DIGITAL COMMUNICATION

Today, with the development of communication technology, more modern digital communication systems are used instead of the communication systems with an amplitude modulation. Digital communication systems have superiorities in comparison to the analog systems. These are; processing convenience, multiplexing convenience and immunity to noise. Digital communication system is the transmission of data between two points with digital (numerical) pulses. The transmission setting between the two points could be conductive wires, coaxial cables, fiber optic cables or atmosphere.

Data in digital communication system is in analog form generally such as sound and image. The first thing that needs to be done for digital communication is the change of the data into digital pulses. They are sent by the transmitter as numerical pulses to the transmission setting. The receiver receives the data that is in numerical pulses from the transmission setting and turns them to analog data again by doing a reverse process.

There are various modulation processes to prepare the analog data for numerical communication setting. Each modulation has a unique demodulation system. Widely used digital communication systems are as follows.

1- PAM (**Pulse Amplitude Modulation**)
2- PCM (**Pulse Code Modulation**)
3- PWM (**Pulse Width Modulation**)
4- PPM (**Pulse Position Modulation**)
5- ASK (**Amplitude Shift Modulation**)
6- FSK (**Frequency Shift Modulation**)
7- PSK (**Phase Shift Modulation**)
8- QPSK (**Quadro Phase Shift Modulation**)
9- PAM (**Pulse Amplitude Modulation**)
10- PCM (**Pulse Code Modulation**)
11- DM (**Delta Modulation**)
12- FDM (**Frequency Division Multiplexing Modulation**)
13- TDM (**Time Division Multiplexing Modulation**)

No doubt, easily made and better working modulation systems will be added to these modulation systems in time.

Digital communication system in general is shown in Figure 4.1 as easily understood.

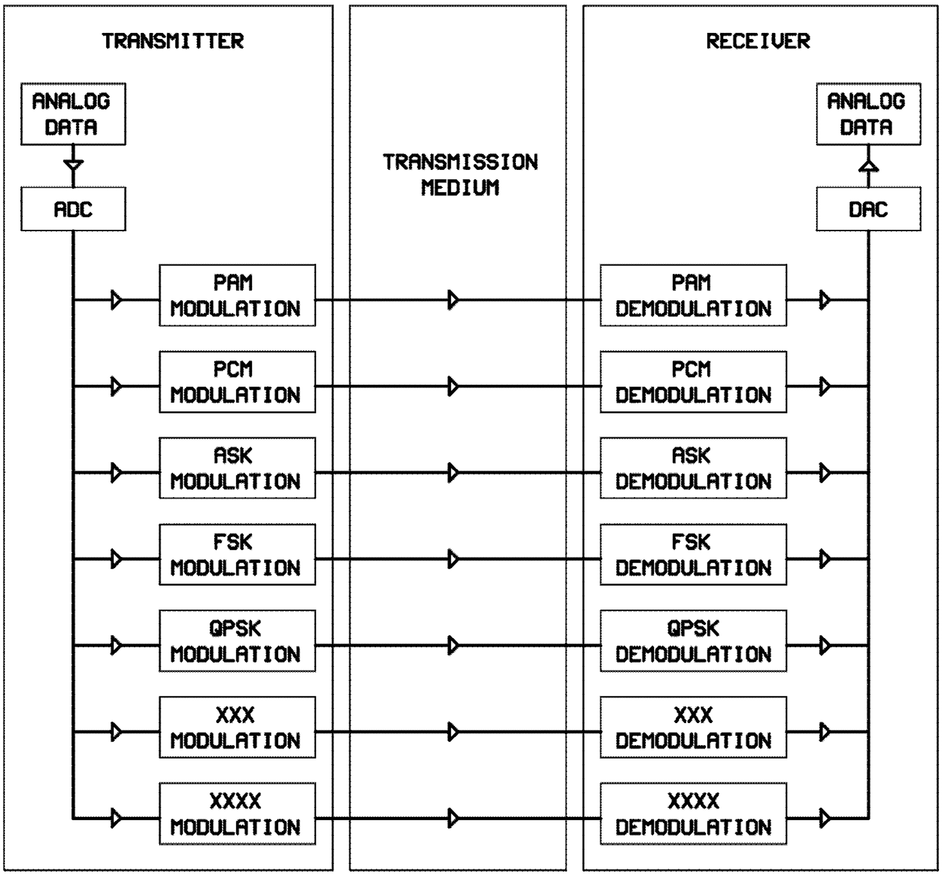


Figure 4.1

In the Figure, **"ADC"** is Analog Digital Converter and **"DAC"** is Digital Analog Converter.

As it is clear, analog data is changed into digital (numerical) data first and then it is modulated in a selected system and sent to the transmission setting. The receiver took this modulated system from the transmission setting and demodulated it and then turned it into analog data again.

EXPERIMENT 4.1
EXAMINATION OF ANALOG DIGITAL CONVERTER (ADC) (ADC 0804)

Values that a variable can take starts from 0 to 1 and if the mid values such as **"0,1-0,2....0,9"** are measured by a voltmeter, Ampere meter or similar device, this variable is an analog signal. If this variable is taking only 0 and 1 values, in other words, if there are no mid values, this variable is a digital (numerical) signal. If a device or a circuit is changing the analog signal into a digital signal, such a device or circuit is called **ADC Analog Digital Converter**. Analog Digital Converters decrease the noise effect. Digital signals are coded easily and stored easily.

A characteristic curve of a 3-bit analog digital converter is shown in Figure 4.1.1.

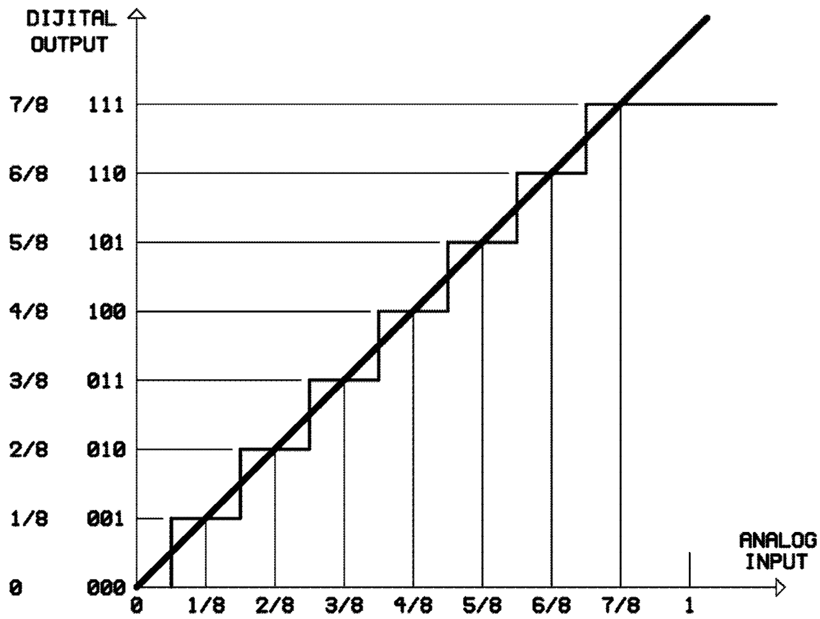


Figure 4.1.1

Analog input is between 0Volt and 1Volt. The input signal can be expressed for 3 bits as $2^3=2x2x2=8$ pieces or intervals. All analog values at each interval are shown by using the same dual codes. During analog conversion, the sub value of a value at the middle point of each interval is sensed as 0, and upper value is sensed as 1. If analog values are right in the middle of the interval or piece, it appears as a point that is not understood what to be in the dual coded system.

