

Solution:

```
        ORG 0H
        CLR     A
AGAIN:  MOV     P1, A     ; send data to DAC
        INC     A         ; count from 0 to FFH
        ACALL   DELAY     ; let DAC work and recover
        SJMP    AGAIN
        END
```

Example 5

Use the circuit in Figure 6, write a program to generate a sine wave of full-scale 10V output. If the output is connected to a CRO, draw the display on the CRO screen.

Solution:

Assume 10V full-scale voltage for the DAC output.

$$V_{out} = [5 + (5 \sin \theta)] \text{ V}$$

A table is drawn up to list the magnitude of the sine of angles between 0 and 360 degrees. The table values are integer numbers representing the voltage magnitude for the sine θ.

Table 10.5 gives the angles, the sine values, the voltage magnitudes and the integer values representing the voltage magnitude for each angle (with 30° interval).

Vout x 256/10

Table 5 Angle vs Voltage Magnitude for Sine Wave

Angle θ (degree)	Sine θ	Vout 5V + (5sin θ)	Voltage Values sent to DAC
0	0	5	128
30	0.5	7.5	192
60	0.866	9.33	238
90	1.0	10	255
120	0.866	9.33	238
150	0.5	7.5	192
180	0	5	128
210	– 0.5	2.5	64
240	– 0.866	0.669	17
270	– 1.0	0	0
300	– 0.866	0.669	17
330	– 0.5	2.5	64
360	0	5	128

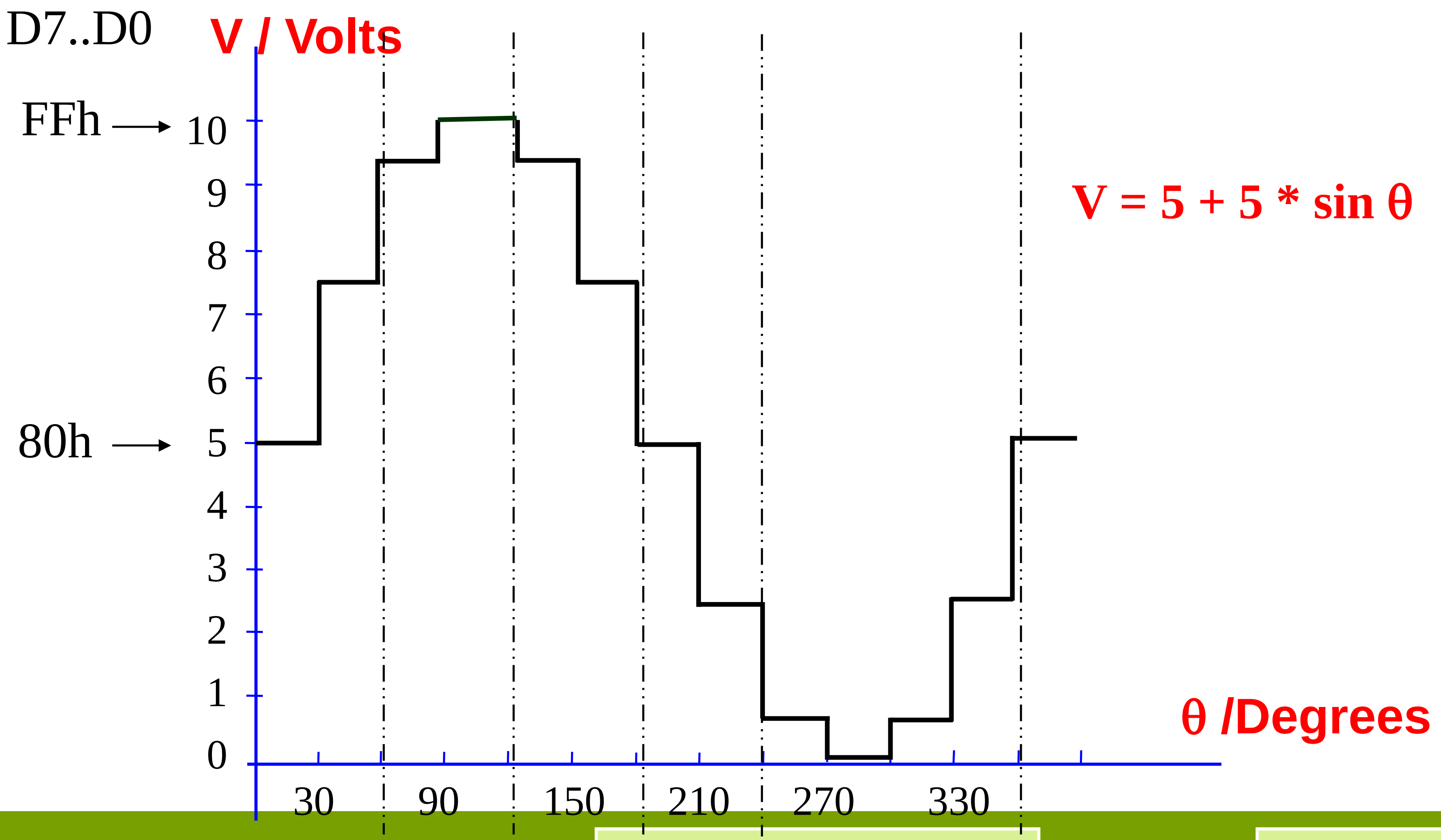
256 steps and full scale Vout is 10 volts

