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Exercise Book

FUNDAMENTAL OF ELECTRONICS SYSTEM

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LIM TIAN PAU
NORMAWAR
NURUL ADILLAH ARIFFIN

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Lim, Tian Pau

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Nurul Adillah Ariffin.

**EXERCISE BOOK****FUNDAMENTAL OF ELECTRONICS SYSTEM**

LIM TIAN PAU**NORMAWAR****NURUL ADILLAH ARIFFIN****PUBLISHER**

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PREFACE

This Fundamental of Electronics System covers three courses offered by the Polytechnic Department, Ministry of Education Malaysia. The three courses are Electronic System, Digital System and Power Electronics. This book is written specifically for exercise on each courses mention according to the latest syllabus prepared by the Polytechnic Department, Ministry of Education Malaysia.

This book is divided into 10 main topic which is covers most of the sub-skills in the syllabus of the three courses. To consolidate students learning, we also provide a basic explanation of the main topic before start the exercises.

We are happy to receive any comments and suggestions to improve the quality of this book. We hope that this book can be beneficial to the students and educationist. We wish you a pleasant study experience.

Lim Tian Pau

- Semiconductor
- Amplifier And Oscillation Circuit
- DC Converter

Normawar

- Semiconductor
- DC Converter
- AC Converter
- Electrical Driver – DC Machine Control & AC Machine Control

Nurul Adillah Ariffin

- Number System and Code System
- Boolean Operation
- Sequential Logic
- Counter, Register & Converter

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1

SEMICONDUCTOR

The electrical resistivity of a good conductor like copper or silver is very small, while that of an insulator is very large. For an example, the resistivity of silver is $1.6 \times 10^{-8} \Omega$ and that of quartz is about $10^{12} \Omega$. A semiconductor is a solid material whose electrical resistivity is higher than a conductor and lower than an insulator. It is possible to manufacture a single piece of a semiconductor material either Germanium or Silicon on half which is doped by *P*-type impurity and the other half by *N*-type impurity. The plane dividing the two halves or zones is called a *P-N* junction. Commercially available diodes usually have some means to indicate which lead is *P* and which lead is *N*. Standard notation consists of two type numbers preceded by '*IN*' such as *IN* 240 and *IN* 1250. The bipolar junction transistor basically consists of two back to back *P-N* junctions manufactured in a single piece of a semiconductor crystal. The two junctions give rise to three called emitter, base and collector. There have a many types of transistor in industry nowadays. Looking forward for thyristor, it provided an efficient control of electrical machines as variable speed drives. Both dc and ac motor are controlled using these power converters. These thyristor power converters are very useful and efficient in the speed control of induction and synchronous motors over a wide range. They also made it possible to develop variable speed drives with a continuous speed control, having higher efficiencies, greater reliability, reduced initial costs and maintenance. Let try do some exercise which is covered some of topics in semiconductors.

EXERCISE

- 1) Define electrical conductivity.
- 2) What are the two types of impurities added to the semiconductor?
- 3) List various applications of diodes.
- 4) Differentiate among conductor, semiconductor and insulator.
- 5) What is intrinsic semiconductor?
- 6) What is extrinsic semiconductor?
- 7) Explain the effects when a P-N junction is supplied with forward biased voltage and reverse biased voltage in term of:
 - a. Area of depletion region
 - b. Junction resistance
 - c. Current flow
- 8) Define insulation breakdown limit.
- 9) Explain what Bipolar Junction Transistor (BJT) is.
- 10) List down BJT's components.
- 11) Define Power diode and its current flow.
- 12) How is diode created?
- 13) Define a LED.
- 14) Define Silicon Controlled Rectifier (SCR) and sketch the symbol of SCR.
- 15) Define Triode for Alternating Current (TRIAC)
- 16) Sketch the construction and schematic symbol of TRIAC.
- 17) Sketch the construction and schematic symbol of DIAC.
- 18) Define Uni-junction Transistor (UJT).
- 19) Differentiate between JFET and MFET.
- 20) Sketch the construction and schematic symbol of UJT.

- 21) List the differences between Field Effect Transistor (FET) and Uni-junction Transistor (UJT).
- 22) Sketch the I-V characteristics curve of Power Diode and labelled it.
- 23) What is an Insulated gate bipolar junction transistor (IBJT)
- 24) Briefly explain N-type and P-type junction in the Power Diode.
- 25) Explain and sketch the schematic diagram for gate controlled switch (GCS)
- 26) Sketch the characteristic curve of the power transistor and explain briefly the three operating regions.
- 27) Explain meaning of depletion layer with a suitable diagram.
- 28) Briefly explain what is forward and reverse bias of a diode.
- 29) How do the transition region width and contact potential across a p-n junction vary with the applied bias voltage?
- 30) Define what is reverse saturation current of a diode.
- 31) Define breakdown voltage.
- 32) Define the limitations in the operation conditions of a p-n junction.
- 33) Why an ordinary junction transistor is called bipolar.
- 34) Why transistor is called current controlled device.
- 35) Define what is the significance of the arrow-head in the transistor symbol
- 36) What are emitter injection efficiency and base transport factor and how do they influence the transistor operation.
- 37) Which of the transistor current are always the largest and which is always the smallest?
- 38) Why silicon type transistors are made often used than germanium type.

- 39) Why the width of the base region of a transistor is kept very small compared to other regions.
- 40) What is Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
- 41) Explain how MOSFET functions?
- 42) Explain the three regions of operation of a MOSFET
- 43) What are the main constructional differences between a MOSFET and a BJT? What effect do they have on the current conduction mechanism of a MOSFET?
- 44) Write down advantages of MOSFET.
- 45) Sketch and explain the I-V characteristic of MOSFET.
- 46) What is meant by GTO?
- 47) How does a GTO differ from a conventional thyristor and give its circuit symbol.
- 48) Draw the DC and AC equivalent circuits of a common emitter transistor circuit.
- 49) Explain why gate current of MOSFET is small compared to that of JFET.
- 50) Draw the schematic symbol of n-channel depletion type of MOSFET.
- 51) List the different members of the thyristor family. Draw their characteristics and explain in brief.
- 52) Explain the following points with respect to IGBT:
- a. Forward blocking capability
 - b. Reverse blocking capability
 - c. Forward conduction mode
- 53) Draw and explain basic structure of IGBT.
- 54) Briefly explain the V-I characteristic of an IGBT.
- 55) Determine the 2 conditions of voltage connection that need to follow in order to bias a transistor.

2

DC CONVERTER

Dc converter known as a rectification process which is converting an alternating current or voltage into direct current or voltage. This conversion can be achieved by a variety of circuits based on and using switching devices. The widely used switching devices are diodes, thyristors, power transistor, power MOS or else. The rectifier circuit can be classified into three which is uncontrolled and fully controlled and half controlled. An uncontrolled rectifier uses only diodes and the DC output voltage is fixed in amplitude by the amplitude of an AC supply. For the controlled rectifier uses thyristors as the rectifying elements and the DC output voltage is a function of the amplitude of the AC supply voltage and the point on wave at which the thyristors are triggered called firing angle α . The half controlled rectifier contains a mixture of diodes and thyristors, allowing a more limited control over the DC output voltage level than the fully controlled rectifier.

The converter type depends on the power to be handled and how much voltage ripple will be tolerated. For low powers, below 20kW a single phase circuits are adequate but they themselves can take different forms. For high powers, above 20kW, three phase circuits are used.

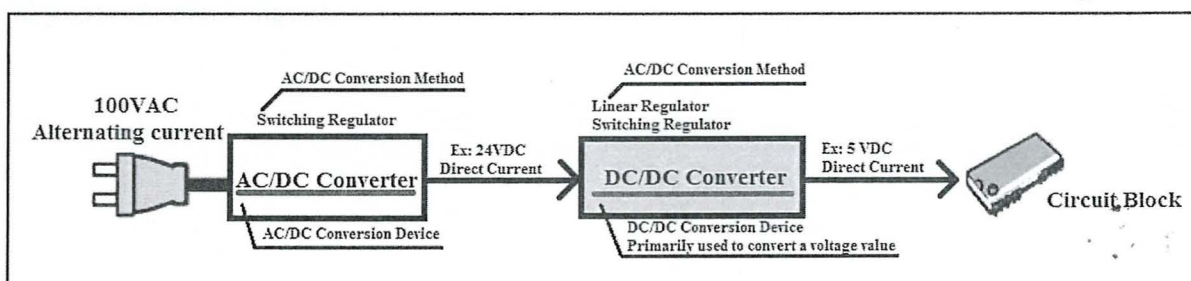


Figure 1

CHOPPER (DC – DC)

A dc chopper is a static device known as a switch used to obtain variable DC voltage from a source of constant DC voltage. Therefore, chopper may be thought of as DC equivalent of an AC transformer since they behave in an identical manner. Besides, to saving in power, the DC chopper is the greater efficiency, faster response, lower maintenance, small size, smooth control and for many applications. Solid state choppers due to various advantages are widely used in trolley cars, battery operated vehicles, traction motor control, marine hoists, forklift trucks and mine haulers.