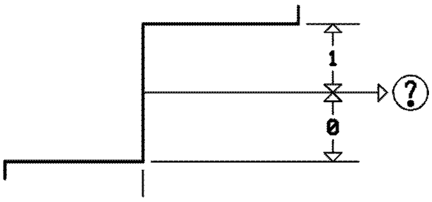


Figure 4.1.2

The uncertainty point is shown in Figure 4.1.2. This situation is called Quantization uncertainty or error. The quantization error is as much as ±0,5 low value bit (**LSB Least Significant Bit**). When the low value bit changes, the result means the least effective bit. The quantization error is decreased by increasing the bit number of analog digital converter. The quantization value **Q** is the voltage value that could lead to the change of low value bit (**LSB**). As a formula;

$$Q = \frac{FS}{2^n - 1} = \frac{1}{2^n}$$

In the formula;
n = Bit count
FS= Full Scale voltage value

During analog digital conversion, different methods are used. Some of these methods are stairs (**Digital Ramp**) type ADC, Flash ADC, **Tracking** ADC and **Successful approximation** ADC.

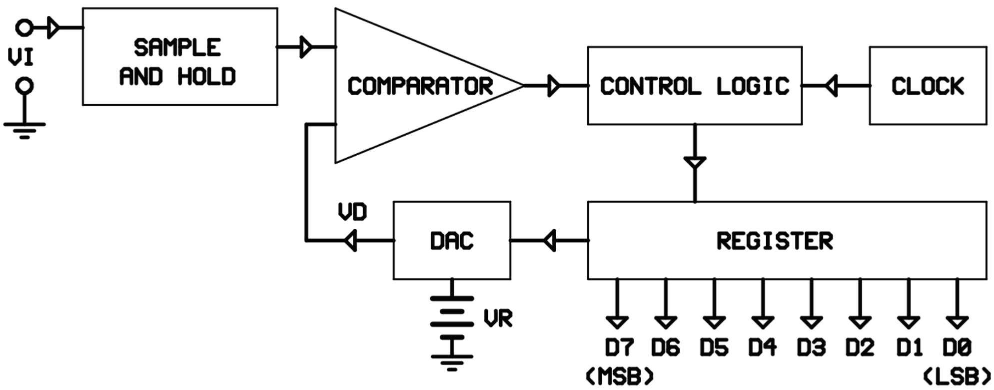


Figure 4.1.3

In Figure 4.1.3, a block scheme of a successful approximation ADC **(ADC 0804)** with an 8 bit resolution is shown. During circuit conversion, **SH Sample and Hold** prevents changing of input signal. **Control Logic** adjust the bits starting from the least significant bit (LSB) until the highest significant bits MSB (Most Significant Bit) (**D0-D1-D2-D3-D4-D5-D6**) to "0", and the highest significant bit (D7) to "1". This digital data is applied to the Digital Analog Converter (DAC) which is situated in ADC 0804 integration. At the same time, a reference voltage (VR) is applied from outside to the digital analog converter.

The output voltage (VD) of the digital analog converter as a formula is as follows;

$$VD = 2^{n-1}.Q \;=\; 2^{n-1}.\frac{VR}{2^n} = \frac{1}{2}VR$$

As it is clear, VD voltage is as half as the reference voltage. If the input voltage (VG) is larger than VD, its highest significant bit (D7) is "1", if it is smaller it becomes "0". After this, D6 bit is made "1", and a new VD is obtained at the output of the digital analog converter. The new obtained VD and the input voltage is compared by **Comparator**. If input voltage (VI) is larger than the new obtained VD, D6 bit becomes ", if it is smaller it becomes 0. The same process is done until D0 bit in turn. At the end of the procedures, all digital outputs from D7 bit until D0 bit are obtained.

ADC 0804 is integration with 8 bit resolution and single channel and 20 pins. The supply voltage is between 5V DC and analog input voltage interval 0-5V DC.

It has 15mW power spending and 100µS (**Micro Second**) conversion time. Since this integration has 8 bit resolution, there is 2^8=256 quantization interval.

If we accept the reference voltage 5V as a quantization error, 5V/256=0.0195V. This means that the error of ADC 0804 integration error is ±1 LSB=0.0195V. This includes full interval error, offset error and nonlinearity error. In Figure 4.1.4, pin connection of ADC 0804 is shown.

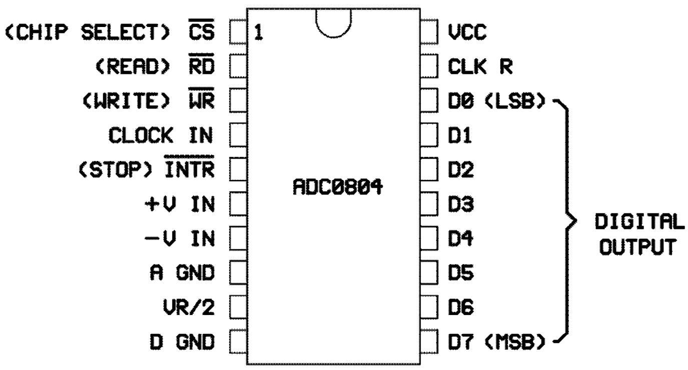


Figure 4.1.4

ADC 0804 integration can generate the required clock sign itself inside. For this, it is necessary that a resistor is connected between pins CLKR and CLKIN and a condenser needs to be connected from CLKIN to "0".

