การเชื่อมต่อกับสัญญาณแอนะล็อก

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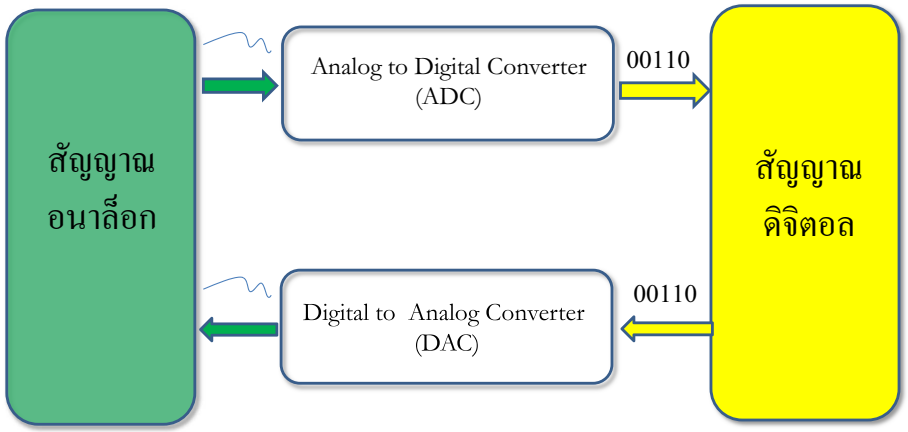
หัวข้อ

1. บทนำ
2. การแปลงสัญญาณดิจิตอลเป็นสัญญาณอนาลอก (Digital to Analog Conversion)
3. การแปลงสัญญาณอนาลอกเป็นสัญญาณดิจิตอล (Analog to Digital conversion)

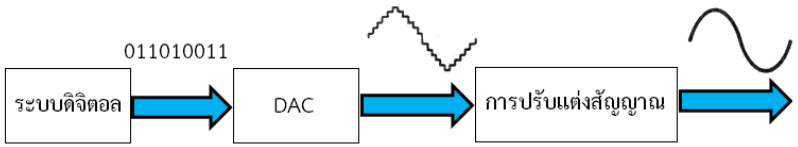
บทนำ

การแปลงสัญญาณ



วงจรแปลงสัญญาณดิจิตอลเป็นสัญญาณ อนาล็อก (Digital-to-Analog Converter หรือ D/A หรือ D2A)

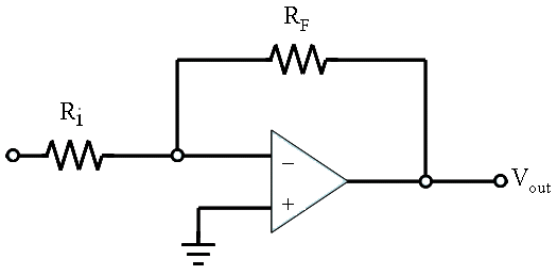
หมายถึงวงจรที่เปลี่ยนข้อมูลทางดิจิตอลให้เป็นค่าอนาล็อก ค่าอนาลอกนี้อาจเป็นกระแสไฟฟ้าหรือแรงดันไฟฟ้าก็ได้



เทคนิคของ DAC

- Binary Weighted DAC
  - Uses switches & precision resistors
  - Difficult to achieve high density due to large resistance values
- R/2R Ladder
  - Most common method
  - Keeps resistance values low
  - Uses intricate interconnections

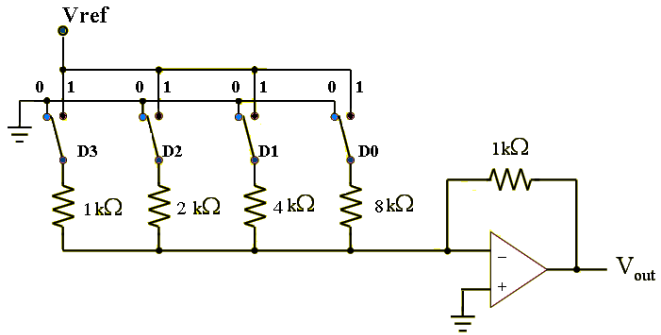
Op-Amp Review



For Negative Feedback,

1. Inputs are high impedance
2. Voltage gain is : $A_v = -R_f / R_i$

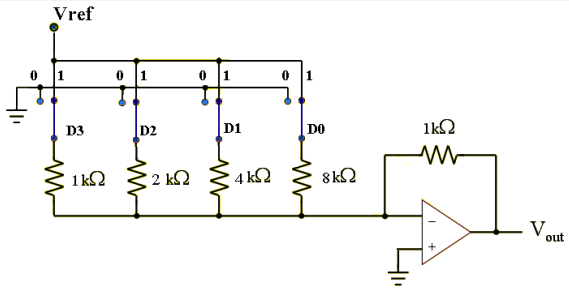
Binary Weighted DAC



แรงดันเอาท์พุทต่ำสุดเกิดเมื่อสวิตซ์ D3- D0 อยู่ตำแหน่ง ‘0’

Vout = 0 โวลท์

Binary Weighted DAC



ถ้า D3- D0 อยู่ตำแหน่ง ‘1’ จะได้แรงดันเอาท์พุทสูงสุด

Vout = - Vref x Rf x(1/1k + 1/2k + 1/4k + 1/8k)

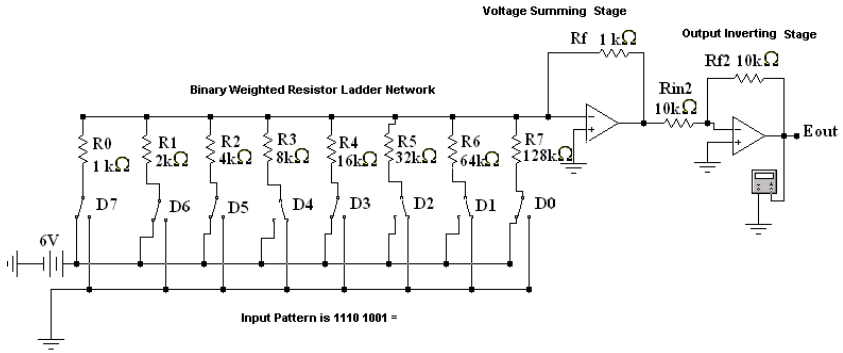
Vout = -Vref x 1 x(1/1 + 1/2 + 1/4 + 1/8)

Vout = -Vref x (1 + .5 + .25 + .125)

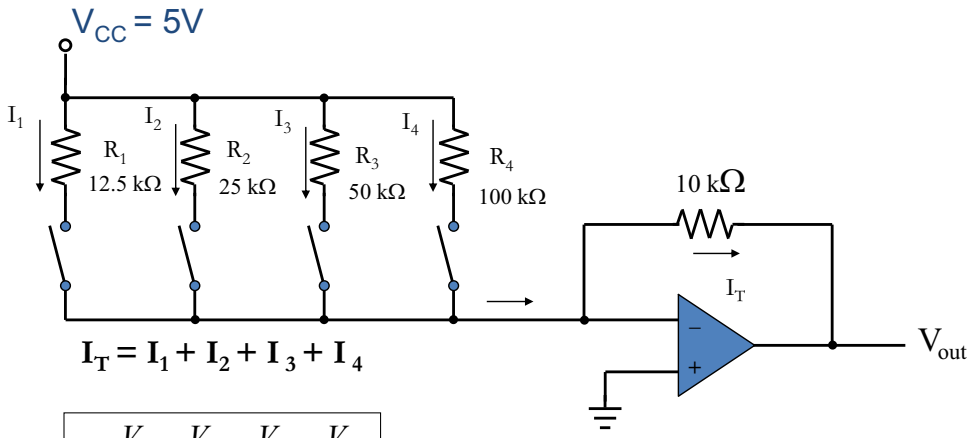
Vout = -1.875 x Vref

เช่นถ้า Vref = +5V Vout เมื่ออินพุทเป็น ‘1’ หมดจะได้ -9.375 โวลท์

แต่การทำวงจรให้มีจำนวนบิตมากขึ้นต้องใช้ความต้านทานขนาดใหญ่ขึ้น



Summation Circuit

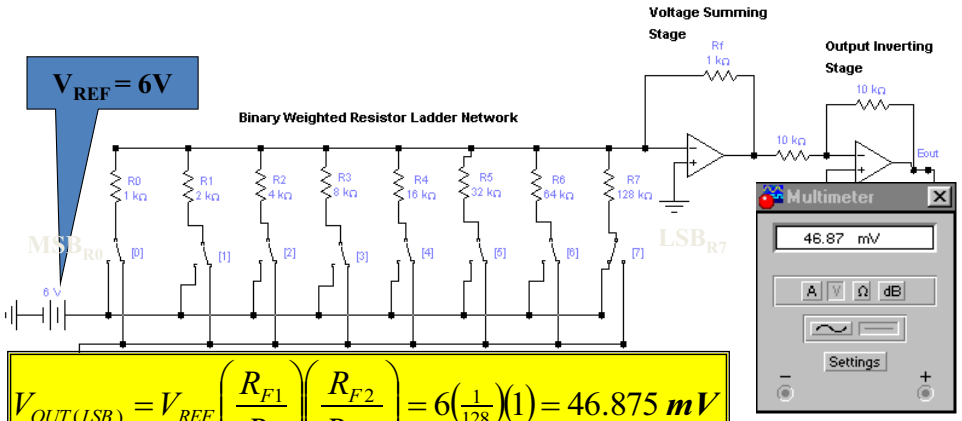


$$I_T = I_1 + I_2 + I_3 + I_4$$

$$I_T = \frac{V_{CC}}{R_1} + \frac{V_{CC}}{R_2} + \frac{V_{CC}}{R_3} + \frac{V_{CC}}{R_4}$$