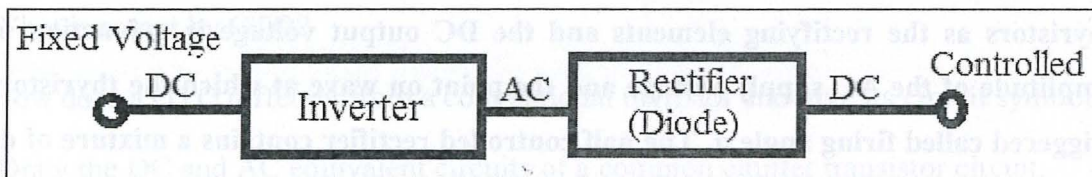
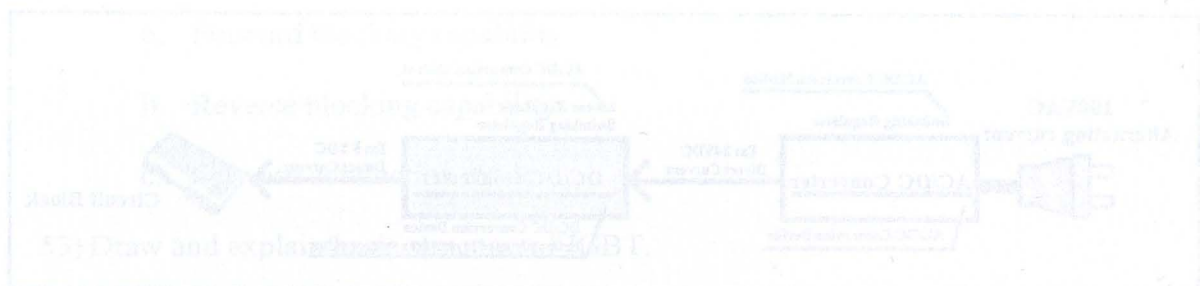


Figure 2



54) Briefly explain the V-I characteristic of a BT.

55) Determine the 2 conditions of voltage connection that used to follow in order to bias a

3

AMPLIFIER AND OSCILLATION CIRCUIT

Transistor has 3 terminals namely base, collector and emitter. By using these 3 terminals the transistor can connect to a circuit with one terminal connect to ground and that terminal common to both input and output in a 3 different possible configurations. These three types of configurations are Common Base, Common Collector and Common Emitter configuration. Common emitter configuration transistor has high voltage gain, high current gain, medium input and output impedance. Transistor need to be biased in order to properly operate. Operational point or Q point is connecting saturation point and cut off point in DC load line. Oscillator used to convert DC to AC voltage, it produces a periodic and oscillating signal. An RC oscillator circuit generates lower frequencies such as Wien Bridge, Phase shift oscillator. Armstrong, Hartley and Colpitts circuits are LC oscillator circuits consisting of inductor and capacitor. Crystal oscillator circuit normally used to stable frequencies and generate clock signal.

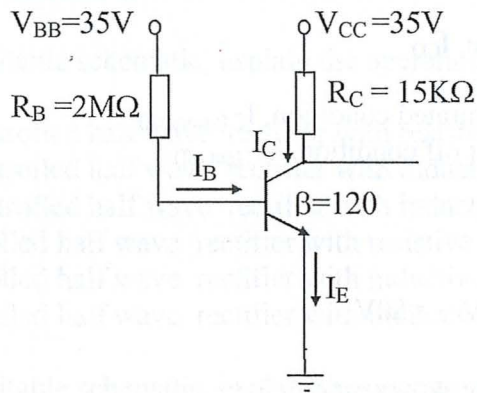
EXERCISE

- 1) What is DC converter?
- 2) Why we need linear DC power supply in electronic equipment?
- 3) Name the components of DC power supply unit
- 4) Sketch the block diagram of DC power supply and explain the function of each block.
- 5) List 4 types of filter.
- 6) Sketch a capacitor filter circuit.
- 7) Explain filter operation based on repeating charging and discharging of capacitor with related diagram.
- 8) Sketch and explain regulator below:
 - i. Zener Diode Voltage Regulator
 - ii. Series Transistor voltage regulator
 - iii. IC Voltage Regulator
- 9) Name and sketch 2 types of voltage divider circuit.
- 10) Draw a complete schematic diagram of a DC power supply unit.
- 11) Explain the function of DC converter and give three examples of its applications.
- 12) A single phase half wave controlled rectifier connected to a 150V, 60 Hz, source is supplying a resistive load, 10Ω . If the delay angle α is 30° , calculate above:
 - a. Maximum load current, I_m
 - b. RMS load current, I_{RMS}
 - c. Power supplied to the load

13) Draw 3 types of transistor configurations.

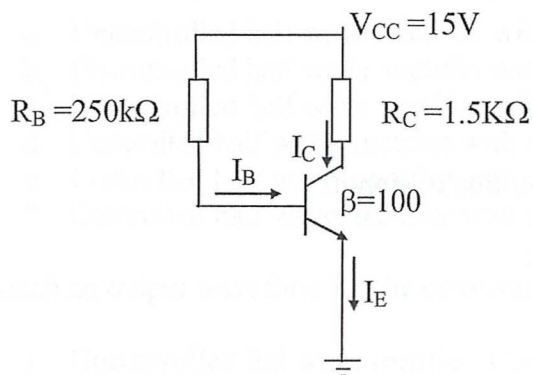
14) Define β_{DC} and β_{AC}

15) Base on figure below, if β transistor is 120 and this transistor is silicon type, calculate the value of I_C and V_{CE}



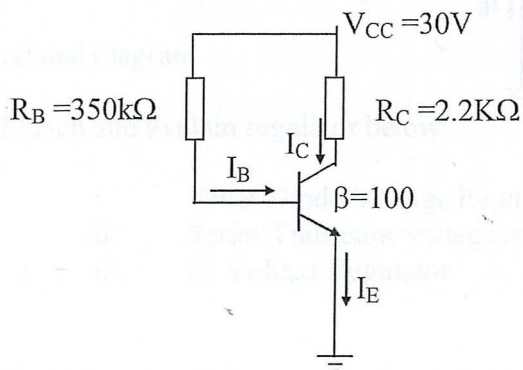
16) Base on circuit below, determine:

- Base current; I_B
- Collector current; I_C
- Voltage drop; V_{CE}



- 17) Define DC load line.
- 18) Differentiate DC saturation point and DC cut-off point.
- 19) Given a common emitter circuit below, calculate:

- i. Collector Current, I_C
- ii. Voltage drop, V_{CE}
- iii. Operation current value, I_{CQ}
- iv. Operation voltage, V_{CQ}
- v. Collector current in saturated condition, I_C (saturated)
- vi. Collector voltage in cut off condition, V_C (cut off)
- vii. Sketch DC load line.



- 20) Explain the operations of a common emitter amplifier circuit when an AC input signal is provided.
- 21) Sketch a block diagram of an oscillator
- 22) Explain the operation of an Armstrong oscillator circuit.
- 23) Sketch the following oscillator circuits:
 - i. Hartley
 - ii. Colpitt's
 - iii. Phase Shift(RC)
 - iv. Crystal

24) Rectifier is used to convert AC source to DC power by using diodes. Sketch the waveforms below for a single phase uncontrolled half wave rectifier with resistive load.

- a. Input voltage, V_{in}
- b. Output voltage, V_{out}
- c. Output current, I_o

25) With aid of suitable schematic, explain the operation of converter below.

- a. Uncontrolled half wave rectifier with resistive load
- b. Uncontrolled half wave rectifier with inductive load
- c. Uncontrolled half wave rectifier with inductive load and freewheeling diode
- d. Controlled half wave rectifier with resistive load
- e. Controlled half wave rectifier with inductive load
- f. Controlled half wave rectifier with inductive load and freewheeling diode

26) With aid of suitable schematic, explain the operation of converter below.

- a. Uncontrolled full wave rectifier (Centre-tapped transformer) with resistive load
- b. Uncontrolled full wave rectifier (Bridge Type) with resistive load
- c. Controlled full wave rectifier (Centre-tapped transformer) with resistive load
- d. Controlled full wave rectifier (Bridge Type) with resistive load

27) Sketch an output waveform for the converter below.

- a. Uncontrolled half wave rectifier with resistive load
- b. Uncontrolled half wave rectifier with inductive load
- c. Uncontrolled half wave rectifier with inductive load and freewheeling diode
- d. Controlled half wave rectifier with resistive load
- e. Controlled half wave rectifier with inductive load
- f. Controlled half wave rectifier with inductive load and freewheeling diode

28) Sketch an output waveform for the converter below.

- a. Uncontrolled full wave rectifier (Centre-tapped transformer) with resistive load
- b. Uncontrolled full wave rectifier (Bridge Type) with resistive load
- c. Controlled full wave rectifier (Centre-tapped transformer) with resistive load
- d. Controlled full wave rectifier (Bridge Type) with resistive load

- 29) Calculate voltage of a single phase wave controlled rectifier with Load, R to produce an average voltage of 40V across 100 Ω load resistor from 120 VRMS, 60Hz AC and calculate the power absorbed by resistor.
- 30) A half wave controlled rectifier connected to a 150V, 60Hz supplying a resistive load of 5 Ω . If the delay angle α is 30°, solve for the:
- Max load current
 - RMS load current
 - Power supplied to load
 - Ripple frequency
 - Power factor
- 31) A single phase halfwave rectifier has a purely resistive load, R= 150 Ω , the peak supply voltage, $V_m=120V$ and the supply frequency, $f=60Hz$. Calculate the:
- Average output voltage, V_{dc}
 - RMS output voltage, V_{rms}
 - AC output power, P_{ac}
- 32) What is peak inverse voltage (PIV) of a diode in a rectifier circuit?
- 33) Why diodes are not operated in the breakdown region in rectifiers?
- 34) Define the DC-DC converter (CHOPPER) and give two examples an application of chopper.
- 35) A buck converter is supplied from a 50V battery source. Given $L= 400\mu H$, $C = 100mF$, $R=20\Omega$, $f= 20k Hz$ and $D=0.4$. Calculate:
- Output voltage
 - Maximum and minimum inductor current
 - Output voltage ripple
- 36) Sketch the circuit based on following:
- Step down chopper
 - Step up chopper

37) The DC converter (Chopper) has a resistive load of $R=10\Omega$ and the input voltage is 220V dc. When the chopper switch remains on its voltage drop = 2V, the duty cycle is 50% and the chopping frequency f is 1 kHz and Find a value for the below:

- a. The average output voltage, V_o
- b. The rms output voltage

38) According to the direction of Output Voltage and current, sketch and explain each types of chopper as mention below:

- i. Class A (types A) chopper
- ii. Class B (types B) chopper
- iii. Class C (types C) chopper
- iv. Class D (types D) chopper
- v. Class E (types E) chopper

39) Explain the effect of freewheeling diode in details. Also, justify the statement freewheeling diode improves the power factor of the system.