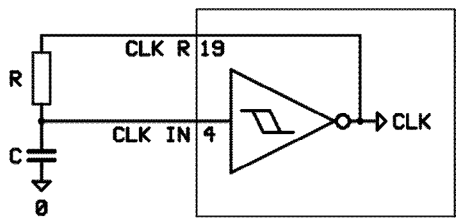


Figure 4.1.5

Clock frequency as a formula;

Fclk= $\frac{1}{1.1.R:C}(Hz)$

In the formula **"R"** is ohm, **"C"** is farad. The frequency of the clock sign that can be generated by ADC 0804 is 100KHz-800KHz. In its inner structure there is also Schmitt-Trigger as shown in Figure 4.1.5.

WR′ is writing control signal. When CS′ and WR′ becomes **"0"**, **CLEAR** process is carried out. When WR′ is taken back to **"1"**′ (**ADC 0804 accepts empty pin sign as "1"**) and analog-digital conversion starts. During the conversion INTR′ is in **"1"** position. When the conversion is completed, INTR′ goes back to **"0"**′. ADC 0804 integration has two GND pins. These are analog ground (**AGND**) and digital ground (**DGND**). Pin no. **"9"** must be as half as the reference voltage. In our experiment circuit, the resource voltage of +5V DC is used as a reference voltage.

In this case, no. **"9"** pin voltage must be made 5/2=2,5V. When reference voltage is 5V DC, each step will be 5V/2560.0195V, therefore;

00000000 (**00H**) 0.00V
11111111 (**11F**) 4.9805V

EXPERIMENTAL PROCEDURE

Mount Y-0024/004 module into its place. Make the circuit connections as shown in Figure 4.1.6.

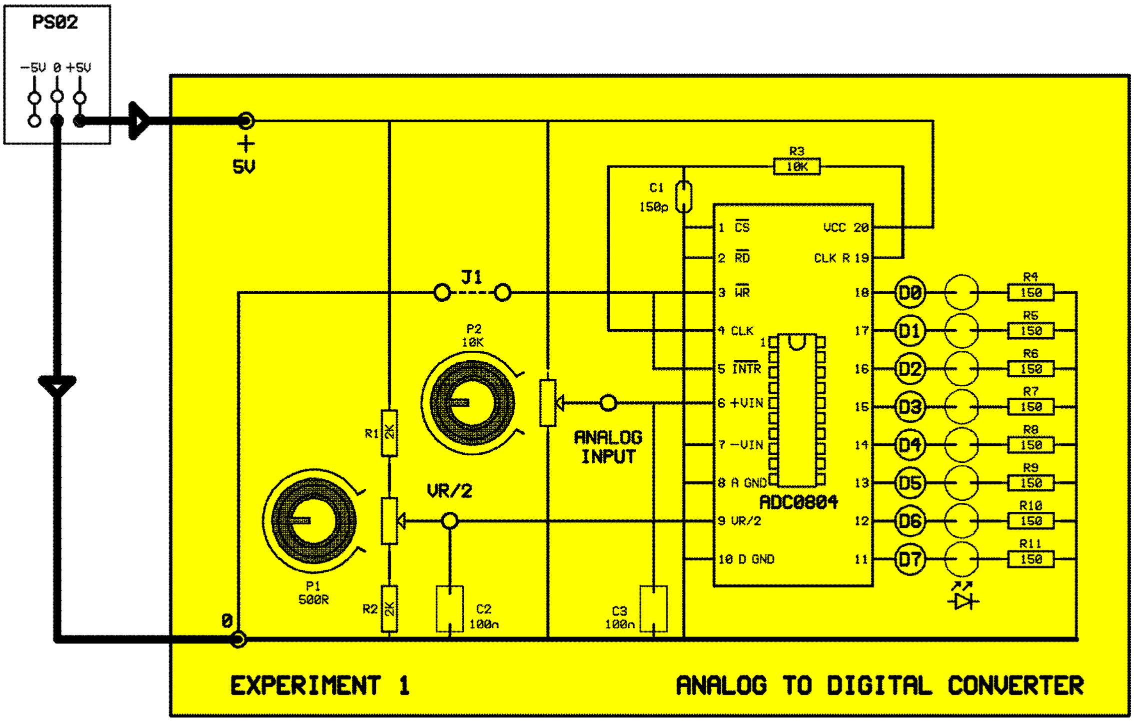


Figure 4.1.6

LEDs are used for digital outputs. When the diodes are on, it is "1", when they are off, it is "0". R4-R11 resistors are the loads of LEDs. In order to obtain a right result, for VR/2 voltage, use a Digital Voltmeter.

1- Adjust P1 as VR/2=2.5V DC by P1 potentiometer. In this case, which analog voltage value is converted into digital values by the analog digital converter?

*The analog voltage that could be applied in this case can change analog values to digital values in the interval of **"0"** and VR voltage (**5V DC**).*

2- Adjust the analog input pin voltage "0"V by using a digital voltmeter with P2 potentiometer. Do the J1 points short circuit for a moment and open up the short circuit. See what happened to the digital outputs and interpret.

*Doing short circuit and opening again of J1 points enables the deletion of the data that remains before at the outputs (**D0....D7**). LEDs that were on became off when J1 is made short circuit and opened again. It was enabled that when analog input voltage was "**0**" all outputs turned off, in other words, digital outputs became "**0**".*

3- Adjust the analog input voltage to the values given in Figure 4.1.7 by P2 potentiometer in a row. Record the value you read at each step to the table. The ideal values that need to be are shown in the middle section in the table. Compare the values you obtained with the ideal values.

ANALOG INPUT V (VOLT)	IDEAL DIGITAL VALUE (BINARY DIGITS)	THE DIGITAL VALUE THAT IS READ (BINARY DIGITS)
0.0	0000 0000	0000 0000
0.5	0001 1010	0001 1010
1.0	0011 0011	0011 0101
1.5	0100 1101	0100 1101
2.0	0110 0110	0110 0111
2.5	1000 0000	1000 0000
3.0	1001 1010	1001 1010
3.5	1011 0011	1011 0100
4.0	1100 1101	1100 1101
4.5	1110 0110	1110 0111
5.0	1111 1111	1111 1111