Min V_{out} = 0.0 V Max V_{out} = -7.5 V

Building a Digital to Analog Converter Circuit



$$V_{OUT(LSB)} = V_{REF}\left(\frac{R_{F1}}{R_7}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 6\left(\frac{1}{128}\right)(1) = 46.875\ \boldsymbol{mV}$$

$$V_{OUT(MSB)} = V_{REF}\left(\frac{R_{F1}}{R_0}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 6(1)(1) = 6\ Volts$$

ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

Binary Weighted Network Formulae

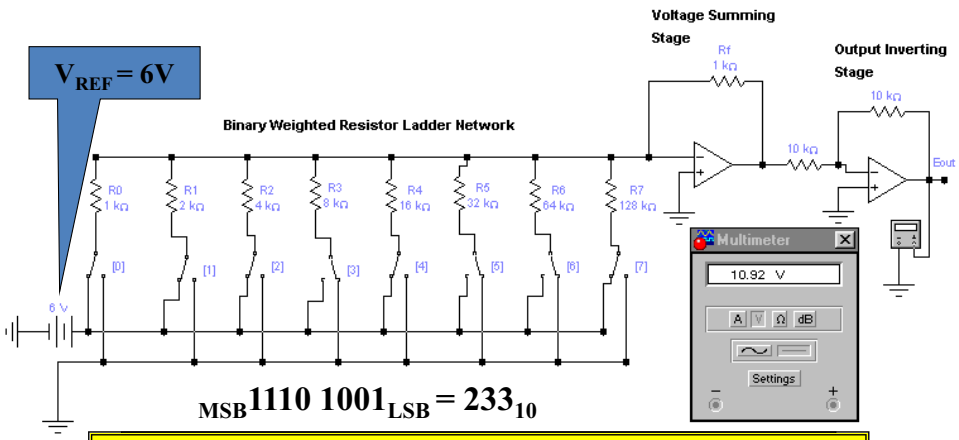
$$V_{OUT(MSB)} = V_{REF}\left(\frac{R_{F1}}{R_0}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 6(1)(1) = 6\ Volts$$

$$V_{OUT(LSB)} = V_{REF}\left(\frac{R_{F1}}{R_7}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 6\left(\frac{1}{128}\right)(1) = 46.875\ \boldsymbol{mV}$$

$$V_{OUT(AnyBit)} = V_{REF}\left(\frac{R_{F1}}{R_{BIT}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right)$$

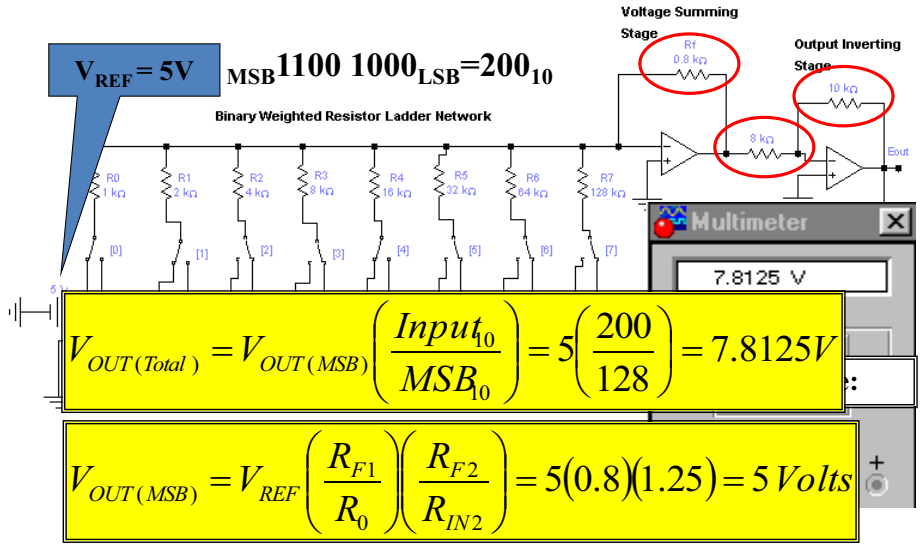
$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{Input_{10}}{MSB_{10}}\right)$$

Binary Weighted DAC Worked Example



$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{Input_{10}}{MSB_{10}}\right) = 6\left(\frac{233}{128}\right) = 10.922V$$

Binary Weighted Student Example



$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{Input_{10}}{MSB_{10}}\right) = 5\left(\frac{200}{128}\right) = 7.8125V$$

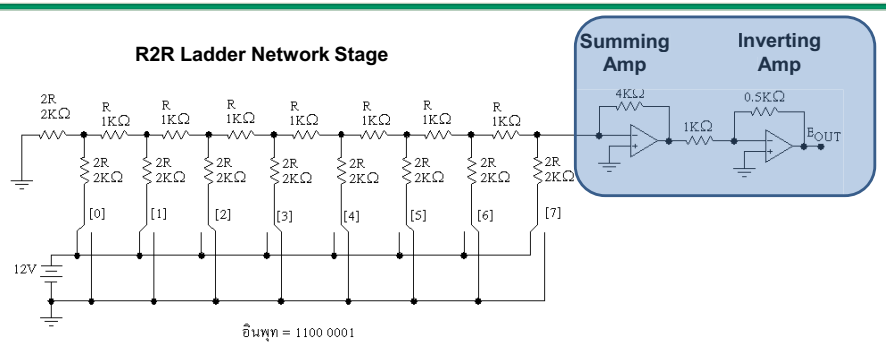
$$V_{OUT(MSB)} = V_{REF}\left(\frac{R_{F1}}{R_0}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 5(0.8)(1.25) = 5\,Volts$$

ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

Some problems with this weighted resistor solution

- Resistor values span a wide range
  - *n*-bit DAC ==> resistors from 2R to 2^nR
  - 8-bit DAC ==> 2R to 512R, e.g., 2K to 512K
  - Difficult to fabricate wide ranges of resistance in semiconductor processes.
- Different resistors in the network have different accuracy requirements.
  - 5% resistance change at MSB has 2.5% effect
  - 5% resistance change at LSB (8-bit) has .02% effect
  - MSB of 16-bit DAC (as in CD player) would require accuracy of one part in 2^{15} (.003%) to have less than one step-size error.

R2R Ladder Network DAC



การวิเคราะห์วงจรโดยใช้ทฤษฎี Thevenin

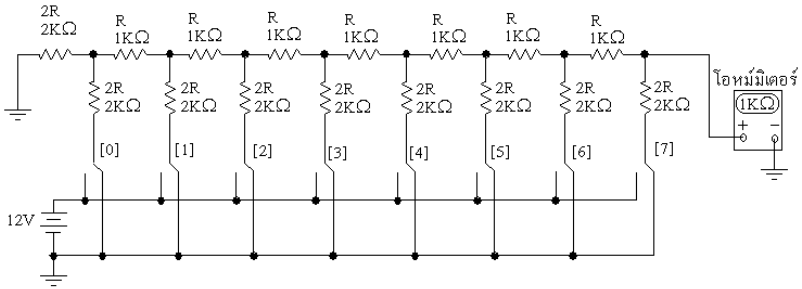
หา Rth ของ Thevenin

ที่ตำแหน่งบิตต่างๆ สามารถหา Rth ได้ดังนี้

บิต 0 Rth = 1 k, บิต 1 Rth = 1 k,บิต 2 Rth = 1 k,บิต 3 Rth = 1 k,บิต 4 Rth = 1 k,บิต 5 Rth = 1 k, บิต 6 Rth = 1 k และ บิต 7 Rth = 1 k

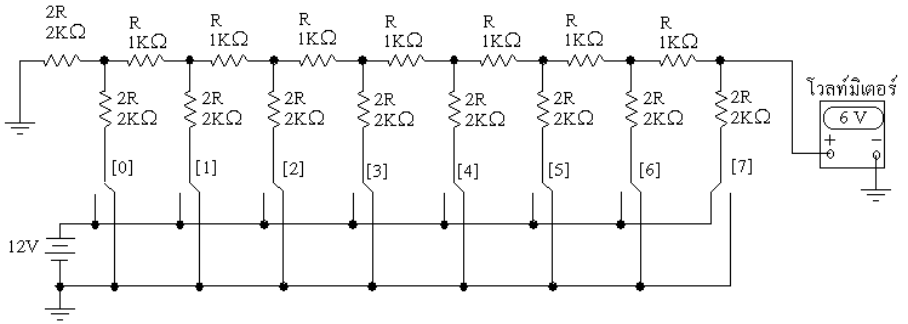
ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