40) Explain the effect of battery load on the performance of single phase fully controlled bridge converter.

ANSWER

- 12) $V_m = 212.13A$
 $I_m = 21.2 A$
 $I_{rms} = 10.45A$
 $P = 1092 W$
- 15) $I_c = 2.06mA$
 $V_{CE} = 4.13 V$
- 16)
- i. $I_B = 60 \mu A$
 - ii. $I_c = 6mA$
 - iii. $V_{CE} = 6 V$
- 19)
- i. $I_C = 8.57mA$
 - ii. $V_{CE} = 11.14V$
 - iii. $I_{CQ} = 8.57mA$
 - iv. $V_{CQ} = 11.14V$
 - v. $I_{C(saturated)} = 13.64A$
 - vi. $V_{C(cut\ off)} = 30V$
- 29) $\alpha = 61.2$
 $V_{orms} = 75.42 V$
 $Power = 0.75 W$
- 30) a) $V_m = 212.13 A$, $I_m = 42.43 A$
b) $I_{rms} = 20.91 A$
c) $P = 2186 W$
d) Ripple Frequency = 60Hz
e) $PF = 0.69$
- 31)
- i. $V_{dc} = 38.19 V$
 - ii. $V_{rms} = 60 V$
 - iii. $P_{ac} = 24 W$
- 35) a) $V_o = 20 V$
b) $I_{max} = 1.75 A$, $I_{min} = 0.25A$
c) Output Voltage Ripple = 4.69 mm
- 37) a) $V_o = 109 V$
b) $V_L = 154.15 V$

4

AC CONVERTER

The DC to AC power converters are known as inverters. In other words, an inverter is a circuit which converts a DC power into an AC power at desired output voltage and frequency. The AC output voltage could be fixed at a fixed or variable frequency. This conversation can be achieved either by controlled turn on and turn devices as an example BJT's, MOSFET's, IGBT's, and GTO's or by forced commutated thyristor depending on applications. For low and medium power outputs, the above mentioned power devise are suitable but for high power outputs, thyristors should be used. The output voltage waveforms of an ideal inverter should be sinusoidal. The voltage waveforms of practical inverters are however non-sinusoidal and contain certain harmonics.

The DC power input to the inverter may be battery, fuel cell, solar cells or other DC source. Inverters are mainly classified as voltage source inverters and current source inverters. Some of the important industrial applications of inverters are as below:

- Variable speed AC motor drives
- Induction heating
- Aircraft power supplies
- Uninterruptible power supplies (UPS)
- High voltage DC transmission lines
- Battery vehicle drives
- Regulated voltage and frequency power supplies.

EXERCISE

- 1) State the function of AC converter (inverter)
- 2) Gives THREE (3) examples of applications for AC converter (inverter)
- 3) How is an inverter different than a UPS
- 4) What is the difference between sine wave and modified sine wave
- 5) Sketch and label the circuit diagram for single phase full bridge inverter circuit with resistive load.
- 6) Explain the operational principle of the circuit and draw the output voltage, V_o and current output, I_o waveform load for single phase full bridge inverter circuit with resistive load.
- 7) Sketch and label the circuit diagram for single phase full bridge inverter circuit with inductive load and draw the output voltage V_o and current output I_o .
- 8) Sketch and label the circuit diagram for single phase half bridge inverter circuit with resistive load and draw the output voltage V_o and current output I_o .
- 9) Sketch and label the circuit diagram for single phase half bridge inverter circuit with inductive load and draw the output voltage V_o and current output I_o .
- 10) Explain the operation of single phase to single phase cycloconverter and sketch the waveform for supply voltage and output voltage.

- 11) To achieve voltage control within the inverter and to reduce the harmonic contents in the output voltage, PWM inverters are used. In PWM inverters, width of the output pulses is modulated to achieve the voltage and it has some technique to allow it. List down all the techniques.
- 12) With a good diagram, sketch a waveform of three phases to single phase cycloconverter and schematic diagram.
- 13) With a table, give a comparison between cycloconverter and DC link converter.
- 14) Describe the basic principle of working of a single phase to single phase cycloconverter.
- 15) Discuss why a three phase to single phase cycloconverter requires positive and negative group phase controlled converter.
- 16) Describe three phase to three phase cycloconverter with relevant circuit arrangements using 18 thyristor and 36 thyristors.
- 17) What are the advantages of three phase bridge cycloconverter circuit over three phase to three phase cycloconverter circuit consisting of 18 SCRs.
- 18) What is a load commutated cycloconverter.

5

ELECTRICAL DRIVERS

DC MACHINE CONTROL & AC MACHINE CONTROL

An electric motor is a machine which converts electrical energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left hand rule. The DC machine consists of the field and an armature, the field being excited by dc windings, which set up a magnetic flux linking the armature. The function of the commutator and brushes is to ensure that the current in the armature conductors under any pole is in a given direction irrespective of the speed of the armature. The commutator acts as a mechanical frequency changer to change the alternating current in a given armature conductor to the direct current in the brush lead. When rotating, an internal voltage (back e.m.f) E is generated in the armature by virtue of its rotation in a magnetic flux. The terminal armature voltage V will differ from E by the internal voltage drop. The load torque will give rise to a current in the armature, the current level being a function of the torque and magnetic flux values.

The construction of the cage induction motor is relatively simple compared to other machines, but it does not lend itself to speed adjustment as readily as does the dc motor. The major use of the power semiconductor device in ac motor control is centered on variable output frequency inverters. To obtain comparable control characteristic comparable with those of the dc motor, a greater complexity of power and control equipment is required, although this additional cost has to be set against the lower cost of the cage induction motor.

EXERCISE

- 1) Explain the various schemes of DC motor speed control.
- 2) A 12 pole, 3phase alternator driven at a speed of 500 rpm supplies to an 8 pole, 3 phase induction motor. If the slip of the motor at full load is 3%, calculate the full load speed of the motor.
- 3) Discuss the comparison of generator and motor action.
- 4) The 6 pole wound rotor induction motor is excited by a 3phase, 60Hz source. The frequency of the rotor current under the following conditions.
 - a. At standstill
 - b. Motor turning at 500 rpm in the same direction as the revolving field.
 - c. Motor turning at 500rpm in the opposite direction to the revolving field.
 - d. Motor turning at 2000rpm in the same direction as the revolving field.
- 5) If a 6 pole motor running from a 50Hz supply has an emf in the rotor of frequency 2.5Hz, determine:
 - a. The slip
 - b. The speed of the motor
- 6) A 230V motor has an armature circuit resistance of 0.6Ω . If the full load armature current is 30A and the no load armature current is 4A, find the change in back emf from no load to full load.

- 7) A 440V shunt motor has an armature resistance of 0.8Ω and a field resistance of 200Ω . Determine the back emf when giving an output of 7.46kW at 85% efficiency.
- 8) A separate excitation DC motor at a chopper drive circuit is controlled by the armature resistance $R_a=0.04\Omega$, $R_f=0.06\Omega$ and back emf constant $K_v=35\text{m V/a-rad/s}$. A 600V DC power supply voltages supplied to the chopper drive. If the torque constant T_d produced is 547Nm, calculate the motor speed. (If the duty cycle of the converter is 75%)
- 9) List down the three of motor characteristics.
- 10) A DC shunt motor 220V has an armature resistance, $R_a=0.5\Omega$, a drop voltage, 5V and armature current, $I_a=20\text{A}$.
 - a. Sketch the circuit diagram for DC shunt motor.
 - b. Calculate back emf
 - c. Calculate armature current if back emf is 185V
- 11) Explain with a good diagram of the characteristics of shunt motors.
- 12) In such motor, a part of the field winding is in parallel with the armature and the other part is in series with it. List down the compound motor types.
- 13) List down the comparison of shunt and series motor and their applications.
- 14) A rectifier DC motor drive is supplies by a three phase fully controlled by SCR bridge 240rms, 50Hz per phase. The field is supplied by a single phase 240Vrms, 50Hz with uncontrolled diode bridge rectifier and the field current is set as maximum as possible. ($\alpha=0$ degree)

Given:

Armature resistance, $R_a=0.3\Omega$

Field resistance, $R_f=175\Omega$

Motor constant, $K_v=1.5\text{V/A-rad/s}$

Armature current, $I_a=30\text{A}$

Armature concerter, $\alpha=45^\circ$

Calculate:

