CHAPTER 6

OSCILLATORS

F5BN3

LEARNING OBJECTIVES

While learning this Chapter, the student will

1. **Understand fundamental principles of oscillator circuits using positive feedback.**
2. **Working principles of crystal oscillators.**
3. **Understand the multivibrator functions and their types.**
4. **Study the applications of oscillator in various fields.**

INTRODUCTION

Have you heard the sound from FM radio receiver or a beeper or a horn? How the sound is generated? What is the source of the sound? All these questions have only one answer, i. e. the sound is generated by an oscillator.

Any circuit, which is used to generate an ac voltage without an ac input is called an oscillator. The oscillator circuit needs energy from a DC source. It is widely used in electronic equipment. For example, in Radio and Television receivers, oscillators are used to generate high frequency wave called carrier wave. Oscillator generates both sinusoidal (sine) and non-sinusoidal (square, rectangle, triangular, sawtooth, etc.) waveforms.

History of Oscillator

In 1912, E. H. Armstrong and Lee Deforests developed a new device audion (triode vacuum tube), by coupling one terminal of the device to another. Armstrong achieved the first electronic amplifier with large gain. He called the process "regeneration" (positive feedback). Further, he had made the first electronic oscillator. These two made a revolution in radio broadcasting.

Armstrong had created components necessary to make continuous wave (CW) radio practicable. Primarily, at that time radio was similar to wireless telegraphy (i.e., dots and dashes) and hence CW radio was used to transmit audio information. With Armstrong oscillator, CW signals at high frequencies in the range of kHz to MHz could be easily generated.

E. H. Armstrong

6.1. CLASSIFICATION OF OSCILLATORS

Oscillators are classified based on different methods and are summarized in the following sub-sections.

6.1.1. According to the Waveforms Generated

Sinusoidal oscillator: If the output voltage is a sine wave function of time the oscillator is called as "sinusoidal" or Harmonic oscillator. Positive feedback and negative resistance oscillators belong to this category. The waveform generated by the sinusoidal oscillator is shown in Figure 6.1(a)

Non sinusoidal (or) Relaxation Oscillator: This type of oscillators has non-sinusoidal output such as a square, triangular and sawtooth waveforms. The waveform generated by Non sinusoidal oscillator shown in Figure 6.1(b)

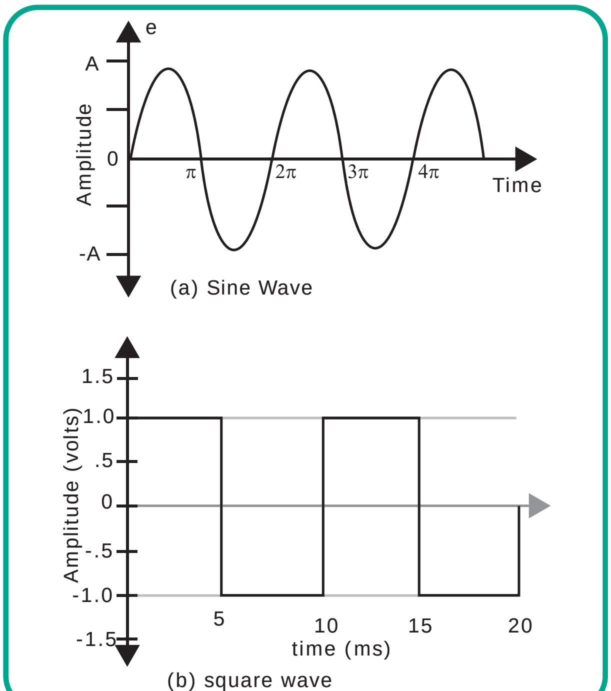

Figure 6.1 (a) Sine Wave, (b) square wave

6.1.2. According to the Fundamental Mechanism Used

1. Negative Resistance Oscillators
2. Feedback Oscillators

Negative resistance oscillator has the negative resistance amplifying device to neutralize the positive resistance of the oscillator. Feedback oscillator uses positive feedback in the feedback amplifiers to satisfy the Barkhausen criterion

6.1.3. According to the Frequency Generated

1. Audio frequency (AF) oscillator: 20Hz to 20 kHz
2. Radio frequency (RF) oscillator 20 kHz-30 MHz
3. Very high frequency (VHF) oscillator: 30 MHz-300 MHz
4. Ultra high frequency (UHF) oscillator: 300 MHz-3 GHz
5. Microwave frequency oscillator: above 3GHz

6.2. TYPES OF SINUSOIDAL OSCILLATION

Sinusoidal oscillation can be of two types

1. Damped oscillation
2. Undamped oscillation

6.2.1. Damped Oscillation

Figure 6.2(a) shows the damped oscillation. In this type of oscillators, during each oscillation, some energy is lost due to electrical losses (I^2R).The amplitude of the oscillation reduced to zero, when no compensating arrangement for the electrical losses is provided.