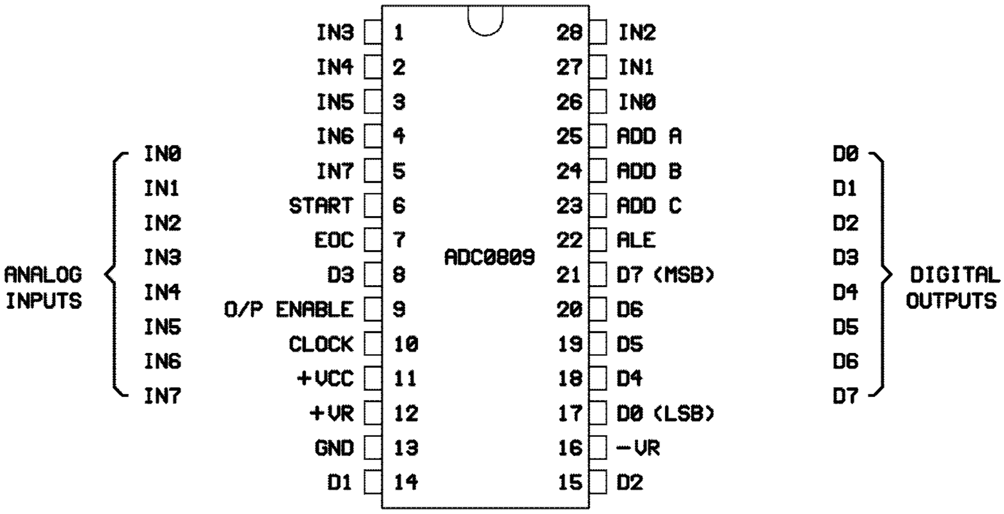
Figure 4.1.7

The values that are obtained are approximately the same as the ideal values. In some values there is a difference of ± 1 LSB.

EXPERIMENT 4.2
EXAMINATION OF ANALOG DIGITAL CONVERTER (ADC) (ADC 0809)

PREPARATION DATA

ADC 0809 is analog digital converter integration with 8 bit resolution and 8 channel multiplexer and 28 pins. The reason it is called 8 channels is because there are 8 analog input pins. Power usage is 150mW. It works at a clock frequency between 10KHz-1280KHz. There is 100μS (**microsecond**) of conversion time at 680KHz clock frequency. Analog input voltage can be applied at an interval of 0-5V DC to ADC 0809 integration by 5V DC power supply. Since its resolution is 8 bits, the quantization step is 2^8=256 and its quantization value is 5/256=0.0195V. As we know, this value is the non-adjustable error value and is equal to ±1 LSB (**least significant bit**).



Analog

Figure 4.2.1

Figure 4.2.1 shows the pin connections of ADC 0809 integration. Pins no.26-27-28-1-2-3-4-5 are the input pins from IN0 till IN7. Separate analog values can be applied from each of the input pins. The pins no.17-14-15-8-18-19-20-21 are numerical output pins from D0 till D7. The input pin for the read value at the numerical output pins selects the position(**ADD A-ADD B-ADD C**) of pin no. 25-24-23. The pins no. 23-24-25 show the numberical data with 3 bits. Pin no. **"25"** is the least valuable pin (**ADD A**) and pin no. **"23"** is the most valuable pin (**ADD C**). In Figure 4.2.2, the input pins that are selected according to the position ADD A- ADD B- ADD C in the table are shown.

+5 VDC=1,GROUND=0			INPUT PIN TO BE READ
ADD C (PIN 23)	ADD B (PIN 24)	ADD A (PIN 25)	
0	0	0	IN0
0	0	1	IN1
0	1	0	IN2
0	1	1	IN3
1	0	0	IN4
1	0	1	IN5
1	1	0	IN6
1	1	1	IN7

Figure 4.2.2

A clock sign must be applied to ADC 0809 integration for conversion. Pin no.10 is the input pin of the clock sign. Pin no. **"12"** must be connected to the positive end of +VR (**positive reference voltage**) source, and pin no. **"16"** must be connected to the negative end of -VR (**negative reference voltage**) source.

ADC 0809 integration can be connected to a microprocessor easily. Pin no. **"6"** (**START**), pin no. **"7"** (**EOC communication end**), pin no. **"9"** (**OE output open**) and pin no. **"22"** (**ALE address receiving open**) are used in the control of data conversion clock signs of microprocessor. If an input with multichannel is used, ADD A-ADD B-ADD C- ALE and START ends are used as free or as connected to +Vcc resource voltage.

EXPERIMENTAL PROCEDURE

Mount Y-0024/004 module to its place. Make the circuit connections as shown in Figure 4.2.3.

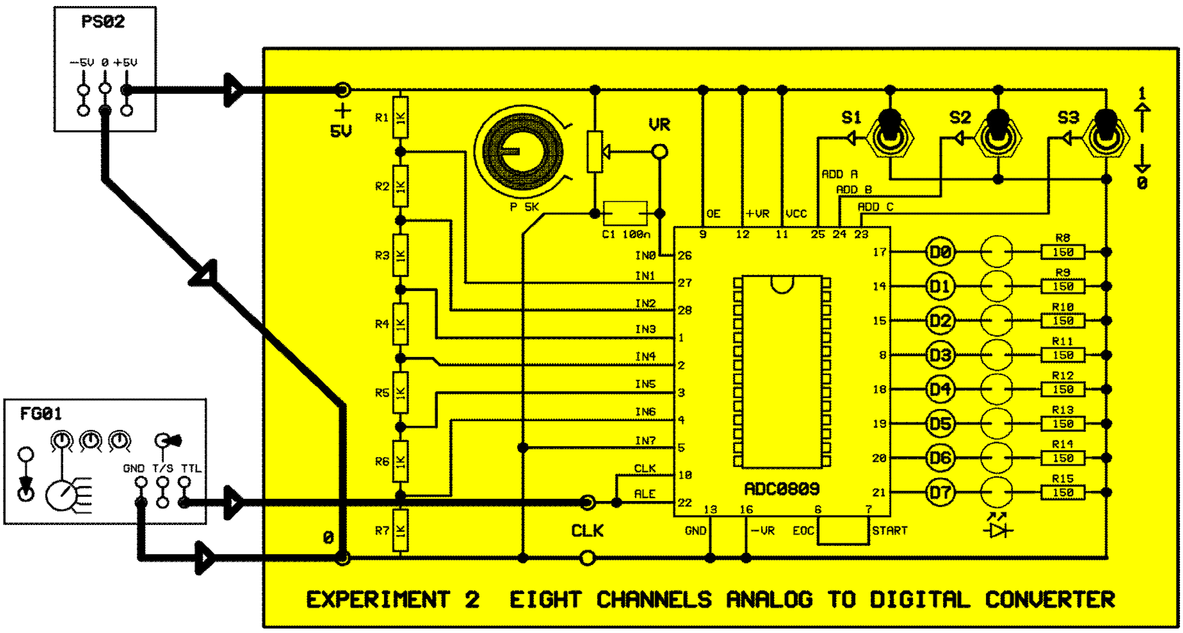


Figure 4.2.3

The circuit is applied to EOC output signal's START input and arranged as the clock signal is applied to ALE and CLOCK ends. The situation of LED diodes to be 'on' at the ends of the digital output pins shows that digital is "1", and 'off' status shows that digital is "0". R8-15 resistors are LED load resistors.