 - a. Developed torque, T_d
 - b. Speed of motor

ANSWER

- 2) $f = 50\text{Hz}$, $N_s = 750\text{ rpm}$, $N = 727.5\text{ rpm}$
- 4) a) $S = 1$, $f_r = 60\text{ Hz}$
 b) $S = 0.583$, $f_r = 35\text{ Hz}$
 c) $S = 1.417$ ($S > 1$, motor rotating as a break), $f_r = 85\text{ Hz}$
 d) $S = -0.667$, $f_r = -40\text{ Hz}$ (The phase sequence of the voltage induced in the rotor winding is reversed)
- 5) a) $N_s = 1000\text{ rpm}$
 b) $N = 950\text{ rpm}$
- 7) $P_{\text{input}} = I_L \times V$
 $I_L = 19.95\text{ A}$
 $I_{SH} = 2.2\text{ A}$
 $I_a = 17.75\text{ A}$
 Back emf = 425.8 V
- 8) Field Current, $I_f = 10000\text{ A}$
 Armature current, $I_a = 1.56\text{ A}$
 Armature voltage, $E_a = 449.94\text{ V}$
 Motor Speed, $N = 12.28\text{ rpm}$
- 10) Back emf, $E_b = 205\text{ V}$
 Armature current if back emf is 185, $I_a = 60\text{ A}$
- 14) a) Developed Torque, $T_d = 55.56\text{ Nm}$
 b) $\omega = 209.4\text{ rad/sec}$

6

NUMBER SYSTEM AND CODE SYSTEM

In digital system, the number system is used for representing the information. The number system has different bases and the most common of them are the decimal, binary, octal, and hexadecimal. The base of the number system is the total number of the digit used in the number system. Suppose if the number system representing the digit from 0 – 9 then the base of the system is the 10. There are several type of number system such as a) Binary number b) Octal number c) Decimal number and d) Hexadecimal number.

Binary Number System

In mathematics, positional numeral system employing 2 as the base and so requiring only two different symbols for its digits, 0 and 1, instead of the usual 10 different symbols needed in the decimal system. The numbers from 0 to 10 are thus in binary 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, and 1010. Mostly computing devices use binary numbering to represent electronic circuit voltage state, (i.e., on/off switch), which considers 0 voltage input as off and 1 input as on.

Octal Number System

The number system whose base is 8 is known as the octal number system. The base 8 means the system uses eight digits from 0 to 7. All the eight digits from 0 to 7 have same physical meaning as that of decimal numbers.

Octal Symbol	Binary equivalent
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Figure 3

As every digit of a number in octal system is represented separately by its three bit binary equivalent the octal system requires one-third of the length as compared to binary numbers. It is basically a positional weighted number system.

Decimal Number System

Decimal is a term that describes the base-10 number system, probably the most commonly used number system. The decimal number system consists of ten single-digit numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. The number after 9 is 10. The number after 19 is 20 and so forth. Additional powers of 10 require the addition of another positional digit.

Hexadecimal Number System

Hexadecimal describes a base-16 number system. That is, it describes a numbering system containing 16 sequential numbers as base units (including 0) before adding a new position for the next number. The hexadecimal numbers are 0-9 and then use the letters A-F. We show the equivalence of binary, decimal, and hexadecimal numbers in the table below.

Decimal	Binary	Hexadecimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Figure 4

Code System

Code is a rule for converting a piece of information into another form or representation not necessarily of the same type. One reason for coding is to enable communication in places where ordinary spoken or written language is difficult or impossible.

Binary Coded Decimal (BCD)

BCD is a way to express each of the decimal digits with a binary code. There are only 10 code groups in the BCD system, one for every digit (0000-1001). Invalid codes are 1010, 1011, 1100, 1101, 1110 and 1111.

The coded values for decimal digit:

Decimal	BCD	Decimal	BCD
0	0000	5	0101
1	0001	6	0110
2	0010	7	0111
3	0011	8	1000
4	0100	9	1001

Figure 5

American Standard Code for Information Interchange (ASCII)

American Standard Code for Information Interexchange, ASCII is a standard that assigns letters, numbers, and other characters in the 256 slots available in the 8-bit code. The ASCII decimal (Dec) number is created from binary, which is the language of all computers. As shown in the table below, the lowercase "h" character (Char) has a decimal value of 104, which is "01101000" in binary.

EXERCISE

Write the following numbers to the number system required by showing the showing the steps clearly.

- 1) 29.53_{10} to Binary number
- 2) 1011010_2 to Octal number
- 3) $FA.69_{16}$ to Decimal number
- 4) 476_8 to Binary number
- 5) 011010110_2 to Octal number
- 6) $FA8_{16}$ to Decimal number
- 7) 317547_{10} to Hexadecimal number
- 8) 101110001111.011_2 to Octal number.
- 9) 0.34375_{10} to Binary number.
- 10) 1111010101.11_2 to Hexadecimal number
- 11) 745.23_8 to Decimal number
- 12) 0110101_2 to Decimal number
- 13) $64BF_{16}$ to Decimal number
- 14) 753_{10} to Octal Number
- 15) 356_{10} to Binary Number
- 16) 896_{10} to Octal Number
- 17) $39DA_{16}$ to Decimal Number
- 18) 1240_{10} to Hexadecimal Number
- 19) 217_{10} to Binary Number
- 20) 1792_{10} to Octal Number
- 21) $52AE_{16}$ to Decimal Number
- 22) 220_{10} to Binary Number

7

BOOLEAN EXPRESSION

Boolean expression allows the rules used in the algebra of numbers to be applied to logic. It formalizes the rules of logic. Boolean algebra is used to simplify Boolean expressions which represent combinational logic circuits. It reduces the original expression to an equivalent expression that has fewer terms which means that less logic gates are needed to implement the combinational logic circuit. The Boolean expression is also an expression that has relational and/or logical operators operating on Boolean variables to evaluates either *true* or *false*. Boolean 0 and 1 do not represent actual numbers but instead represent the state, or logic level.

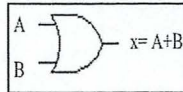
Logic 0	Logic 1
False	True
Off	On
Low	High
No	Yes
Open switch	Closed switch

Figure 6

Three basic Logic Operations of gate:

a) OR gate

An OR gate is a gate that has two or more inputs and whose output is equal to the OR combination of the inputs.

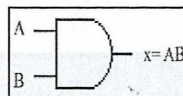


Boolean expression for the OR operation: $x = A + B$

OR		
A	B	x
0	0	0
0	1	1
1	0	1
1	1	1

b) AND gate

An AND gate is a gate that has two or more inputs and whose output is equal to the AND product of the inputs.

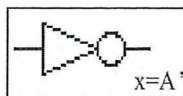


Boolean expression for the OR operation: $x = A B$

AND		
A	B	x
0	0	0
0	1	0
1	0	0
1	1	1

c) NOT gate

The NOT operation is an unary operation, taking only one input variable.



Boolean expression for the NOT operation: $x = A$

NOT	
A	$x = A'$
0	1
1	0

EXERCISE

- 1) By using 1's and 2's complements, solve $84_{16} - 2A_{16}$.
- 2) Use the Karnaugh Map to simplify the expression below :

$$X = \overline{A}BC + \overline{A}\overline{B}\overline{C} + \overline{A}BC + A\overline{B}\overline{C} + A\overline{B}C$$

- 3) Simplify the following Boolean expressions.

$$\text{a) } F = \overline{(\overline{A} + C)(B + \overline{D})}$$

$$\text{b) } F = \overline{(\overline{A} + B)(\overline{C})}$$

- 4) Figure 1(a) shows a combinational logic circuit with three inputs and single output.

Solve the following questions :

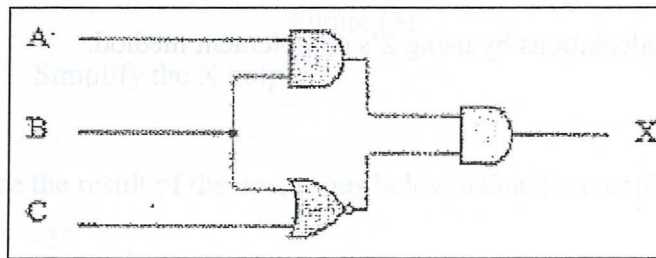


Figure 1(a)

- a) Write an equation of output X.
- b) Draw the truth table for equation (a) (i).
- c) Draw the timing diagram for output X.

- 5) An indicator light is installed on RED-YELLOW-GREEN traffic light system in order for monitoring malfunction of traffic light system. This indicator light is turned on when two or more traffic light lamp function at the same time.

Determine:

- The truth table for the indicator light with state '1' = on and '0' = off.
 - Interpret and simplify the Boolean equation using Karnaugh Map in Product of Sum (POS) form.
- 6) Identify the Boolean expression for three input Ex- Or (X-OR) gate and given the Truth Table.
- 7) State **THREE (3)** Boolean Laws.
- 8) Solve the following calculations by using 2's complement method.
- $48 - 23$
 - $-48 - 23$
 - $23 - 48$

9) Summarise the following Boolean expression below :

a) $F_1 = (A + B) (A + C)$

b) $F_2 = PS + P\bar{Q}\bar{S} + PQS$

10) State the Boolean expression for the X outputs in figure (b) given.

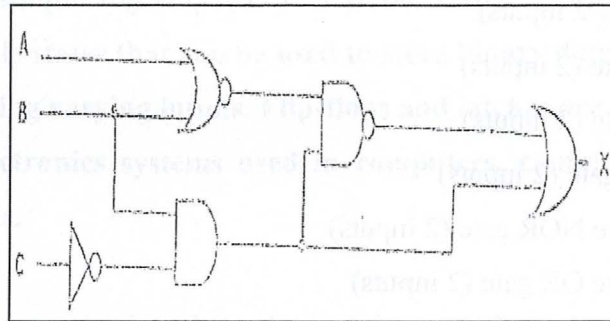


Figure (b)

a) Simplify the X output.