6.2.2. Undamped Oscillation

Figure 6.2(b) shows the undamped oscillations. In these types, the amplitude of each oscillation remains constant with time. Although the electrical system in which these oscillations are being generated has losses, but now right amount of energy is being supplied to overcome these losses. Therefore, the generated wave remains constant. It is also called as sustained oscillations. These continuous waves are produced by electronic oscillator circuits for utilizing in various electronic equipment.

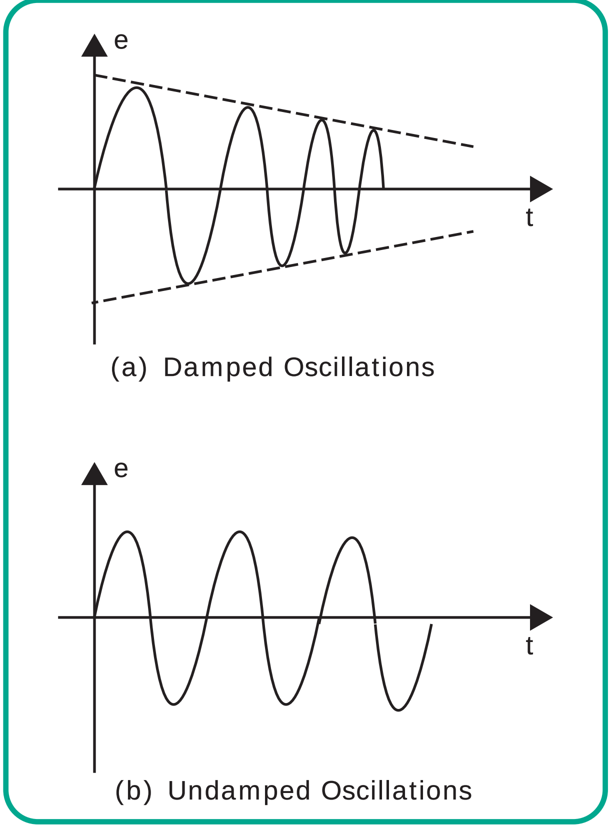

Figure 6.2 **Damped and Undamped Oscillations**

6.3. ESSENTIAL PARTS OF AN OSCILLATOR

Figure 6.3 shows the block diagram of an oscillator. Its essential components are:

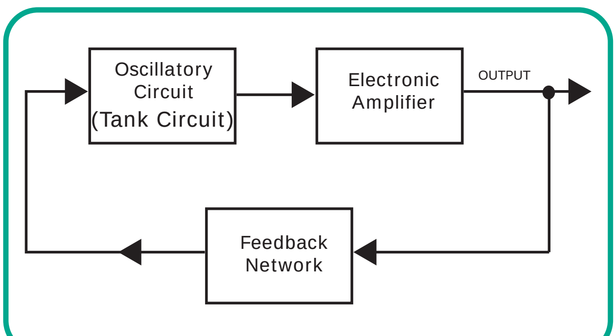

Figure 6.3 **Block Diagram of an Oscillator**

Tank Circuit: It consists of inductor or coil (L) and capacitor (C). The frequency of oscillation depends upon the values of inductance of the coil and capacitance of the capacitor.

Transistor Amplifier: The transistor amplifier receives DC power from the battery and changes it into AC power for supplying to the tank circuit. The main function of the amplifier is to amplify the generated oscillation from the tank circuit.

Feedback Circuit: This circuit provides positive feedback to the oscillator. It gives a part of amplifier output to the tank circuit in correct phase to make oscillation as undamped (constant amplitude).

6.4. FEEDBACK IN OSCILLATOR

In feedback, a part of the output signal is fedback to the amplifier input in such a way that the feedback signal re-generates, re-amplifies and sustain the feedback to maintain a constant output Signal.

Commonly an oscillator is constructed from an amplifier that has part of its output signal feedback to the input. This is done in such a way to keep the amplifier producing signal without the need for any external signal input as shown in the Figure 6.4. Here, the DC supply is converted into AC signal.

6.4.1. Positive Feedback

The feedback in the amplifier section of an oscillator must be positive feedback. Here a fraction of the amplifier output signal is feed-back as input. Note that the feedback signal is in phase with the input signal. As a result, the amplitude of the signal is increased.