1- Adjust S1,S2 and S3 keys to **"0"** position. Which analog entries, numerical outputs does this situation show?

*Keys S1, S2 and S3 at **"0"** position show the analog voltage value at **"IN0"** input.*

2- Apply a square wave with %5V DC amplitude and 100KHz frequency to the clock input. Adjust the voltage at VR point by "P" potentiometer according to the ground by using a digital Voltmeter in turn to the values in Figure 4.2.4. Write down the numerical values that you read at each step to the table. The ideal values that need to be are shown in the Table in the middle section. Compare the values you obtained with the ideal values.

ANALOG INPUT V (VOLT)	IDEAL DIGITAL VALUE (BINARY DIGITS)	THE DIGITAL VALUE THAT IS READ (BINARY DIGITS)
0.0	0000 0000	0000 0000
0.5	0001 1010	0001 1010
1.0	0011 0011	0011 0100
1.5	0100 1101	0100 1101
2.0	0110 0110	0110 0111
2.5	1000 0000	1000 0001
3.0	1001 1010	1001 1010
3.5	1011 0011	1011 0110
4.0	1100 1101	1100 1110
4.5	1110 0110	1110 0111
5.0	1111 1111	1111 1111

Figure 4.2.4

In some steps, voltage is read with ±1 LSB error.

3- Adjust VR=5V DC by P potentiometer. Adjust the keys S1, S2 and S3 to the positions seen in Figure 4.2.5 in turn. At which input the analog value is read at each step? Write down the analog input voltage and numerical value at the relevant input on the table.

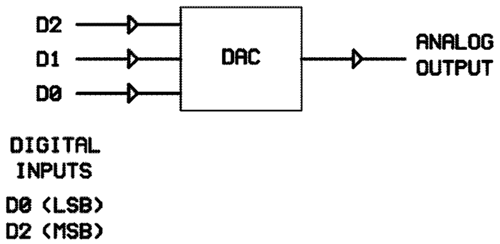
+5 VDC=1,GROUND=0			INPUT PIN TO BE READ	THE ANALOG VOLTAGE SEEN (VOLT)	THE DIGITAL VALUE SEEN
ADD C S3(MSB)	ADD B S2	ADD A S1(LSB)			
0	0	0	IN0	5.00	1111 1111
0	0	1	IN1	4.29	1101 1011
0	1	0	IN2	3.57	1011 0111
0	1	1	IN3	2.86	1001 0010
1	0	0	IN4	2.14	0110 1110
1	0	1	IN5	1.43	0100 1001
1	1	0	IN6	0.71	0010 0101
1	1	1	IN7	0.00	0000 0000

Figure 4.2.5

EXPERIMENT 4.3
UNIPOLAR DIGITAL ANALOG CONVERTER
(DAC 0800)

PREPARATION DATA

Devices or circuits that change digital signals to analog signals are called (**DAC**) . Figure 4.3.1 shows a block scheme and correction table of a digital analog converter having 3 bit digital input. 3 bit indicates 2^3=8 dual group. The dual group number is called step number.



DIGITAL INPUTS			ANALOG OUTPUT
D2	D1	D0	
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

Figure 4.3.1

The circuit generates a certain output current or voltage for each input value. The change in the output value for two consecutive input data is called step value or input weight. If we take a look at the step value in the correction table, when the input is “000”, the output is “0”, and when the following input is “001”, the output is “1”, therefore the change in the output sign in other words step value is 1-0=1.

Output sign “VO” of digital analog converters;

VO=Step value, step number.

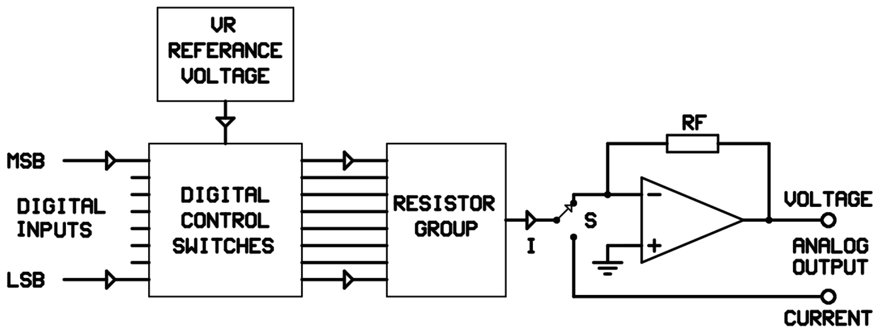


Figure 4.3.2

Figure 4.3.2 shows the structure of digital analog converter. If the resistor group output signal is to be used as current, no other component is necessary.

If resistor group output signal is to be used as current, an operational amplifier circuit (Op-Amp) that is arranged as a collector is needed.

Digital analog converters are examined in two groups according to the connections of the resistor group.

1- WEIGHTED RESISTORS DAC:

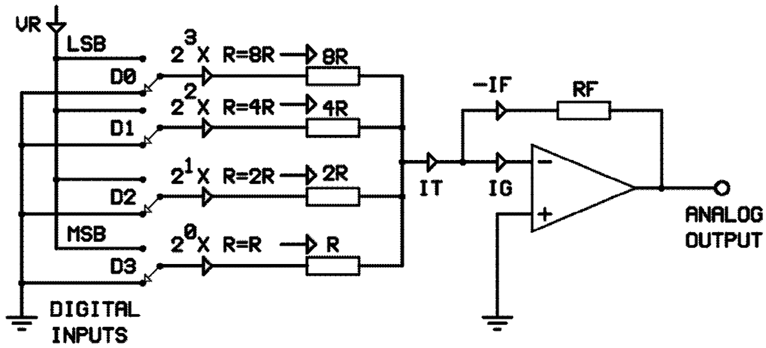


Figure 4.3.3

Figure 4.3.3 shows a digital analog converter with 4 bit nominal resistor. The essence of the circuit is collector operational amplifier circuit. For the highest value bit (MSB), if a resistor in the value of an "R" is used, the resistor values necessary for other entries becomes "2^n.R". Here "n" is the step number of variable. Since the step number of the highest value bit is "0" and the circuit number of the lowest value bit is 4 bit, it is "3". Each input is applied to resistors of different values. The input number obtained in a 4 bit circuit is the dual group 2^4=2.2.2.2=16. According to this, the output signal will be "16" analog value that is folds of each other. In order to obtain correct result in the nominal resistor digital analog converter, all resistors must be without tolerance. Nominal resistor digital analog converters are not used much.