11) Determine the result of the operations below using 2's complement method

a) -25

b) $6 - 14$

12) Determine the result of the operations below using 2's complement method:

a) $23 - 48$

13) Draw the symbol of:

- a) OR gate
- b) AND gate
- c) NOR gate
- d) NOT gate
- e) Exclusive NOR gate

14) Build the truth table of:

- a) OR gate (2 inputs)
- b) AND gate (2 inputs)
- c) NOR gate (2 inputs)
- d) NAND gate (2 inputs)
- e) Exclusive NOR gate (2 inputs)
- f) Exclusive OR gate (2 inputs)

15) State the Boolean expression for the outputs X & Y of Figure (c) below.

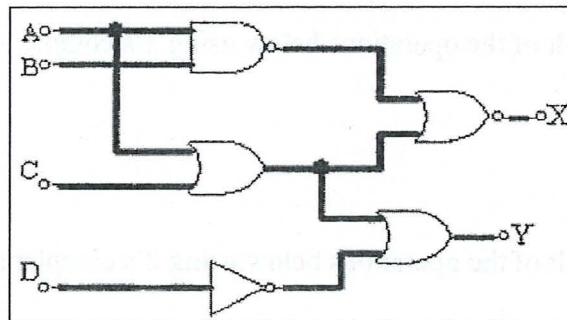


Figure (c)

- a) Build a truth table for output data X and Y.

8

SEQUENTIAL LOGIC

Sequential logic is a form of binary circuit design employs one or more inputs and one or more outputs. Each of the inputs and outputs can attain either of two stages; HIGH (1) or LOW (0). A simple flip flop has two stable states. A flip flop is an electronic circuit with two stable states that can be used to store binary data. The stored data can be changed by applying varying inputs. Flip-flops and latches are fundamental building blocks of digital electronics systems used in computers, communications, and many other types of systems.

Flip-flops and latches are used as data storage elements. It is the basic storage element in sequential logic. But first let's clarify the difference between a latch and a flip flop. There are several different kinds of flip flop such as JK, SC or SR, D, T and Master Slave JK. For a basic flip flop circuit, it can be constructed from two NAND gates or two NOR gates. Each flip flop has two outputs known as Q and $\bar{Q}$. The outputs Q and $\bar{Q}$ complements of each other and are referred to as the normal and complements outputs respectively. The binary state of flip flop is taken to be the value of normal output.

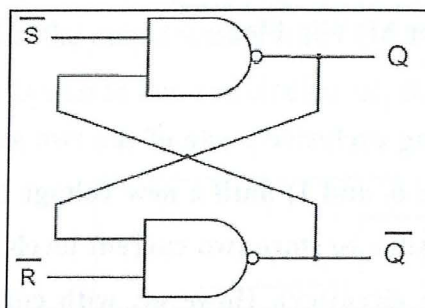


Figure 7: NAND Gates

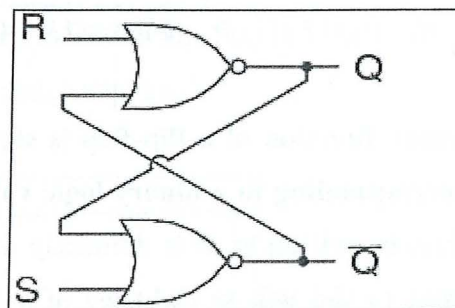


Figure 8: NOR Gates

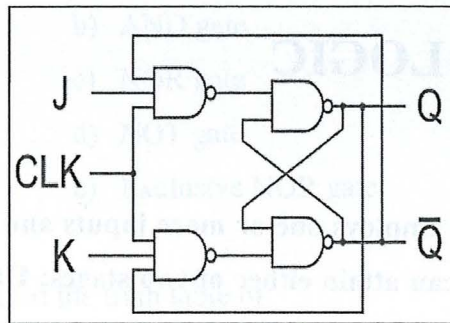


Figure 9: JK Flip Flop

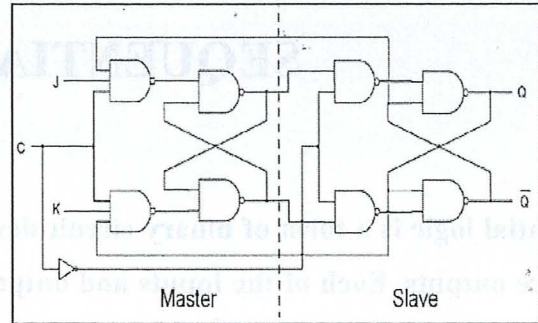


Figure 10: Master- Slave JK Flip Flop

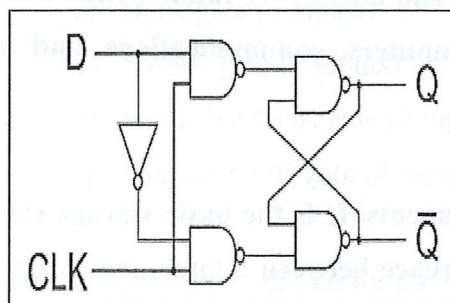


Figure11: D Flip Flop

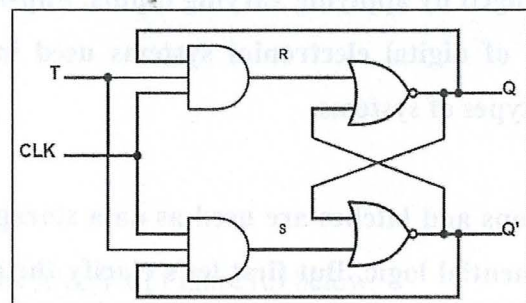


Figure 12: T Flip Flop

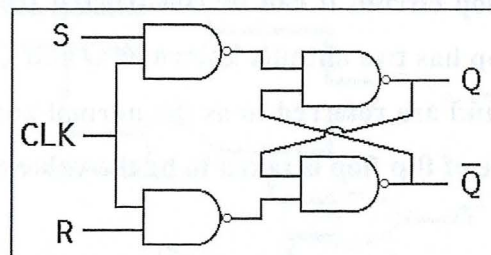


Figure 13: SC or SR Flip Flop

The primary function of a flip-flop is storing exclusively one of the two stable voltage levels (corresponding to a binary logic value 0, and 1) until a new voltage level (a new logic value) is written to. It is definitely possible to store two current levels (or steering the current to the left or right leg of some circuitry). However, with current CMOS technologies, current-steering flip-flops are no longer used due to its larger power consumption. More specifically, in an electronic computer, it is used to implement a sequential logic, where the output of the logic circuit depends not only on the present value but also on the previous states.

EXERCISE

- 1) Give **TWO (2)** other name for D flip-flop, draw and label the symbol of D flip-flop.
- 2) Based on Figure 2(a)
 - a) Identify the type of SR flip-flop used.
 - b) Obtain the truth table based on the timing diagram.
 - c) Explain what will happen for the output Q if the input S at T6 is HIGH.
 - d) If the input R is High at T1 and the input S is HIGH at T5, predict the generated waveform of output and its inverted output.

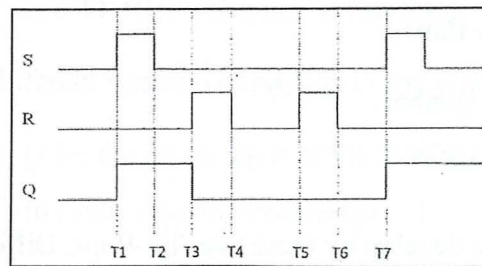


Figure 2(a)

- 3) State **THREE (3)** differences between SR flip-flops NOR gate and SR flip-flop NAND gate.
- 4) Determine the output waveform of Q for the clocked T flip-flop in Figure 2(b). Assume Q start at low and clock is negative edge triggered.

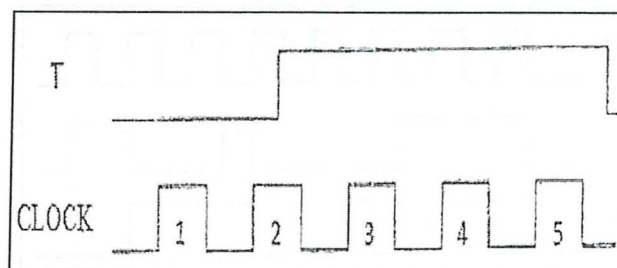


Figure 2(b)

- 5) Draw the output waveform of Q and $\bar{Q}$ for the clocked JK flip-flop in Figure 2(c). Assume Q and $\bar{Q}$ start at low and clock is positive edge triggered.

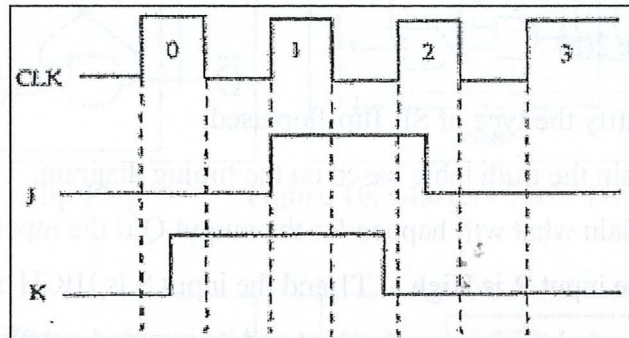


Figure 2(c)

- 6) For active high SR flip-flop:
- Draw the logic symbol.
 - Show the truth table
- 7) The JK flip-flop can be develop by these two flip-flops. Differentiate the logic circuit by using:
- D flip-flop.
 - T flip-flop.
- 8) Complete the timing diagram in Figure 2(d) for the negative edge triggering active high clocked SR flip-flop by assuming the initial conditions Q is '0'.