วงจร Thevenin equivalent เพื่อหา Rth



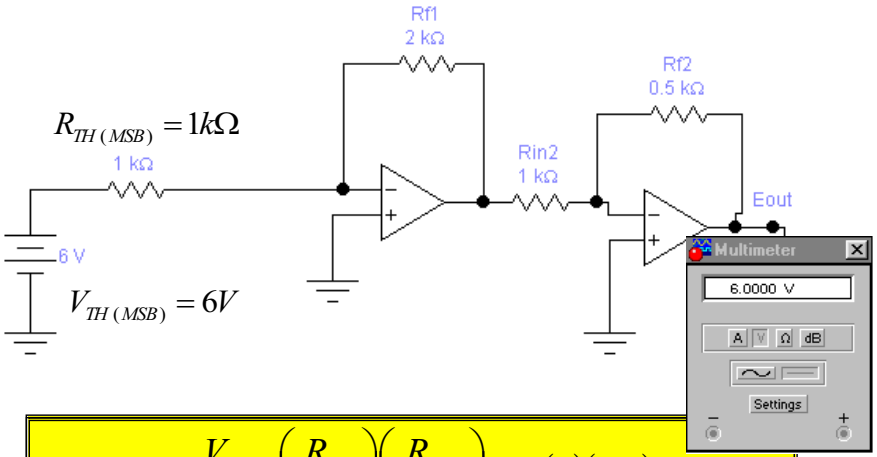
Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
1 kΩ	1 kΩ	1 kΩ	1 kΩ	1 kΩ	1 kΩ	1 kΩ	1 kΩ

หา Thevenin Voltage ใน the R2R Ladder Network (Vth)



Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
46.875 m V	93.75 m V	0.1875 V	0.375 V	0.75 V	1.5 V	3 V	6 V

Thevenin Equivalent Circuit for MSB



$$V_{OUT(MSB)} = \frac{V_{REF}}{2}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 6(2)(0.5) = 6\,Volts$$

ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

Analog Outputs from R2R DAC

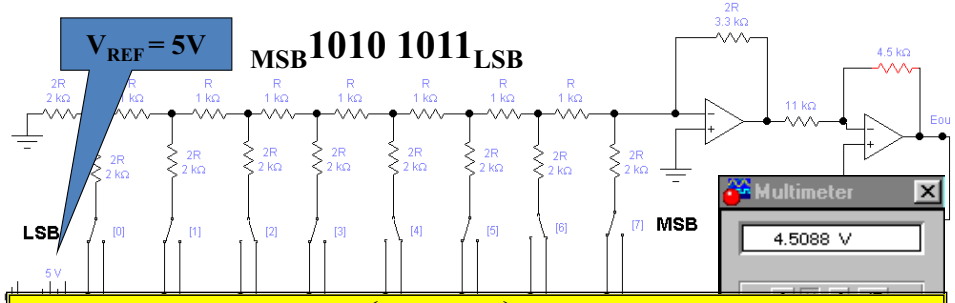
$$V_{OUT(MSB)} = \frac{V_{REF}}{2}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right)$$

$$V_{OUT(LSB)} = \frac{V_{REF}}{256}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right)$$

$$V_{OUT(AnyBit)} = \frac{V_{REF}}{2^{8-n}}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right)$$

$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{Input_{10}}{MSB_{10}}\right)$$

R2R DAC Worked Example

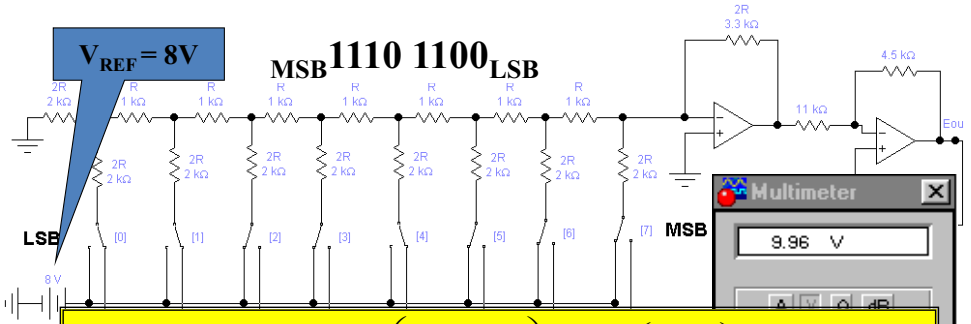


$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{\text{Input}_{10}}{\text{MSB}_{10}}\right) = 3.375\left(\frac{171}{128}\right) = 4.5088\text{V}$$

$$V_{OUT(MSB)} = \frac{V_{REF}}{2}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 2.5(3.3)(0.4091) = 3.375\,Volts$$

ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

R2R DAC Student Example



$$V_{OUT(Total)} = V_{OUT(MSB)}\left(\frac{Input_{10}}{MSB_{10}}\right) = 5.4\left(\frac{236}{128}\right) = 9.95625V$$

$$V_{OUT(MSB)} = \frac{V_{REF}}{2}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = 4(3.3)(0.4091) = 5.4\,Volts$$

ระวัง Vref กับ OP-Amp ค่าไม่เท่ากัน

Limitations of the R2R DAC

Although Ladder Network Resistor Values are now of a Common pattern & therefore easier to realize, the Tolerance Requirements are still valid.

A 1% Tolerance on R_7 can swamp the Effect of the LSB.

For an LSB accuracy of 1%, MSB Resistor must have a tolerance of 1/128.

Most Modern fast DAC's employ the R2R ladder Network at their core.

Speed of conversion is still limited by the Slew Rate of the Op-Amps.

เทอมที่เกี่ยวกับ DAC

Resolution:

เป็นขนาดที่เล็กที่สุดที่ D/A สามารถสร้างได้ ขนาดนี้ขึ้นอยู่กับจำนวนบิตของ D/A หรือ มีค่าเท่ากับค่าที่ได้จากบิต LSB คำนวณได้จาก

$$V_{OUT(LSB)} = \frac{V_{REF}}{2^n}\left(\frac{R_{F1}}{R_{TH}}\right)\left(\frac{R_{F2}}{R_{IN2}}\right) = \left(\frac{V_{REF}}{2^n}\right)$$

When no Op-Amp Stages are provided

หรือกล่าวว่า Resolution ขนาดกี่บิต เช่นขนาด 12 บิต

จำนวนระดับของสัญญาณอะนาลอก

This is the total number of analog levels achievable by the DAC and is determined by the number of bits "n".

$$Analog\ Levels = 2^n$$

ค่าความเที่ยงตรง(Accuracy)

เป็นการเปรียบเทียบค่าจริงกับค่าที่คำนวณได้ ปกติจะกำหนดเป็นเปอร์เซนต์ของค่าเอาท์พุทเมื่อเต็มสเกล (Full scale)

$10\ V_{fs}$, ± 0.2% accuracy ® ± 20 mV

ความเร็ว (Speed)

หมายถึงความเร็วของ Output settling time ซึ่งเป็นเวลาที่ต้องใช้เพื่อสร้างค่าเอาท์พุทเมื่ออินพุทมีการเปลี่ยนแปลง

การผิดพลาดใน DAC

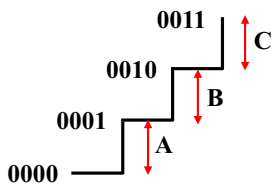
Distortion Effects in DAC's

Distortion:

DAC ที่ดีต้องให้ค่าเอาท์พุทออกมาตรงตามค่าอินพุท เมื่ออินพุทให้ค่ามากขึ้น สัญญาณเอาท์พุทก็ต้องมีค่ามากขึ้น และการเพิ่มขึ้นของอินพุทแต่ละขั้นก็ต้องให้ค่าเอาท์พุทเพิ่มขึ้นในแต่ละขั้นเท่าๆกันด้วย แต่ถึงกระนั้น ในทางเป็นจริง DAC ก็มีการผิดเพี้ยนเช่นกัน การผิดเพี้ยนใน DAC มี 2 แบบใหญ่ๆ คือ Non-linear distortion และ Non-monotonic distortion

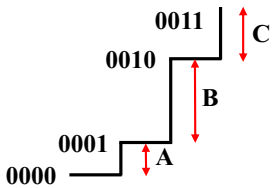
Non-Linear Distortion

ลักษณะการผิดเพี้ยนแบบนี้จะให้ค่าเอาท์พุทของแต่ละสเต็ปไม่เท่ากัน



A=B=C=Resolution

LINEAR

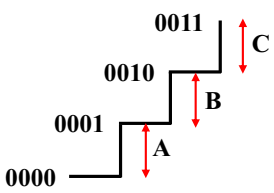


A≠B ≠ C ≠ Resolution

NON-LINEAR

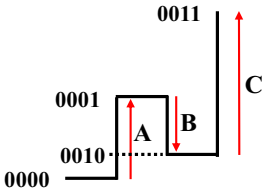
Non-monotonic Distortion in DAC's

ลักษณะการผิดเพี้ยนแบบนี้จะให้ค่าเอาท์พุทของแต่ละสเต็ปไม่เท่ากัน และบางครั้งให้ค่าเอาท์พุทลดลงทั้งๆที่อินพุทมีค่าเพิ่มขึ้น