2- R-2R RESISTOR LADDER TYPE DAC:

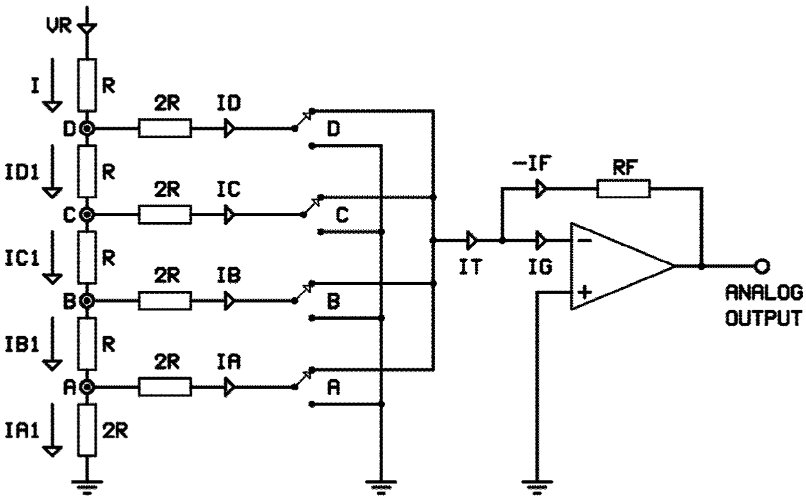


Figure 4.3.4

R-2R stairs type digital analog converters are used the most. Figure 4.3.4 shows a 4 bit "R-2R" type digital analog converter. It is clear that the resistor value that is used is only two types. That is why it is called "R-2R".

The maximum numerical value is applied to the converter at "D" point. The numerical value at "C" point is half of the "D" point, and the numerical value of "B" point is half of "C" point, and numerical value of "A" point is half of "B" point.

The numerical value at each knot point is half of the previous one. According to this, the reference resistor (VR) reaches the operational amplifier at "D" knot at the ratio of "1", at "C" knot point at the ratio of "1/2", at "B" knot point at the ratio of "1/4" and at "A" knot point" at the ratio of "1/8".

The currents that leave from each knot point are equal to one another.

ID=ID1, IC=IC1, IB=IB1 and IA=IA1

Since the input impedance of operational amplifier is high, if we accept the input current as "IG=0", the total current will be IT=-IF=ID+IC+IB+IA

In this case, the output voltage (**VO**);

VO=-IF.RF

If we call the voltages at each knot point **"VD-VB-VA",** and write down the branch currents;

$$ID = \frac{VD}{2R}, IC = \frac{VC}{2R}, IB = \frac{VB}{2R}, IA = \frac{VA}{2R}$$

According to this, output voltage is;

$$VO = -\left(\frac{VD}{2R} + \frac{VC}{2R} + \frac{VB}{2R} + \frac{VA}{2R}\right).RF$$

$$VO = \left[\frac{1}{2R}(VD + VC + VB + VA)\right].RF$$

If we accept the voltage at **"D"** knot point as VD=VR, voltages at other knot points as VR;

$$VD = VR, VC\frac{VR}{2}, VB = \frac{VR}{4}, VA = \frac{VR}{8}$$

When we place these values in the output voltage formula;

$$VO = -\left[\frac{1}{2R}\left(VR + \frac{VR}{2} + \frac{VR}{4} + \frac{VR}{8}\right)\right].RF$$

When the denominators within the parenthesis are equalized;

$$VO = -\left[\frac{1}{2R}\left(\frac{8VR + 4VR + 2VR + VR}{8}\right)\right].RF$$

$$VO = -\left[\frac{1}{2R}.\frac{1}{8}(8VR + 4VR + 2VR + VR)\right].RF$$

$$VO = -\left[\frac{1}{16R}.(8VR + 4VR + 2VR + VR)\right].RF$$

If we determine the reference voltages (VR) factors within parenthesis to be at which knot point, it is seen digitally how much and which bit affects the output voltage.

$$VO = -\left[\frac{1}{16R}\left(8D.VR + 4C.VR + 2B.VR + A.VR\right)\right].RF$$

If we pull "VR" from the parenthesis;

$$VO = -\left[\frac{1}{16R}.VR\left(8D + 4C + 2B + A\right)\right].RF$$

$$VO = \frac{VR.RF}{16R}\left(8D + 4C + 2B + A\right)$$

The values within parenthesis are digital values. The output voltage is the multiplication of the input bits with the sum of logic situations – VR.RF/16R.

The integration circuits that do digital analog conversion process are used often. DAC 0800 integration is a digital analog converter that is made by "R-2R" method, operating between 8 bit ±4.5V DC and ±18V DC, and consuming 33mW power at ±5V DC, and doing the conversion process with 85nS (nanoseconds) time delay.

Figure 4.3.5 shows the pin connection of DAC 0800 integration.

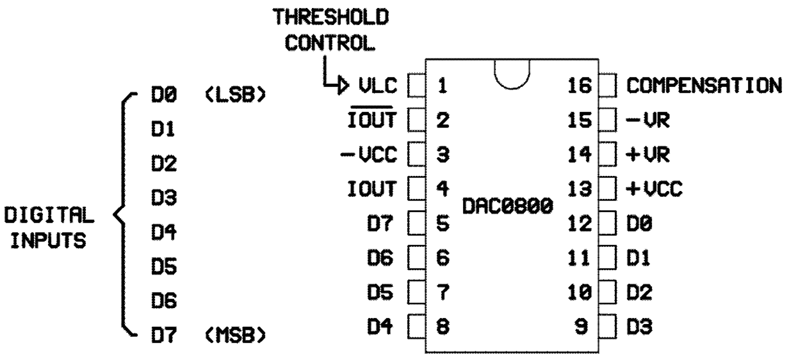


Figure 4.3.5

"Pin no. 14" is the pin where **+VR"** positive reference voltage will be applied. In DAC 0800 integration, +VR=5V DC. **"15"** no. **"-VR"** pin no. "15" should be connected to the ground by a resistor. Figure 4.3.6 shows an application circuit.