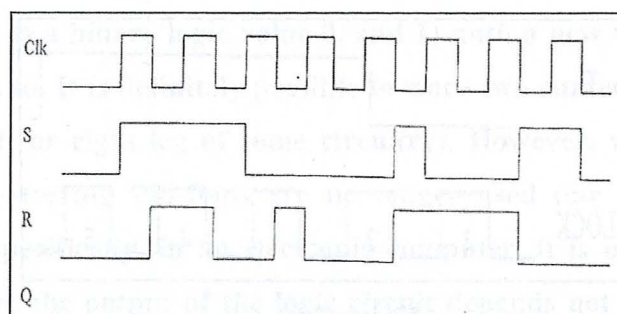


Figure 2(d)

- 9) Based on Figure 2(e), Draw the output for the flip-flop. Given $Q_{\text{initial}} = 1$, Preset = Clear = 1, and Clock is negative edge triggered.

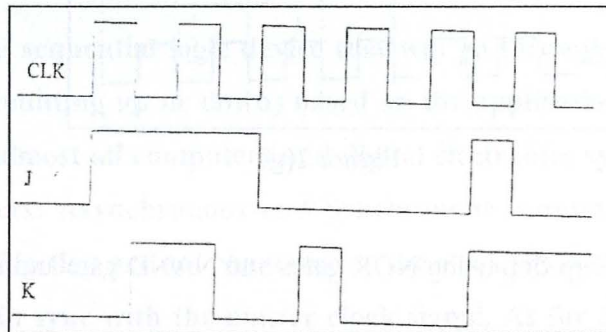


Figure 2(e)

- 10) Define flip flop and state **THREE (3)** types of flip flop.
- 11) Identify **TWO (2)** different names for flip-flop D and draw the logic circuit.
- 12) Determine the Q and $\bar{Q}$ for the given input of SR Active Low and Positive Edge Trigger Clock (PGT) in figure below. Assume $Q_a = 1$

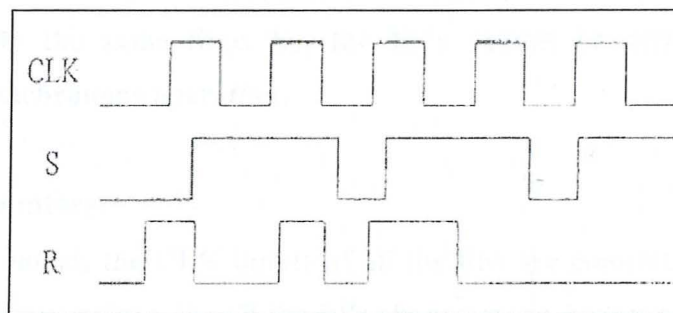


Figure 2(f)

13) Draw the output (f_{out}) for the Figure 2(g) below.

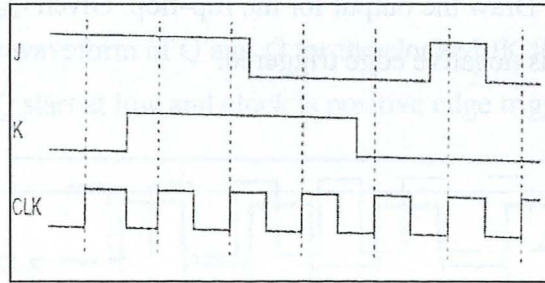


Figure 2(g)

14) Construct the SR flip flop using NOR gates and NAND gate and include their truth table.

15) State the function of Preset and Clear in flip flop.

16) State **THREE (3)** differences between SR flip flop NOR gate and SR flip flop NAND gate.

17) Illustrate the way to develop D flip flop by using JK flip flop with aid of block diagram.

9

COUNTER

A counter is a digital sequential logic device that will go through a certain predefined states (for example counting up or down) based on the application of the input pulses. They are utilized in almost all computers and digital electronics systems. There are two main types of counters: Asynchronous and Synchronous counters. For Asynchronous counter, most of the flip flop are not connected to the clock signal therefore, the flip flop do not change state in sync with the master clock signal. As for Synchronous counter, the arrangement of flip flops and logic gates are clocked simultaneously.

Asynchronous Counters

The diagram of a 2-bit asynchronous counter is shown below. The exterior clock is connected to the clock input of the FF0 (first flip-flop) only. So, this FF changes the state at the decreasing edge of every clock pulse, but FF1 changes only when activated by the decreasing edge of the Q o/p of FF0. Because of the integral propagation delay through a FF, the change of the input clock pulse and a change of the Q o/p of FF0 can never occur at precisely the same time. So, the FF's cannot be activated concurrently, generating an asynchronous operation.

Synchronous Counters

In this type of counters, the CLK inputs of all the FFs are connected together and are activated by the input pulses. So, all the FFs change states instantaneously. The circuit diagram below is a three bit synchronous counter. The inputs J and K of flip-flop 0 are connected to HIGH. Flip-flop 1 has its J & K i/p connected to the o/p of flip-flop0 (FF0), and the inputs J & K of flip-flop2 (FF2) are connected to the o/p of an AND gate that is fed by the o/p of flip-flop 0 and flip-flop1. When the both the outputs of FF0 & FF1 are HIGH. The positive edge of the fourth CLK pulse will cause FF2 to alter its state because of the AND gate.

EXERCISE

- 1) Describe **TWO (2)** differences between Synchronous Counter and Asynchronous Counter.
- 2) An Asynchronous Counter has 100kHz of output frequency. If the input frequency is 10MHz, calculate:
 - a) Number of flip-flops required
 - b) Modulus of counter.
 - c) Output frequency at third flip-flop
- 3) Design an Asynchronous Counter Modulo 8 using JK flip-flop with negative edge triggered. Determine :
 - a) Number of flip-flop required
 - b) Maximum decimal number
 - c) State diagram
 - d) The truth table
 - e) The logic circuit
- 4) Explain each of the following terms with the aid of diagram :
 - a) Synchronous counter up
 - b) Asynchronous counter down
 - c) Asynchronous counter up/down
- 5) List **THREE (3)** advantages of Synchronous Counter over Asynchronous Counter.
- 6) An asynchronous up counter has 2MHz input frequency. The output frequency for the last flip-flop is 125 kHz. Determine :
 - a) The number of flip-flops required.
 - b) The frequency input for the third flip-flop.
 - c) The logic circuit.

7) Based on Figure 3(a), solve the following questions.

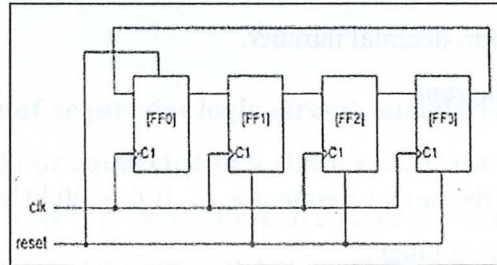


Figure 3(a)

- Identify the type of counter circuit.
 - Describe the definition of the counter.
 - List the types of flip-flops that can be used to design the counter.
 - Draw a sequence table for the counter until fourth clock pulses.
- 8) Refer to Figure 3(b), sketch a synchronous counter using JK flip-flop by following the sequence number. Illustrate :
- Excitation table.
 - The logic circuit.

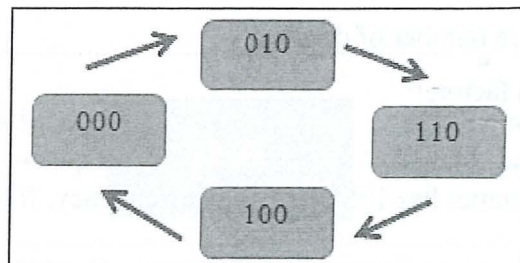


Figure 3(b)

9) Draw a decade counter using T flip-flop.

- 10) Draw the circuit of the asynchronous counter MOD 8 using JK flip-flop negative trigger. Determine :
- The number of flip-flop.
 - The maximum decimal number.
 - The state diagram.
- 11) Calculate the value of the output frequency, f_{out} if $f_{in} = 20$ kHz in each of the following asynchronous counter :
- 5 Bit
 - MOD – 9
 - MOD – 7
- 12) Draw a 3-bit Asynchronous up Counter using JK flip-flop. Assume that the flip-flops are triggered on negative edge of the clock waveform.
- Sketch the output waveform for question 11
- 13) An asynchronous counter can operate as frequency divider. If the asynchronous 6 bit counter is used as frequency divider, calculate:
- Number of flip flop required.
 - Modulus.
 - Maximum number of decimal.
 - Division factor.
- 14) An asynchronous counter has 10MHz of input frequency. If the output frequency is 1 MHz, calculate:
- MOD number of counter.
 - Number of flip flop required.
- 15) Design an asynchronous binary-up counter MOD-6 by using JK flip flop. Your answer must include:
- Number of flip flop required.
 - Maximum decimal number.

10

REGISTER

Shift registers are a type of sequential logic circuit, mainly for storage of digital data. They are a group of flip-flops connected in a chain so that the output from one flip-flop becomes the input of the next flip-flop. There are several basic types of register such as Serial in Serial out (SISO), Serial In Parallel Out (SIPO), Parallel In Serial Out (PISO) and Parallel In Parallel Out (PIPO). Two characteristics of shift register a) a temporary holds the data/memory and b) storage the data. Shift registers can be found in many applications.