A=B=C=Resolution

LINEAR & MONOTONIC



A≠B ≠ C ≠ Resolution

NON-MONOTONIC

ตัวอย่าง DAC

DAC ขนาด 2 บิต มีแรงดันอ้างอิง 8 โวลท์และค่าความเที่ยงตรง @ ± 0.2% acc จงหาค่า resolution และค่าความเที่ยงตรงในเทอมของแรงดัน

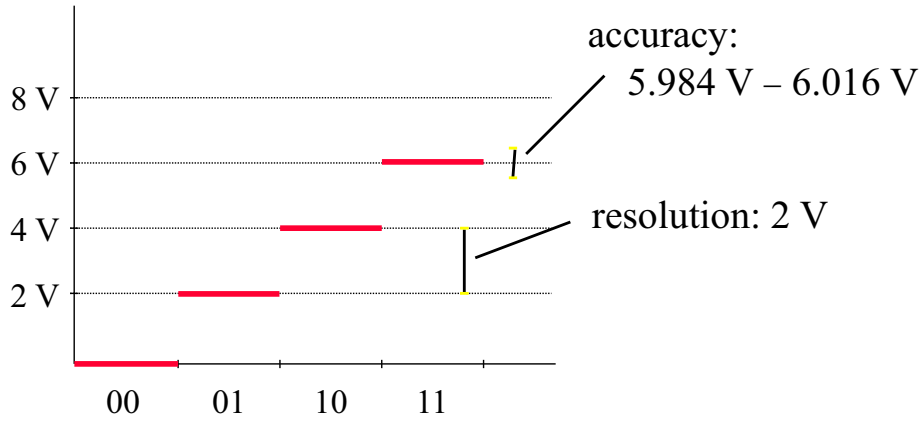
resolution:

$$\frac{1}{2^2} = \frac{1}{4} = 25\% \quad \text{หรือ} \quad \left(\frac{1}{4}\right)(8\text{ V}) = 2\text{ V}$$

accuracy:

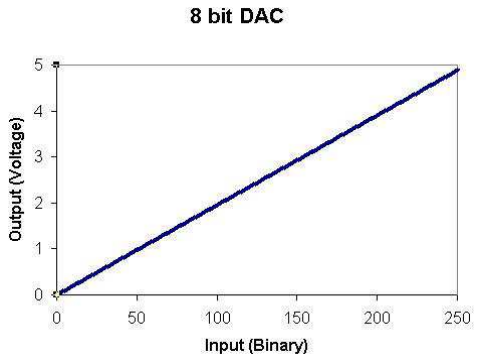
$$(\pm 0.2\%)\,(8\text{ V}) = \pm 16\text{ mV}$$

ตัวอย่าง DAC



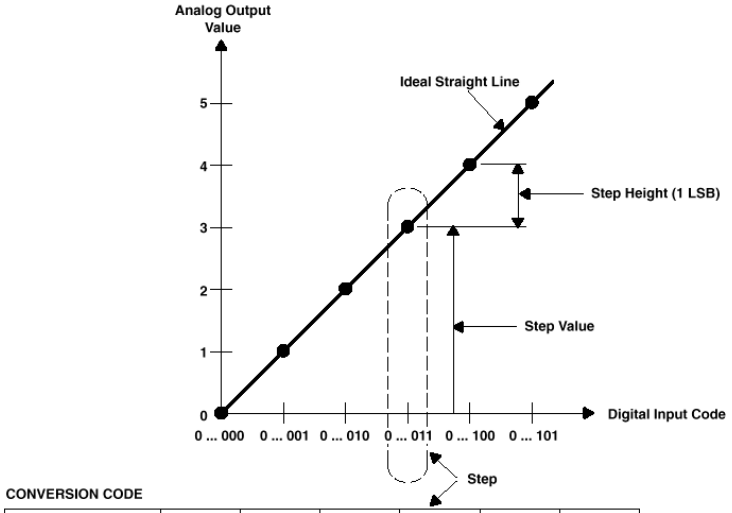
8-Bit DAC

Input		Output
Dec	Binary	
0	00000000	0V
1	00000001	0.020V
2	00000010	0.039V
3	00000011	0.059V
252	11111100	4.922V
253	11111101	4.941V
254	11111110	4.961V
255	11111111	4.980V



Ideal DAC Diagram

The resolution is voltage step size.

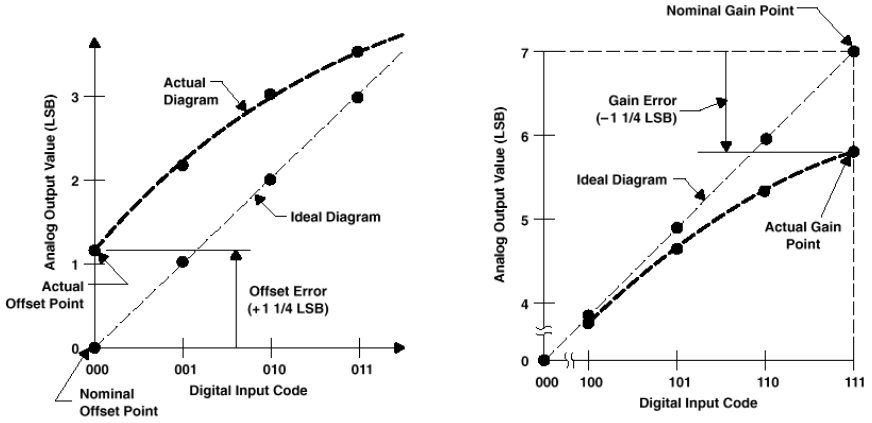


CONVERSION CODE

Digital Input Code	0 ... 000	0 ... 001	0 ... 010	0 ... 011	0 ... 100	0 ... 101
Analog Output Value	0	1	2	3	4	5

Elements of Transfer Diagram for an Ideal Linear DAC

DAC Errors



Errors can arise from components that are not ideal. When choosing a DAC this is one specification that is provided.

สรุปการคำนวณ

$$V_{OUT} = V_{ref}^{-} + X_{10}\left(\frac{V_{ref}^{+} - V_{ref}^{-}}{2^{n}}\right)$$

$$V_{OUT} = V_{\min} + X_{10}\left(\frac{V_{\max} - V_{\min}}{2^{n} - 1}\right)$$

$$\text{Resolution} = \left(\frac{V_{ref}^{+} - V_{ref}^{-}}{2^{n}}\right)$$

$$\text{Resolution} = \left(\frac{V_{\max} - V_{\min}}{2^{n} - 1}\right)$$

$$V_{OUT} = V_{ref}^{-} + X_{10}\,\text{Resolution}$$

$$V_{OUT} = V_{\min} + X_{10}\,\text{Resolution}$$

V_{OUT} = Output Voltage

V_{ref}^{-} = Voltage Reference -

V_{ref}^{+} = Voltage Reference +

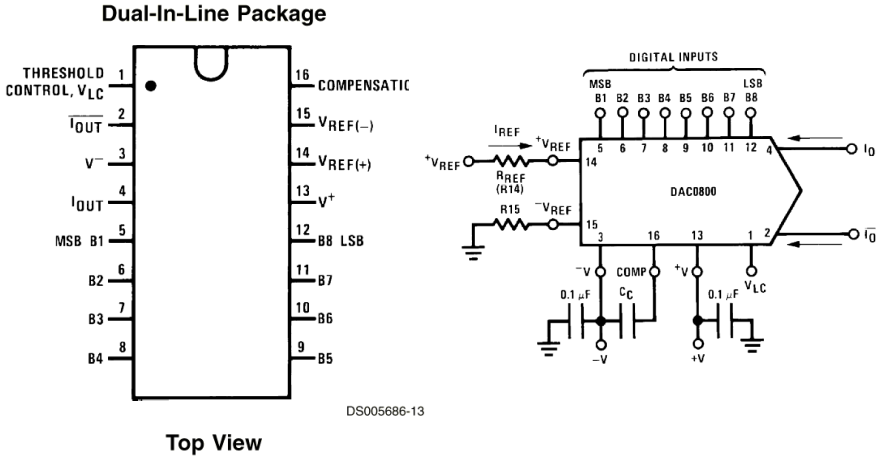
$V_{\min}$ = Minimum output voltage

$V_{\max}$ = Maximum output voltage

X_{10} = Input value base 10

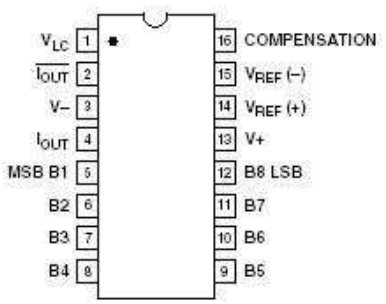
n = จำนวนบิต

DAC0800 Pinout and Application



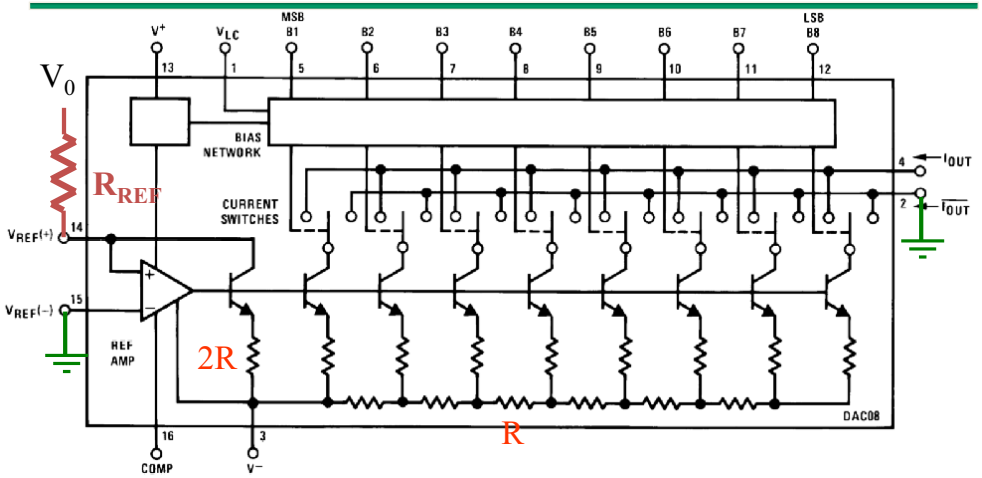
This is a current producing DAC, with the output determined by the digital code and by the input voltage V_{ref}. It is very fast (~100 ns), as with most DACs