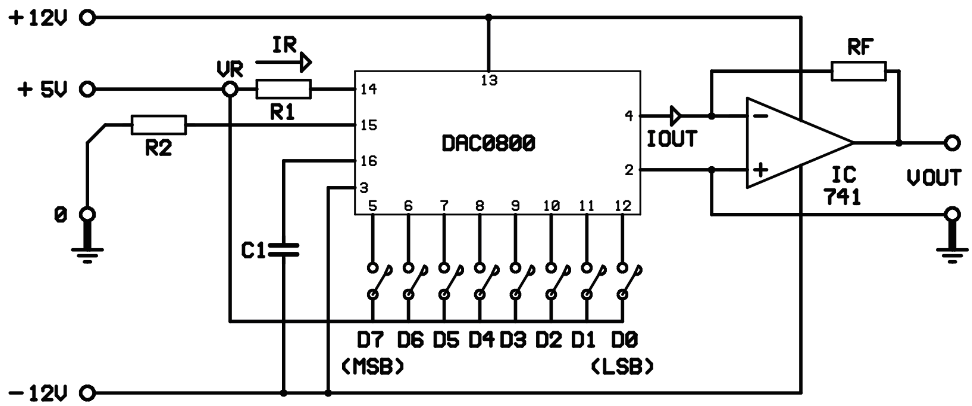


Figure 4.3.6

The voltage obtained at the output has a single pin. In other words, output voltage is always positive according to the ground. Therefore such connections are called UNIPOLAR. The reference current (IR) going through R1 resistor as a formula;

$$IR = \frac{VR}{R1}$$

The output current (IOUT) that could be drawn from pin no.**"14"** is as a formula;

$$IOUT = \frac{VR}{R1}\left(\frac{D7}{2} + \frac{D6}{4} + \frac{D5}{8} + \frac{D4}{16} + \frac{D3}{32} + \frac{D2}{64} + \frac{D1}{128} + \frac{D0}{256}\right)$$

D7-D6-D5-D4-D3-D2-D1-D0 are the voltage values of the connected pin according to the ground. Operational amplifier where current output is applied is used to convert the current output to voltage output.

Output voltage (VO) of the circuit as a formula;

VO=IOUT.RF

EXPERIMENTAL PROCEDURE

Mount Y-0024/004 module to its place. Make the circuit connections as shown in Figure 4.3.7.

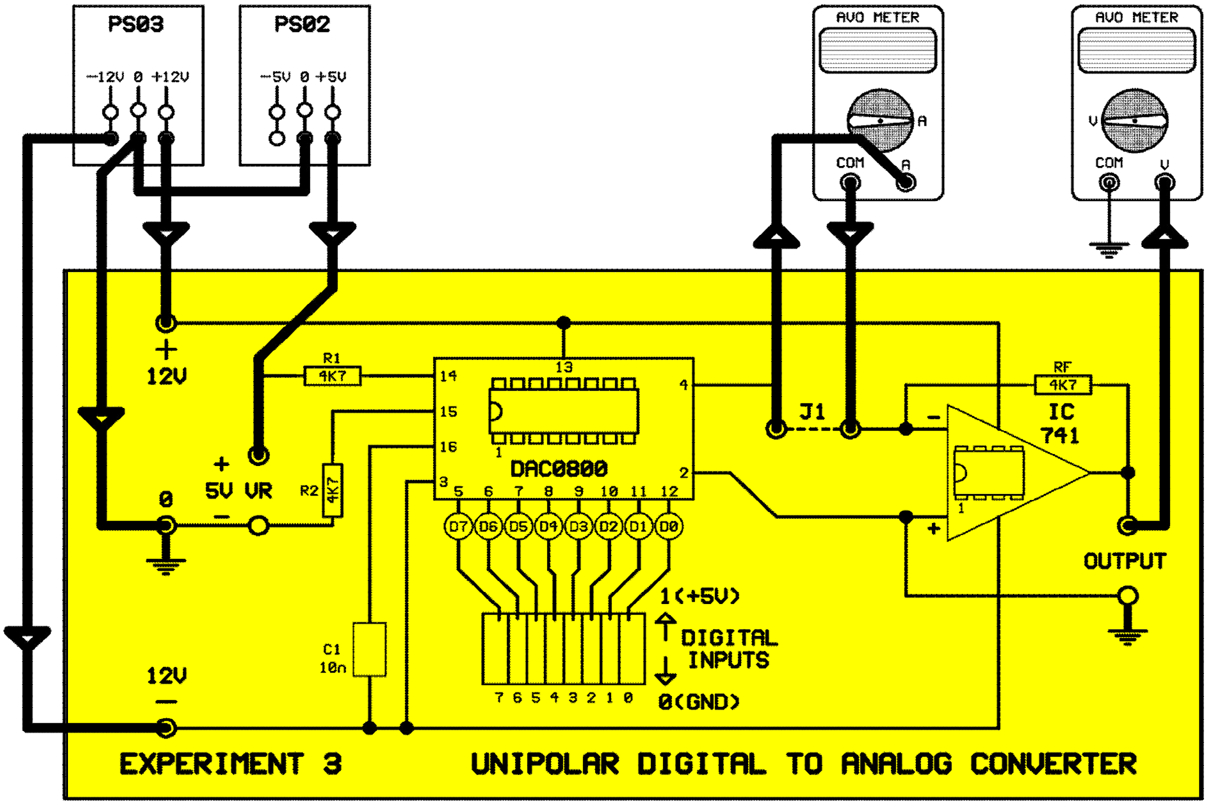


Figure 4.3.7

1- Since DAC 0800 has an 8 bit resolution, calculate the step number, and if the reference voltage is +5V, calculate the step interval.

Step number= 8bits =2^8 *=256*

Step interval=$\frac{5}{256}$ *=0,019 Volt*

2- Connect a Digital Ampere meter between J1 points, and a Voltmeter between the output pins. Adjust D0-D7 digital input keys in turn to the positions in Figure 4.3.8. Write down output current and output voltage for each step.

DIGITAL INPUTS								VO (VOLT)	IOUT
D7	D6	D5	D4	D3	D2	D1	D0		
0	0	0	0	0	0	0	0	0.000	0 00
0	0	0	0	0	0	0	1	0.197	3µA
0	0	0	0	0	0	1	0	0.390	13µA
0	0	0	0	0	1	0	0	0.078	20µA
0	0	0	0	1	0	0	0	0.156	30µA
0	0	0	1	0	0	0	0	0.312	64µA
0	0	1	0	0	0	0	0	0.624	132µA
0	1	0	0	0	0	0	0	1.25	267µA
1	0	0	0	0	0	0	0	2.50	530µA
1	1	1	1	1	1	1	1	4.98	1mA

Figure 4.3.8

EXPERIMENT 4.4
EXAMINATION OF BIPOLAR DIGITAL ANALOG CONVERTER (DAC 0800)

PREPARATION DATA:

If DAC 0800 digital analog converter's two current output pins (pin no. 2 and 4) are applied simultaneously to the input of an operational amplifier, two polar outputs are obtained at the output of the operational amplifier in other words positive and negative voltage values are obtained according to the ground. Therefore such a circuit is called bipolar (double polar or without a polar) converter.