9.33*256/10

Program Generating a Sine Wave

```
            ORG 0H
AGAIN:      MOV     DPTR, #TABLE
            MOV     R2, #COUNT
BACK:       CLR     A
            MOVC    A,@A+DPTR
            MOV     P1,A
            INC     DPTR
            DJNZ    R2, BACK
            SJMP    AGAIN
            ;
            ORG     300
TABLE:      DB      128, 192, 238, 255, 238, 192
            DB      128, 64, 17, 0, 17, 64, 128
            ;
; To get a better looking sine wave, regenerate the look-up table for 2-degree angles
            END
```

Display on the Generating Sine Wave on CRO



Transducer/sensors

- Digital computer/microcontrollers use binary values, but in the physical world most things is in analog nature (continuous).
- Data (such as temperature, pressure, humidity, velocity, voltage) are analog data.
- A device called transducer is used to convert the physical quantity to electrical signals (i.e. voltage, current).
- Transducer are also referred to as sensors.
- Sensors for temperature, velocity, pressure, light, and many other natural quantities can produce an output voltage (or current) which the value is proportional to the quantity being measured.
- Then an analog-to-digital converter is used to translate the analog voltage to digital numbers so that microcontroller can read and process them.

Temperature sensors (Thermistor)

- Temperature can be converted to electrical signals by thermistor.
- Thermistor is a kind of resistor responds to temperature change by changing its resistance.
- But its response is not linear, as seen in the Table 10.1 below.

Table 10.1

Temperature (°C)	Thermistor Resistance (kΩ)
0	29.490
25	10.000
50	3.893
75	1.700
100	0.817

Temperature sensors (LM34 and LM35)

- LM34 series are precision integrated-circuit temperature sensors whose output voltage is linearly proportional to Fahrenheit temperature.華氏
- LM35 series are precision integrated-circuit temperature sensors whose output voltage is linearly proportional to Celsius temperature.攝氏
- They require no external calibration since it is internally calibrated.
- Their output voltage changes 10mV for each degree of temperature change.

Table 10.2

Item	Temperature Range	Accuracy	Output
LM34	-50 F to +300 F	+3.0 F	10 mV/F
LM34C	-40 F to +230 F	+3.0 F	10 mV/F
LM35	-55 °C to +150 °C	+1.5 °C	10 mV/°C
LM35C	-40 °C to +110 °C	+1.5 °C	10 mV/°C
LM35D	0 °C to +100 °C	+2.0 °C	10 mV/°C