Pins



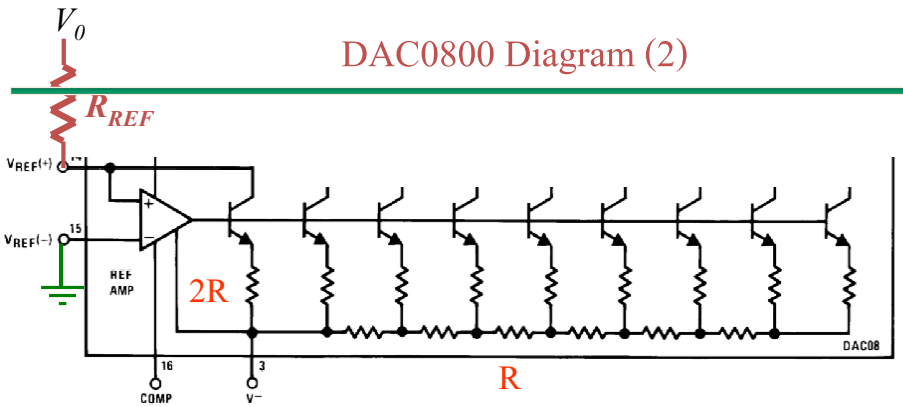
Pins	Purpose
1. V_{LC}	Ground
2. I_{OUT}'	Output'
4. I_{OUT}	Output
Digital Input B1 → MSB : : : B8 → LSB	5. Input : : : : 12. Input
14. $V_{REF}(+)$ 15. $V_{REF}(-)$	Reference voltage for output

DAC0800 Diagram



The current output makes it faster (no op amp to limit). It still has the R-2R ladder. To analyze this imagine this connection diagram. We will first focus on the REF AMP, then look at the currents in the R-2R ladder.

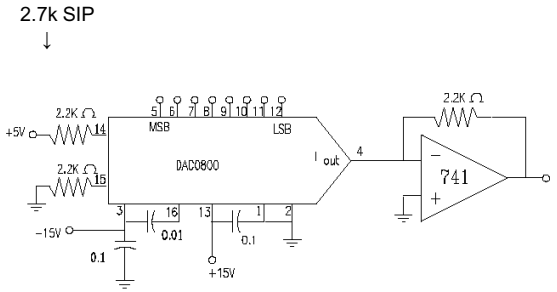
DAC0800 Diagram (2)



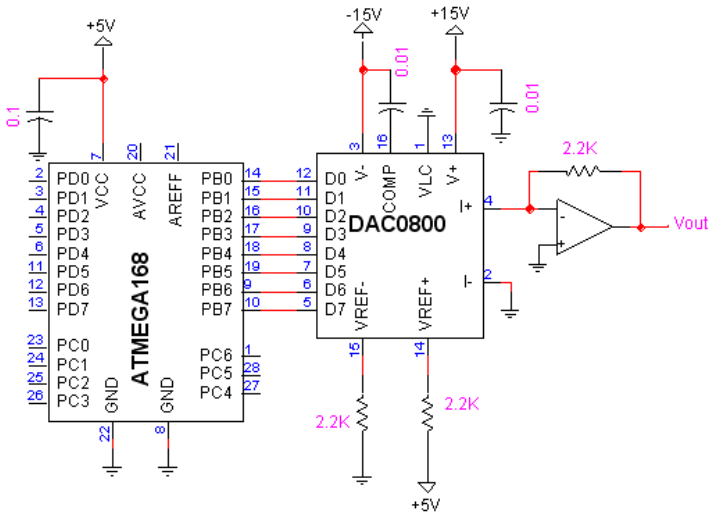
The current is set by V_0/R_{REF}. That means the output current is controlled not only by the digital code but be an analog input as well. This is called a multiplying DAC.

The emitter voltage will be the same on all the BJTs, but the currents will be different. The total current is V_0/R_{REF}. Each branch will have 1/2 of the previous branches value. Note the rightmost transistor - why is it there?

ตัวอย่าง



ATmega168 กับ DAC0800

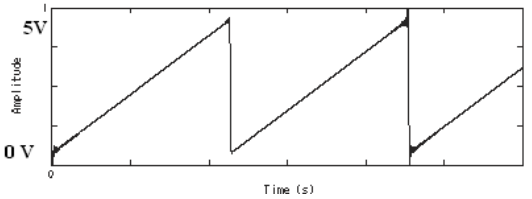


ตัวอย่างโปรแกรมภาษา C สร้างสัญญาณฟันเลื่อย

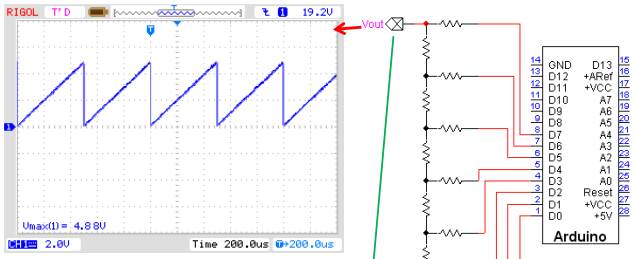
(sawtooth wave generator)

```
unsigned char c;
#include <avr/io.h>

int main(void)
{
    unsigned char i;
    DDRB = 0xFF;
    while(1)
    {
        PORTB = i;
        i++;
    }
}
```



Simple 8 bit DAC for the Arduino ATmega168



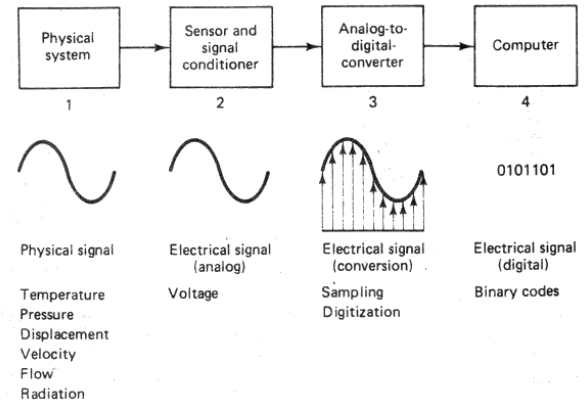

```
int i=0;
void setup()
{
    DDRD = 0xff;
}

void loop()
{
    PORTD = i;
    if(i==256) i=0;
    i++;
}
```


วงจรแปลงสัญญาณอนาลอกเป็นสัญญาณดิจิตอล

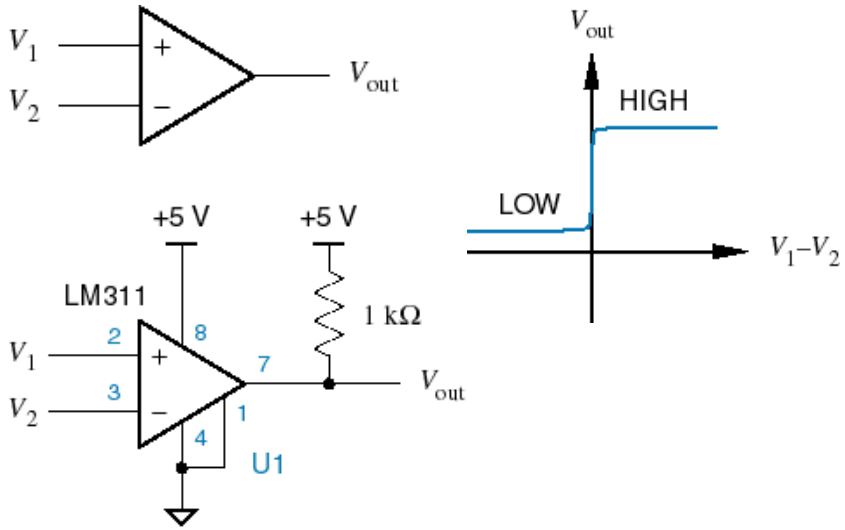
(Analog-to-Digital Converter หรือ A/D หรือ A2D)