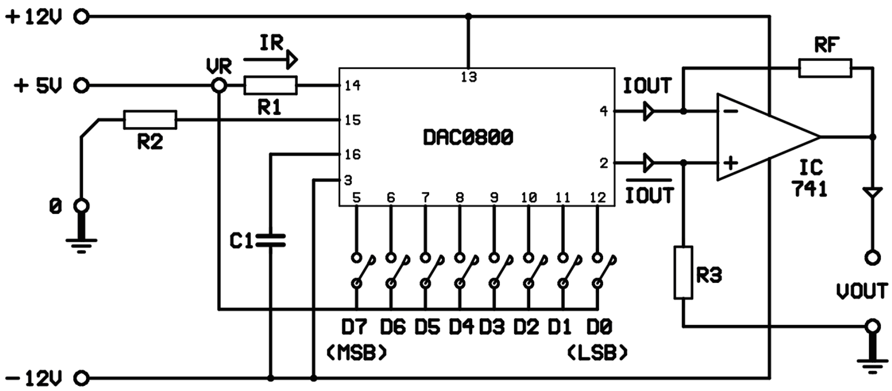


Figure 4.4.1

Figure 4.4.1 shows the bipolar application circuit of DAC 0800 integration. The voltage value that is obtained at the output:

VO=±VR=2VR=±5=10 Volt

As we already know, DAC 0800 integration has an 8-bit resolution. According to this, the step number is:
2^8=256. When step interval is calculated, the voltage interval that is obtained at the output is taken as the basis.

According to this, the step interval: 10/256=0.038'dir.
Output voltage of operational amplifier is as a formula;

VO=(IOUT-IOUT').RF

Here IOUT and IOUT are complementary output currents. IOUT+IOUT' full scale current value is **"IFS"**. If IOUT=IFS, IOUT'=0. Or if IOUT'=IFS, IOUT=0. Maximum value of the output voltage is positive (**+**) VO=IFS.R4. Minimum value of output voltage is negative (**-**) VO=IFS.R4.

EXPERIMENTAL PROCEDURE

Mount Y-0024/004 module to its place. Make the circuit connections as in Figure 4.4.2.

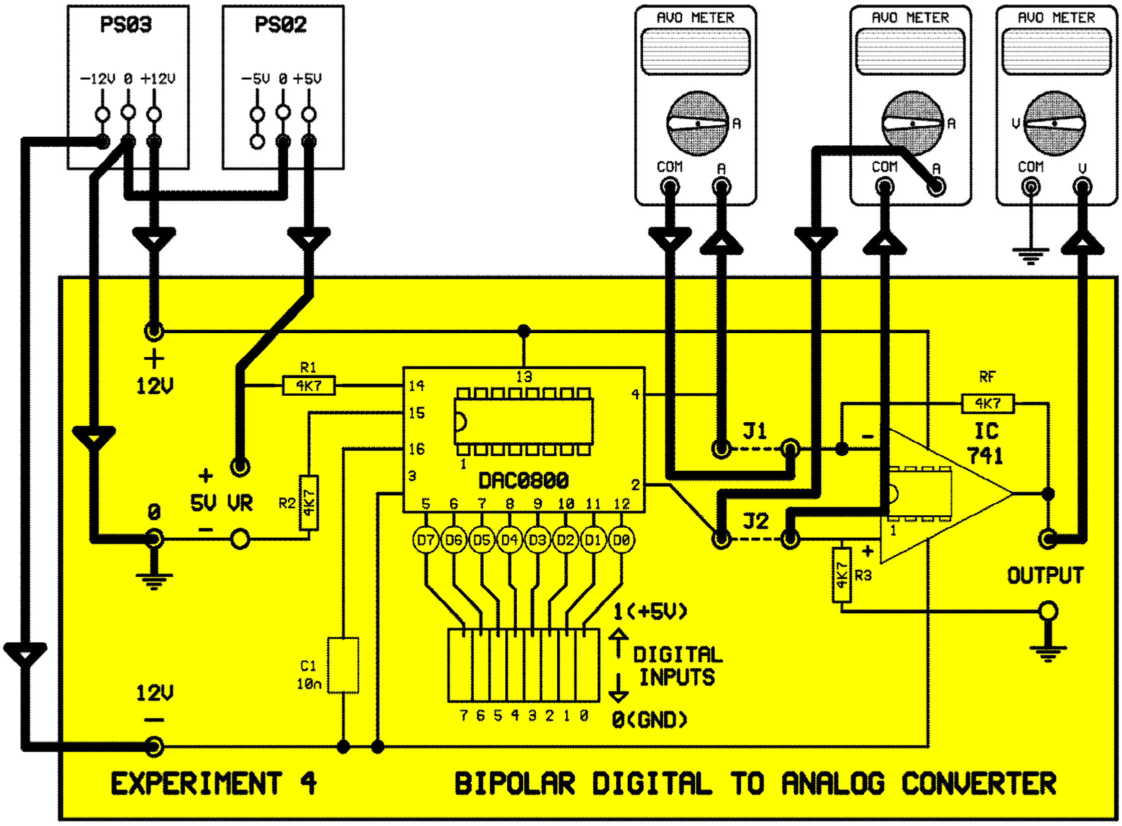


Figure 4.4.2

1- DAC 0800 bipolar digital is doing analog conversion, and if the reference voltage is +5V, calculate the step interval.

Step interval$=\frac{2VR}{2^8}=\frac{10}{256}=0.038$ *Volt*

2- Connect a digital Ampere meter at each J1 and J2 points and connect a digital voltmeter at the output pins. Adjust D0-D7 digital input keys to the positions shown in Figure 4.4.3 in turn. Write down output currents and output voltages for each step.

DIGITAL INPUTS								VO (VOLT)	$\overline{\text{IOUT}}$ (mA)	IOUT (mA)
D7	D6	D5	D4	D3	D2	D1	D0			
0	0	0	0	0	0	0	0	−5.00	1.062	0.000
0	0	0	0	0	0	1	0	−4.94	1.060	0.004
0	0	0	0	1	0	0	0	−4.70	1.030	0.033
0	0	1	0	0	0	0	0	−3.76	0.930	0.134
1	0	0	0	0	0	0	0	+0.008	0.530	0.536
1	0	0	0	0	0	1	0	+0.086	0.515	0.540
1	0	0	0	1	0	0	0	+0.322	0.494	0.560
1	0	1	0	0	0	0	0	+1.26	0.400	0.670
1	1	0	0	0	0	0	0	+2.50	0.266	0.800
1	1	1	1	1	1	1	1	+4.95	0.000	1.060

Figure 4.4.3

3- Calculate IFS values at each step and interpret the result.

IFS DAC 0800 is complementary output currents of the digital analog converter. As a formula: IFS=IOUT+IOUT' ~ 1.060mA
It can be said that it is equal to one another at each step.