Serial In, Serial Out

The input to this register is given in serial fashion i.e. one bit after the other through a single data line and the output is also collected serially. The data can be shifted only left or shifted only right. Hence it is called Serial in Serial out shift register or a SISO shift register. As the data is fed from right as bit by bit, the shift register shifts the data bits to left. A 4-bit SISO shift register consists of 4 flip flops and only three connections.

**Figure 14**

Serial In, Parallel Out

Unlike the serial in serial out shift registers, the output of Serial in Parallel out (SIPO) shift register is collected at each flip flop. Q1, Q2, Q3 and Q4 are the outputs of first, second, third and fourth flip flops, respectively. The main application of Serial in Parallel out shift register is to convert serial data into parallel data. Hence they are used in communication lines where demultiplexing of a data line into several parallel line is required.

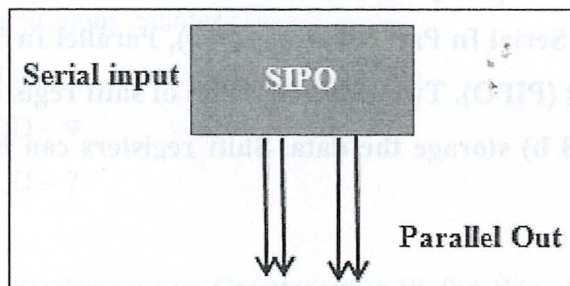


Figure 15

Parallel In, Serial Out

The input to this register is given in parallel i.e. data is given separately to each flip flop and the output is collected in serial at the output of the end flip flop. A Parallel in Serial out (PISO) shift register converts parallel data to serial data. Hence they are used in communication lines where a number of data lines are multiplexed into single serial data line.

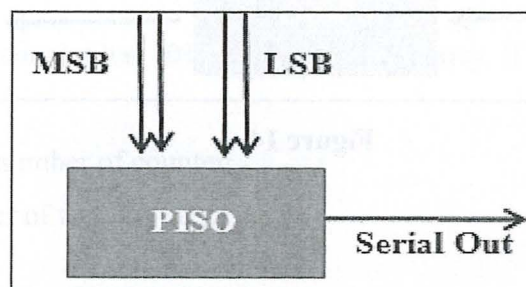


Figure 16

Parallel In, Parallel Out

In this register, the input is given in parallel and the output also collected in parallel. The clear (CLR) signal and clock signals are connected to all the 4 flip flops. Data is given as input separately for each flip flop and in the same way, output also collected individually from each flip flop.

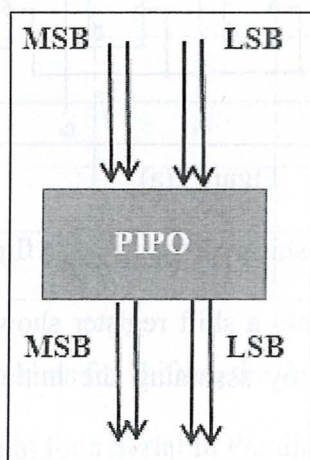


Figure 17

EXERCISE

- 1) With the aid of a diagram, compare the shift register counters.
- 2) Sketch the expected waveforms of the 4-bit binary number 1101 which were shifted in serial into the shift register as in Figure 2(a) that initially contains all 0s.

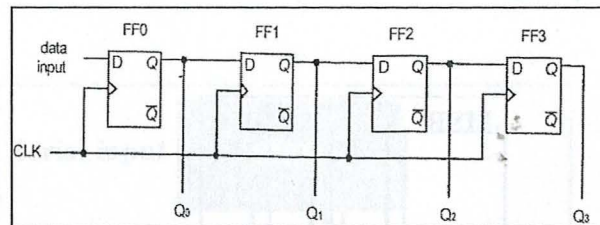


Figure 2(a)

- 3) Draw a 5-bit serial in serial out shift register using D flip-flop.
- 4) A serial data 0111 is shifted into a shift register shown in Figure 4(a). Explain the operation of the shift register by assuming the initial data in the shift register is cleared.

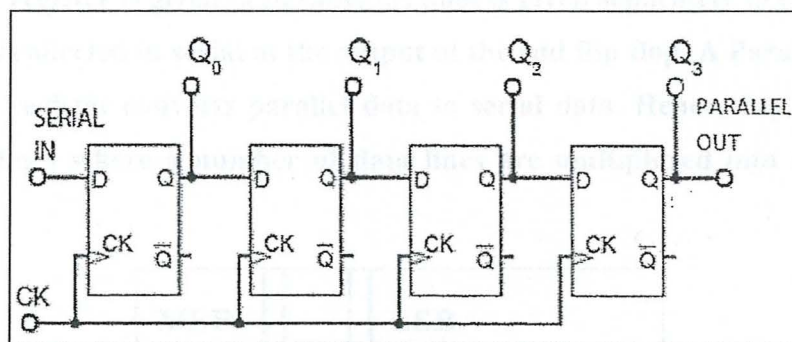


Figure 4(a)

- 5) Identify **TWO (2)** methods of shift register by using diagrams. (Use input data "10010" as reference).
- 6) If series data "1010110" is shifted to 5-bit shift register Serial In Serial Out (SISO),
 - a) Sketch the timing diagram that shows the shifted data.
 - b) Calculate the required time for 5-bit data above if the clock pulse frequency is 500 Hz and 8MHz.

- 7) Explain **THREE (3)** classes of shift register according to its input/output shifting methods using suitable diagram.
- 8) Complete the table below using the input data given and draw the output waveform using result at the table above.

Operation	Qa	Qb	Qc	Qd
Shift	1	1	0	1
1 st clock				
2 nd clock				
3 rd clock				
4 th clock				

- 9) List down FOUR (4) methods for shifting the data into shift register.
- 10) Sketch the circuit diagram for a Serial In Parallel Out 6-bit using D flip flop.
- 11) Create a table for shifting 100011 of data to the right into the serial in parallel out shift register. Assume the initial data in the shift register is cleared.
- 12) Sketch the circuit of ring counter 4-bit together with its sequence table.
- 13) Draw a timing diagram of 4-bit ring counter if the first register stores a 0100 data.

11

CONVERTER

Analog to Digital Converter

In electronics, an Analog to Digital Converter (ADC) is a device for converting an analog signal (current, voltage etc.) to a digital code, usually binary. In the real world, most of the signals sensed and processed by humans are analog signals. Analog-to-Digital conversion is the primary means by which analog signal are converted into digital data that can be processed by computers for various purposes.

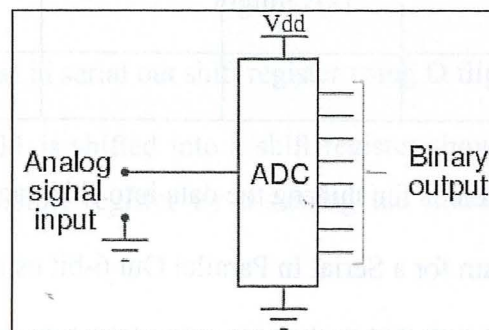


Figure 18: Block Diagram of A/D Converter

There are many types of ADC for different applications. The most inexpensive type of ADC is a Successive-Approximation ADC. Figure below shows the transfer curve of a 4-bit ADC. Inside a Successive-Approximation ADC, a series of digital codes, each corresponds to a fix analog level, are generated successively by an internal counter to compare with the analog signal under conversion. The generation is stopped when the analog level becomes just larger than the analog signal. The digital code corresponds to the analog level is the desired digital representation of the analog signal.

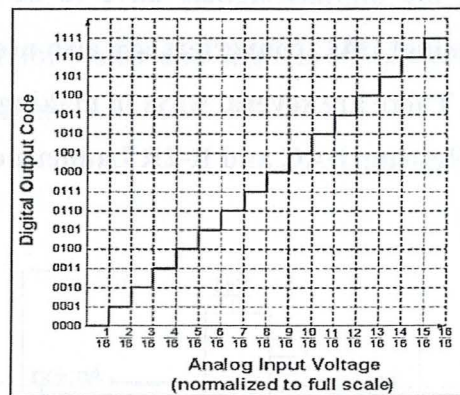


Figure 19

Digital to Analog Converter

Digital to analog converter is used to convert digital quantity DAC converter produces an output current of voltage proportional to digital quantity applied to its input. Today microcomputers are widely used for industrial control. The output of the microcomputer is a digital quantity. In many applications the digital output of the microcomputer has to be converted into analog quantity which is used for the control of relay, small motor, actuator and etc. In communication system digital transmission is faster and convenient but the digital signals have to be converted back to analog signals at the receiving terminal DAC converters are also used as a part of the circuitry of several ADC converters. There are several ways in making digital to analog converter which is Binary Weighted Resistor DAC and R-2R Ladder network.