หมายถึงวงจรที่เปลี่ยนสัญญาณอนาลอกให้เป็นสัญญาณทางดิจิตอล



Analog-to-digital conversion

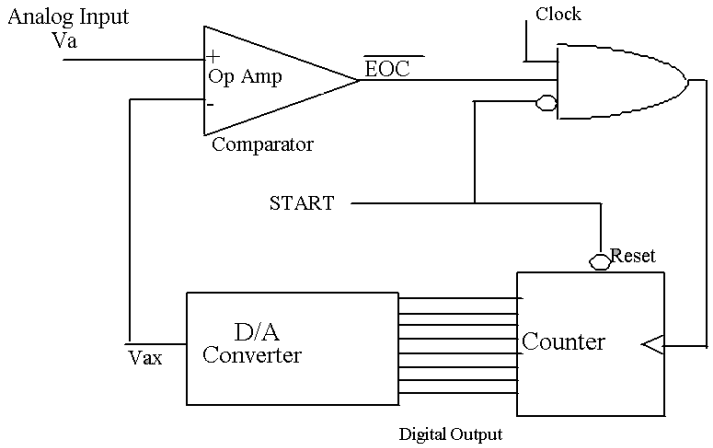
- Analog comparator = 1-bit A-to-D



ADC Techniques

- Digital Ramp ADC (Counter method)
- Successive Approximation
  - High Speed, Medium Resolution
- Parallel Comparator ("Flash")
  - Very high-speed conversion
- Dual Slope
  - Slow Speed, High Resolution

Digital Ramp ADC (Counter method)



•This simplest ADC uses a binary counter as the register

•A Start pulse resets the counter & disables the And gate

•With all 0s at its input, the DAC's output is VAX=0 volts

•Since VAX < VA, the op-amp EOC output will be High

•When Start returns Low, the AND gate is enabled.

•As the counter advances, the DAC output, VAX, increases one step at a time

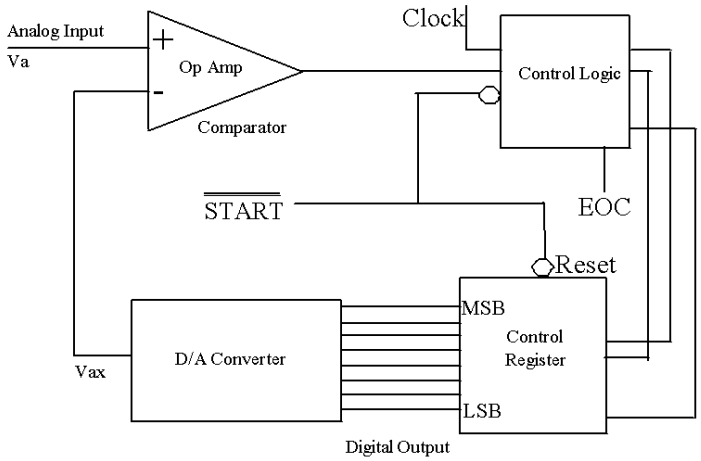
•This continues until VAX reaches a step that just exceeds

•VA by about VT. EOC is then Low disabling the AND.

•The A/D Conversion is now complete and the contents of the counter are the digital representation of VA.

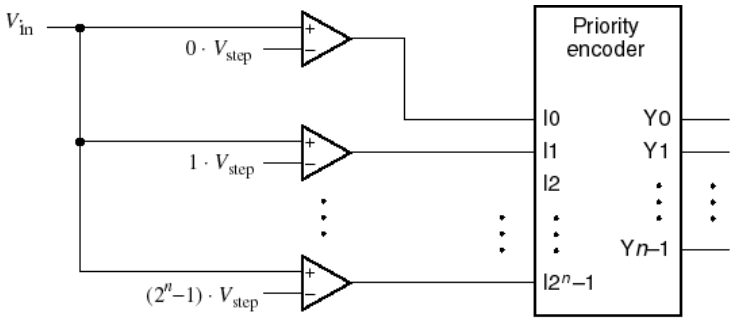
•The digital data is lost at the next START pulse.

Successive Approximation ADC (SAC)



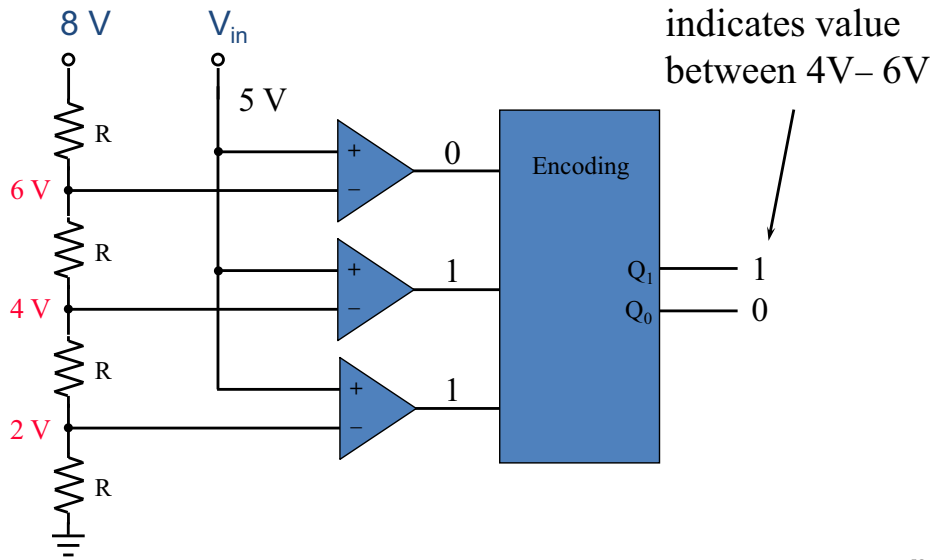
- The Successive-approximation ADC is widely used.
- A Start pulse clears all the bits and disables the CLU.
- A/D Conversion begins with the MSB = 1.
- If VAX > VA, then clear the last set bit back to 0.
- If all bits have been checked then proceed, otherwise repeat by setting the next lower significant bit to a 1.
- After all bits have been checked, EOC = 1.
- The A/D Conversion is now complete and the contents of the register are the digital representation of VA.
- The digital data is lost at the next START pulse unless stored in some sort of memory device or location.

Flash ADC



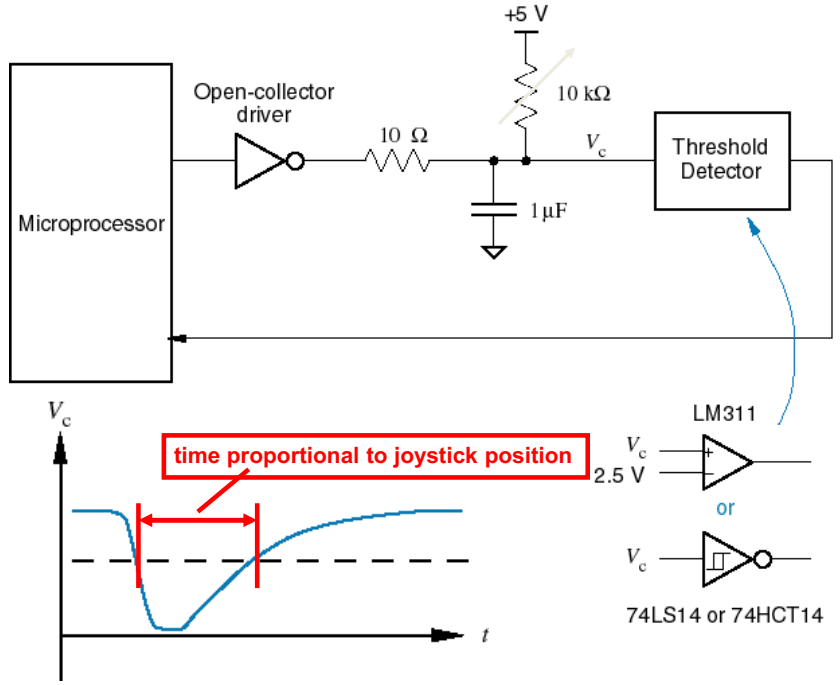
- Fastest conversion time
  - used in digital scopes, video sampling, etc.
- Good for only a few bits of resolution
  - too much hardware

Flash ADC



Other clever ideas, e.g., Apple II A-to-D for joystick

- Converts analog position into numeric value.
- Idea:
  - Use a potentiometer whose resistance is a function of position (joystick).
  - Combine the resistance with a capacitance and measure the *RC* time constant
  - Use a program loop.



ADC Specifications

Resolution –

Also referred to as quantizing error. Error between actual analog value and its digital representation.

ADC Specifications

Accuracy –

A comparison of the actual output with the expected output. Same as for DAC.

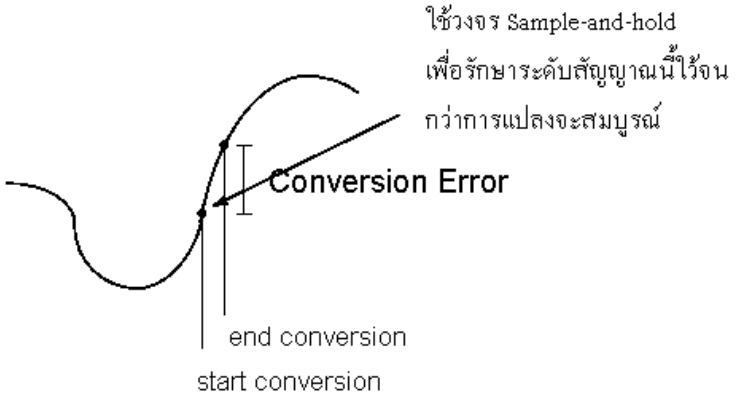
ADC Specifications

Conversion Time

- ระยะเวลาที่ใช้ในการแปลงสัญญาณ
- **Time required to digitize each sample. Function of conversion method and number of bits.**

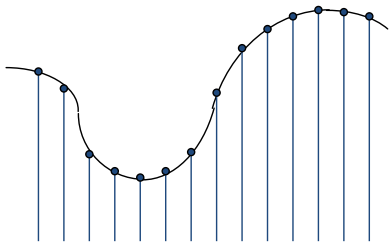
Sample and Hold

Used when input signal is quickly Changing (high frequency applications).