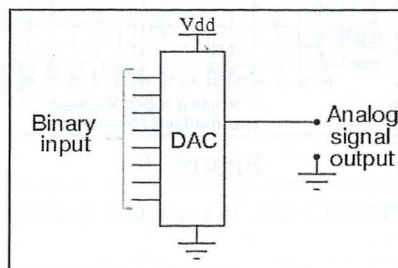


Figure 20: Block Diagram of D/A Converter

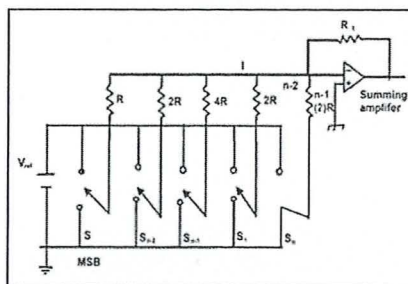


Figure 21: Binary Weighted Resistor DAC

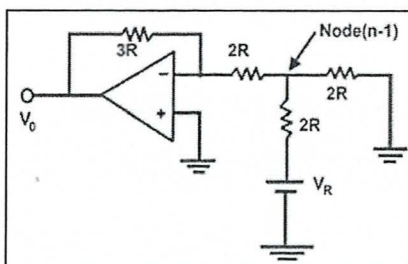


Figure 22: R-2R Ladder network

EXERCISE

- 1) Define the following terms:
 - a) Analog Signal
 - b) Digital Signal
 - c) Digital to Analog converter
 - d) Analog to Digital converter
- 2) Sketch the block diagram and symbol of DAC.
- 3) State an advantage of successive approximation ADC compared with digital ramp ADC.
- 4) By assuming the input 'low' is 0V and 'high' is 5V, determine the output of DAC in Figure 4(a) if the input data is:
 - a) 1010
 - b) 1100
 - c) 0100
 - d) 1101

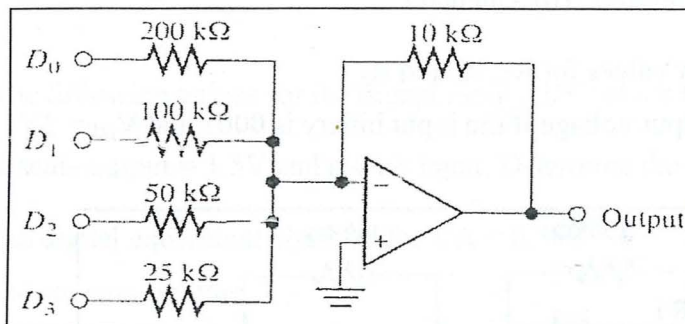


Figure 4(a)

- 5) Figure 5(a) shows the circuit of 4-bit weighted resistor DAC. The inputs are binary inputs which have the values between 0V and 10V. Calculate :

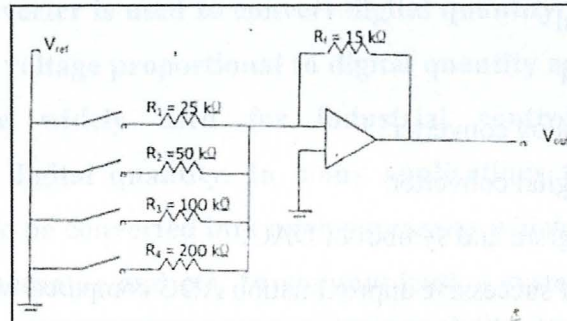


Figure 5(a)

- V_{out} if data in is 1011.
 - The converter step size. Based on the step size, construct the output voltage table for each input.
 - The percentage resolution.
 - The full scale output if R_f is reduced to 750Ω .
- 6) By referring to Figure 5(b), calculate :
- Resistor values for R_1 , R_2 and R_3
 - The output voltage if the input binary is 0001 and $V_{ref} = 3V$.

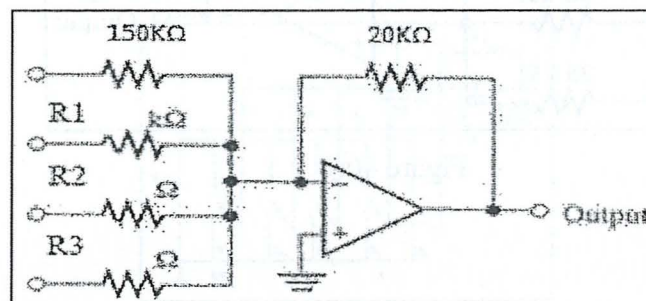


Figure 5(b)

- 7) Refer to Figure 5(c) below, given $R_1 = 150 \text{ k}\Omega$, $R_2 = 75 \text{ k}\Omega$, $R_3 = 37.5 \text{ k}\Omega$, $R_4 = 18.7 \text{ k}\Omega$ and $R_f = 20 \text{ k}\Omega$. Calculate the value of the output, V_{out} for a digital entries below :

- Binary input = 0010
- Binary input = 0101

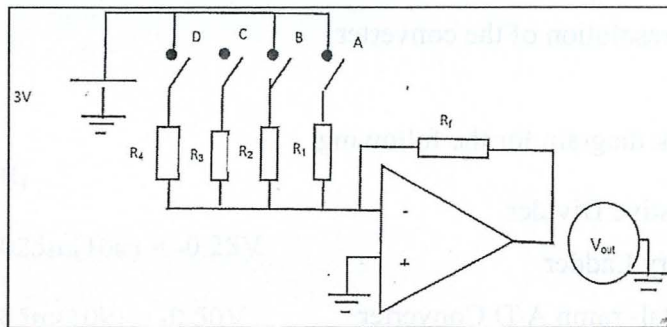


Figure 5(c)

- Sketch a 4-bit DAC with resistive divider, where the value of $D_0 = 200 \text{ k}\Omega$, $D_1 = 100 \text{ k}\Omega$, $D_2 = 50 \text{ k}\Omega$ and $D_3 = 25 \text{ k}\Omega$.
- Sketch the block diagram of ADC.
- Assume the following values for the digital ramp ADC: clock frequency = 1MHz;
DAC full-scale output = 1.5V and a 4-bit input. Determine the following values:
 - The digital equivalent obtained for $V_A = 0.78 \text{ V}$
 - The conversion time
 - The resolution of the converter

11) Assume the following values for the digital ramp ADC: clock frequency = 3MHz;

DAC full-scale output = 4.2V and a 4-bit input. Determine the following values:

- a) The digital equivalent obtained for $V_A = 0.90V$
- b) The conversion time
- c) The resolution of the converter

12) Draw a block diagram for the following.

- a) Resistive Divider
- b) Binary Ladder
- c) Digital- ramp A/D Converter
- d) Successive Approximation A/D Converter

13) Define:

- a) ADC Converter
- b) Resolution
- c) Step size

14) State TWO (2) DAC converter specifications.

15) Determine the following values:

- a) The digital equivalent obtained for $V_A = 3.728V$
- b) The conversion time
- c) The resolution of this converter.

ANSWER

4) $I_0 = 0.025\text{mA}$

$I_1 = 0.05\text{mA}$

$I_2 = 0.1\text{mA}$

$I_3 = 0.2\text{mA}$

$V_{\text{out}} = - (I_{\text{out}}) R_f$

$V_{\text{out}}(\text{D0}) = -0.025\text{m}(10\text{k}) = -0.25\text{V}$

$V_{\text{out}}(\text{D1}) = -0.05\text{m}(10\text{k}) = -0.50\text{V}$

$V_{\text{out}}(\text{D2}) = -0.1\text{m}(10\text{k}) = -1\text{V}$

$V_{\text{out}}(\text{D3}) = -0.2\text{m}(10\text{k}) = -2\text{V}$

Digital Input Data	Analog Output Voltage
1010	$V_{\text{out}} = V_{\text{out}}(\text{D1}) + V_{\text{out}}(\text{D3}) = -(0.5+2) = -2.5\text{V}$
1100	$V_{\text{out}} = V_{\text{out}}(\text{D2}) + V_{\text{out}}(\text{D3}) = -(1+2) = -3\text{V}$
0100	$V_{\text{out}} = V_{\text{out}}(\text{D2}) = -1\text{V}$
1101	$V_{\text{out}} = V_{\text{out}}(\text{D0}) + V_{\text{out}}(\text{D2}) + V_{\text{out}}(\text{D3}) = -(0.25 + 1 + 2) = -3.25\text{V}$

5) a) V_{out} if data in is 1011.

$$V_{\text{out}} = -\frac{R_f V_R}{R} \left[\frac{b_3}{2^0} + \frac{b_2}{2^1} + \frac{b_1}{2^2} + \frac{b_0}{2^3} \right]$$

$$V_{\text{out}} = -\frac{15\text{k}(10)}{25\text{k}} \left[\frac{1}{2^0} + \frac{0}{2^1} + \frac{1}{2^2} + \frac{1}{2^3} \right]$$

$$= -8.25\text{V}$$

- b) The converter step size. Based on the step size, construct the output voltage table for each input.

$$V_{out} = \frac{-15k(10)}{25k} \left[\frac{0}{2^0} + \frac{0}{2^1} + \frac{0}{2^2} + \frac{1}{2^3} \right]$$

$$= 6 \left[\frac{1}{8} \right]$$

$$= 0.75 \text{ V.}$$

- c) The percentage resolution.

$$\% \text{ resolution} = \frac{1}{\text{Total number of steps}} \times 100\%$$

$$= \frac{1}{2^n - 1} \times 100\%$$

$$= \frac{1}{2^4 - 1} \times 100\%$$

$$= 6.67\%.$$

- d) The full scale output if R_f is reduced to 750Ω .

$$V_{out} = \frac{-750(10)}{25k} \left[\frac{1}{2^3} + \frac{1}{2^1} + \frac{1}{2^2} + \frac{1}{2^3} \right]$$

$$= -0.5625 \text{ V.}$$

6. a) Resistor values for R_1 , R_2 and R_3 .

$$R_1 = 75k\Omega.$$

$$R_2 = 37.5k\Omega.$$

$$R_3 = 18.75k\Omega.$$

- b) $R_1 = 150k\Omega$

$$R_f = 20k$$

$$R_f/R_1 = 0.133\Omega$$

$$V_{out} = 0.4V.$$

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