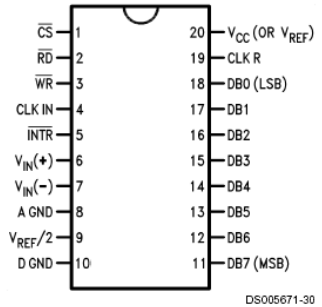
Sampling Rate

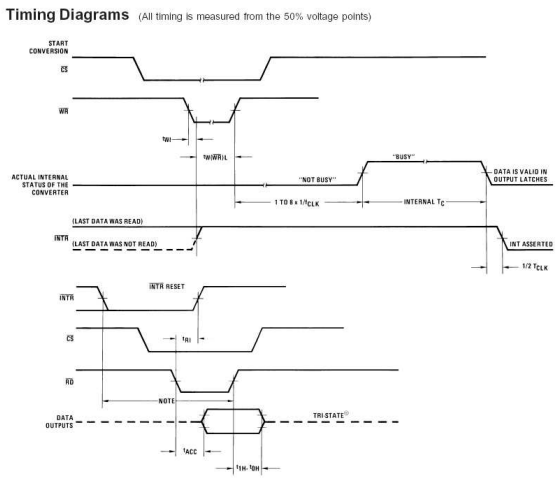
Frequency of samples.
(e.g. 44 kHz or every 22.7 μs)



Each sample is quantized into a digital number.
(e.g. 12 bits)

ADC0804 8-Bit μP Compatible A/D Converters

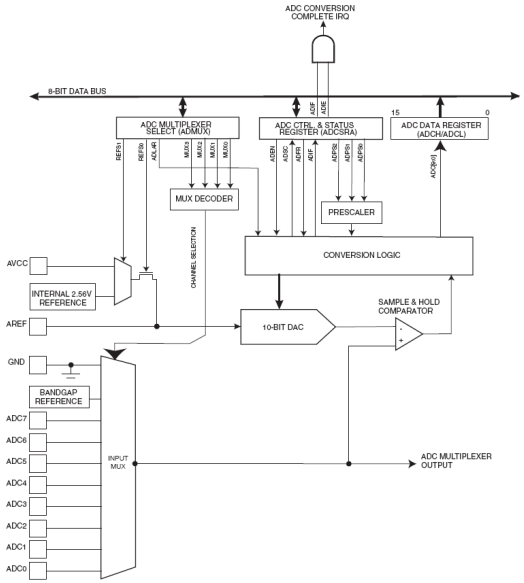




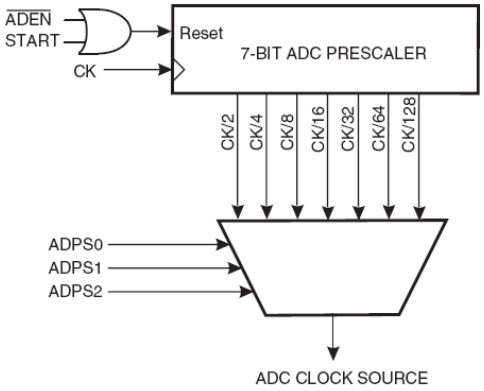
Analog-to-Digital Converter (ADC) ของ ATmega8 ขนาด 10 บิต

- **10-bit Resolution**
- **0.5 LSB Integral Non-linearity**
- **± 2 LSB Absolute Accuracy**
- **13 - 260 µs Conversion Time**
- **Up to 15 kSPS at Maximum Resolution**
- **6 Multiplexed Single Ended Input Channels**
- **2 Additional Multiplexed Single Ended Input Channels (TQFP and QFN/MLF Package only)**
- **Optional Left Adjustment for ADC Result Readout**
- **0 - VCC ADC Input Voltage Range**
- **Selectable 2.56V ADC Reference Voltage**
- **Free Running or Single Conversion Mode**
- **Interrupt on ADC Conversion Complete**
- **Sleep Mode Noise Canceler**

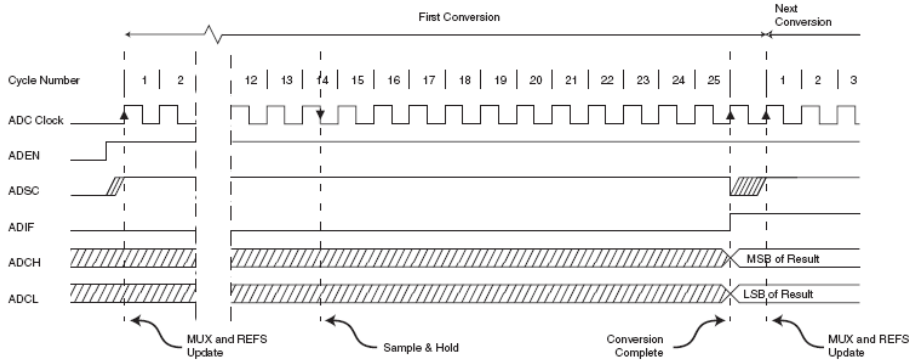
Analog to Digital Converter Block Schematic Operation



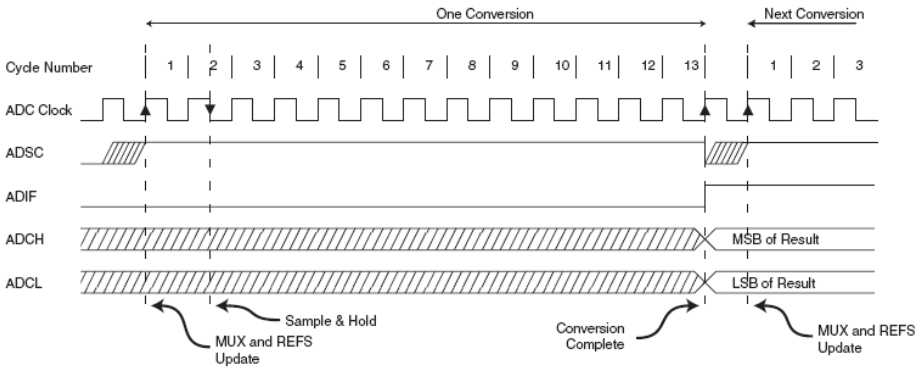
Prescaling and Conversion Timing



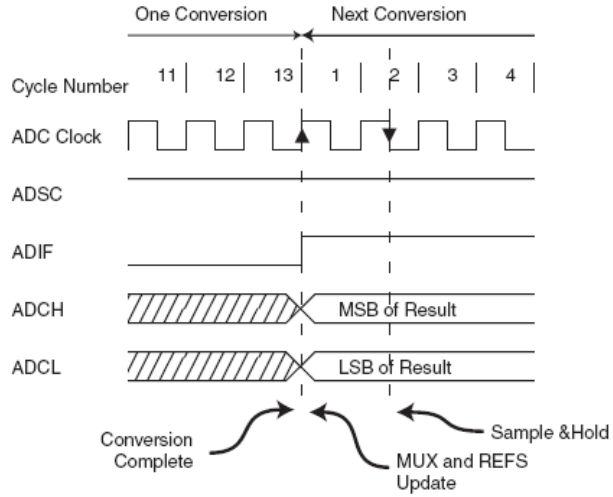
ADC Timing Diagram, First Conversion (Single Conversion Mode)



ADC Timing Diagram, Single Conversion



ADC Timing Diagram, Free Running Conversion



ADC Conversion Time

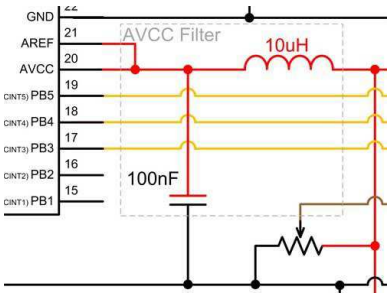
Condition	Sample & Hold (Cycles from Start of Conversion)	Conversion Time (Cycles)
Extended conversion	13.5	25
Normal conversions, single ended	1.5	13

ADC ใน ATMega168

AVCC

Atmega168 มีขาแหล่งจ่ายแรงดันอยู่ 2 ขา คือ VCC และ AVCC.

AVCC เป็นแหล่งจ่ายสำหรับ PC0-PC5 เมื่อทำเป็นขาอินพุทสำหรับสัญญาณ analog แหล่งจ่าย AVCC นี้ต้องการความเสถียรมาก ดังนั้นจะใช้ low pass filter ซึ่งประกอบด้วย inductor และ capacitor.



AREF

ขา AREF ใช้เป็นขาสำหรับแรงดันอ้างอิง ที่ 100% (เมื่อสัญญาณ analog เท่ากับค่านี้ จะได้ค่าดิจิตอลเท่ากับ 1024)

Analogue Input

Atmega168 มีขาสำหรับสัญญาณ analog อยู่ 6 ขา PC0 to PC5. – ขาเหล่านี้เป็นได้ทั้ง digital I/O และ analogue input

Registers

Atmega168 มีรีจิสเตอร์ที่ใช้งานเกี่ยวกับการแปลงสัญญาณอนาลอกอยู่ 6 ตัว

Register	Description
• ADMUX	ADC Multiplexer Selection Register
• ADCSRA	ADC Control and Status Register A
• ADCSRB	ADC Control and Status Register B
• DIDR0	Digital Input Disable Register 0
• ADCL	ADC Data Register – Low
• ADCH	ADC Data Register – High

ADMUX

The ADMUX register allows you to control:

- The Reference Voltage
- Left adjustment of results (used for 8 bit results)
- Selection of input channel

ADMUX – ADC Multiplexer Selection Register – ADMUX

Bit	7	6	5	4	3	2	1	0	
	REFS1	REFS0	ADLAR	–	MUX3	MUX2	MUX1	MUX0	ADMUX
Read/Write	R/W	R/W	R/W	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• **Bit 7:6 – REFS1:0: Reference Selection Bits**

These bits select the voltage reference for the ADC, as shown in Table 22-2. If these bits are changed during a conversion, the change will not go in effect until this conversion is complete (ADIF in ADCSRA is set). The internal voltage reference options may not be used if an external reference voltage is being applied to the AREF pin.

Table 22-2. Voltage Reference Selections for ADC

REFS1	REFS0	Voltage Reference Selection
0	0	AREF, Internal V_{ref} turned off
0	1	AV_{CC} with external capacitor at AREF pin
1	0	Reserved
1	1	Internal 2.56V Voltage Reference with external capacitor at AREF pin

ADMUX : ADLAR และ MUX3:0

• **Bit 5 – ADLAR: ADC Left Adjust Result**

กำหนดผลลัพทธ์การแปลง

1 = left adjust

0 = right adjusted

รายละเอียดดู “ADCL and ADCH – The ADC Data Register”

• **Bits 3:0 – MUX3:0: Analog Channel Selection Bits**

เลือกสัญญาณอินพุทที่ต้องการแปลง

Table 22-3. Input Channel Selections

MUX3:0	Single Ended Input
0000	ADC0
0001	ADC1
0010	ADC2
0011	ADC3
0100	ADC4
0101	ADC5
0110	ADC6
0111	ADC7
1000	
1001	
1010	
1011	
1100	
1101	
1110	1.30V (V_{BG})
1111	0V (GND)

Atmega168

เลือก 1.1 V หรือ 0 V

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• **Bit 7 – ADEN: ADC Enable**

1 = enables the ADC

0 = ADC is turned off ถ้า turnoff ในขณะแปลง การแปลงจะหยุด

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• **Bit 6 – ADSC: ADC Start Conversion**

แบบ Single Conversion mode

ให้บิตนี้เป็น 1 = สั่งให้เริ่มแปลง

แบบ Free Running mode

ให้บิตนี้เป็น 1 = start the first conversion. The first conversion จะเริ่มหลังจาก ADC enabled

เมื่อแปลงเสร็จบิตนี้จะเป็น 0

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• Bit 5 – ADFR: ADC Free Running Select

1 = ทำงานแบบ Free Running mode

ในโหมดนี้ จะแปลงต่อเนื่องไปตลอด

0 = หยุดการทำงานแบบ Free Running mode.

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• Bit 4 – ADIF: ADC Interrupt Flag

ถูกทำให้เป็น 1 เมื่อแปลงเสร็จและข้อมูลถูกส่งไปที่ ADCL/ADCH

ใช้เป็นบิตบอกให้เกิดการอินเตอร์รัพท์ (บิต I ใน SREG ต้องเป็น 1 ด้วย)

บิตนี้จะถูก clear เมื่อการอินเตอร์รัพท์ได้รับการตอบสนอง

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• Bit 3 – ADIE: ADC Interrupt Enable

1 = Enable

0 = Disable

When this bit is written to one and the I-bit in SREG is set, the ADC

Conversion Complete Interrupt

is activated.

ADCSRA – ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADFR	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

• Bits 2:0 – ADPS2:0: ADC Prescaler Select Bits

เลือกตัวหาร

Table 22-4. ADC Prescaler Selections

ADPS2	ADPS1	ADPS0	Division Factor
0	0	0	2
0	0	1	2
0	1	0	4
0	1	1	8
1	0	0	16
1	0	1	32
1	1	0	64
1	1	1	128

ADCL and ADCH – The ADC Data Register

ADLAR = 0

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	–	–	ADC9	ADC8	ADCH
	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADC1	ADC0	ADCL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R	
	R	R	R	R	R	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

ADLAR = 1

Bit	15	14	13	12	11	10	9	8	
	ADC9	ADC8	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADCH
	ADC1	ADC0	–	–	–	–	–	–	ADCL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R	
	R	R	R	R	R	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

ตัวอย่างโปรแกรมภาษา C

```
//----- Includes ------//
#include <avr/io.h>                 // AVR device-specific IO definitions
#include <avr/interrupt.h>          // Interrupt Service routine

#define F_CPU 8000000UL             // 8 MHz
#include <util/delay.h>         // header file implement simple delay loops

#include "lib_UART.c"                           // Use Module USART

#define Vadc      1024                          // 1024 (10-bit Resolution)

//----- delay_ms ------//
void delay_ms(uint16_t i)
{
   for (;i > 0; i--)
       _delay_ms(1);
}
```



```
int main(void)
{
    unsigned int adc;
    Init_Serial(96);   // Init Serial port

    ADMUX = (0<<REFS1)|(1<<REFS0); // AVCC with external capacitor at AREF pin
    ADCSRA = (1<<ADEN)|(0<<ADATE); // ADC Enable & Auto Trigger Disable
    ADCSRA |= (0<<ADPS2)|(1<<ADPS1)|(1<<ADPS0);      // XTAL/8

   while (1) {

      ADCSRA |= (1<<ADSC);                          // ADC Start Conversion
      while (!(ADCSRA &(1<<ADIF)))    // Wait Coversion completes
         ;
       adc = ADCW;                    // Read ADC
       printf("\fAnalog to Digital Converter (ADC) \ \nADC0: %d Voltage: %d.%d V", \
                                          adc,(adc*5)/Vadc,(adc*5)%Vadc);
      delay_ms(1000);                  // Delay 1s
   }

   return 0;
}
```


ฟังก์ชั่นเกี่ยวกับสัญญาณอนาล็อก ของ Arduino

- analogReference(type)
- analogRead()
- analogWrite() - PWM

analogReference(type)

Configures the reference voltage used for analog input (i.e. the value used as the top of the input range). The options are:

- DEFAULT: the default analog reference of 5 volts (on 5V Arduino boards) or 3.3 volts (on 3.3V Arduino boards)
- INTERNAL: an built-in reference, equal to 1.1 volts on the ATmega168 or ATmega328 and 2.56 volts on theATmega8 (*not available on the Arduino Mega*)
- INTERNAL1V1: a built-in 1.1V reference (*Arduino Mega only*)
- INTERNAL2V56: a built-in 2.56V reference (*Arduino Mega only*)
- EXTERNAL: the voltage applied to the AREF pin (**0 to 5V only**) is used as the reference.

analogRead()

Description

Reads the value from the specified analog pin. The Arduino board contains a 6 channel (8 channels on the Mini and Nano, 16 on the Mega), 10-bit analog to digital converter. This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023. This yields a resolution between readings of: 5 volts / 1024 units or, .0049 volts (4.9 mV) per unit. The input range and resolution can be changed using analogReference().

It takes about 100 microseconds (0.0001 s) to read an analog input, so the maximum reading rate is about 10,000 times a second.

Syntax

analogRead(pin)

ตัวอย่างโปรแกรมอ่านค่าอนาล็อกของ Arduino

```
int analogPin = 3;    // potentiometer wiper (middle terminal) connected
to analog pin 3       // outside leads to ground and +5V
int val = 0;          // variable to store the value read
void setup()
{
        Serial.begin(9600); // setup serial
}
void loop()
{
        val = analogRead(analogPin); // read the input pin
        Serial.println(val); // debug value
}
```


analogWrite() - PWM

analogWrite(pin, value)

Parameters

- pin: the pin to write to.

  กรณี atmega168 มี D3 D5 D6 D9 D10 และ D11

- value: the duty cycle: between 0 (always off) and 255 (always on).

ตัวอย่างสร้าง PWM ด้วย analogWrite

```
#define pwm_1 3
#define pwm_2 5
#define pwm_3 6
#define pwm_4 9
#define pwm_5 10
#define pwm_6 11

void setup()
{
  analogWrite(pwm_1, 10);
  analogWrite(pwm_2, 50);
  analogWrite(pwm_3, 100);
  analogWrite(pwm_4, 150);
  analogWrite(pwm_5, 200);
  analogWrite(pwm_6, 250);
 }

void loop()
{

}
```