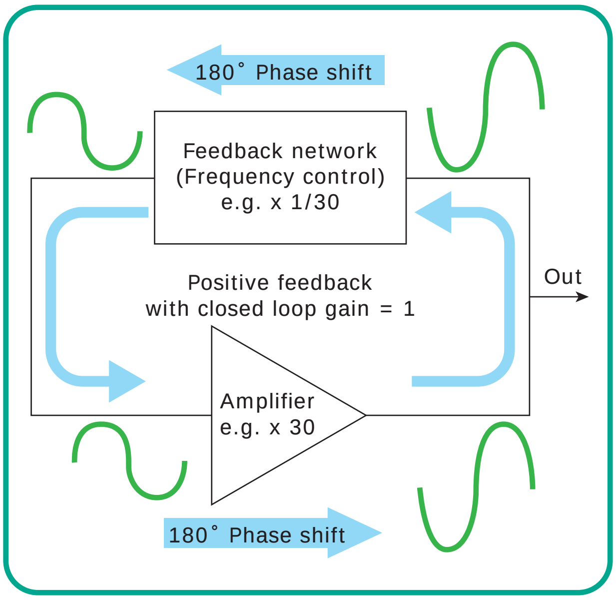

Figure 6.4 **Positive Feedback**

For example, common emitter amplifier creates a phase shift of 180° between its input and output. Similarly, the positive feedback loop also produce a 180° phase shift in the signal feedback from output to input in order to provide positive feedback.

The result of small amount of positive feedback in amplifiers results in higher gain, at the cost of increased noise and distortion. If the amount of positive feedback is large enough, the result is oscillation where the amplifier circuit produces its own signal.

6.4.2. Using Positive Feedback

When an amplifier is operating without feedback is called as "open-loop" mode and with feedback *(either +ve or -ve)*, is known as "closed-loop" mode. In ordinary amplifiers, negative feedback is used to provide advantages in bandwidth, distortion and noise generation, and in these circuits the closed-loop gain of the amplifier is much less than the open-loop gain. However, when positive feedback is used in an amplifier system, the closed-loop gain (with feedback) will be greater than the open-loop gain; the amplifier gain is now increased by the feedback. Additional effect of positive feedback are reduced bandwidth, (but this does not a matter in an oscillator producing a sine wave having a single frequency), and increased distortion. However, even severe distortion in the amplifier is allowed in some sine wave oscillator designs, where it does not affect the shape of the output waveform.

In oscillators using positive feedback, it is important that amplitude of the oscillator output remains stable. Therefore, the closed loop gain must be 1 (unity). In other words, the gain within the loop (provided by the amplifier) should exactly match the losses (caused by the feedback circuit) within the loop. In this way, there will be no increase or decrease in the amplitude of the output signal as shown in the waveform 6.5.

This is achieved by Barkhausen criteria given by $|A\beta| = 1$.

where A is the amplifier gain and β is the transfer function of feedback.

6.4.3. The Condition for Oscillation

Positive feedback must occur at a frequency where the voltage gain of the amplifier is equal to the losses (attenuation) occurring in the feedback path. For example, 1/30 of the output signal feedback to be in phase with the input at a particular frequency, and the gain of the amplifier (with feedback) is 30 times or more, thus oscillation should take place. The conditions for oscillation are, (i) the oscillations should take place at one particular frequency and (ii) the amplified output of the oscillation should be constant.

There are many different oscillator designs in use, each design achieving the above criteria in different ways; some designers are particularly suited to producing certain wave shapes or work best within certain band of frequencies. Whatever design is used, the way of achieving a signal of constant frequency and constant amplitude, by using one or more of the following three basic methods.

Method 1: Make sure that positive feedback occurs only at one frequency of oscillation. This may be achieved by ensuring that only signal of the required frequency are feedback or by ensuring feedback signal is the correct in-phase at only one frequency.

Method 2: Make sure that sufficient amplification for oscillation can take place only the required frequency by using an amplifier that has an extremely narrow bandwidth extending to the frequency of oscillation only.

Method 3: Use amplifiers in "Switch mode" to switch the output between two set voltage levels together with some form of time delay to control the time at which the amplifiers switch-on or off, thus controlling the period of the signal produced.

Methods 1 and 2 are used extensively in sine wave oscillators.

Method 3 is used in square wave generators (multivibrator).

6.4.4. Constant Amplitude

As shown in Figure 6.4, oscillators must have an amplifier, a positive feedback loop and some method of controlling the frequency of oscillation. In RF sine wave oscillator, the frequency may be controlled by an LC tuned circuit, but as well as controlling the frequency of oscillation, there must be some means, such as negative feedback for stabilizing the amplitude of signal produced.

Without this stabilization, the oscillations would either die away and stop (damped oscillation) or rapidly increased in amplitude until the amplifier produces severe distortions due to the transistors within the amplifier becoming "saturated" as shown in Figure 6.5. To produce constant amplitude output the gain of the amplifier is automatically controlled during oscillation.

6.5. TYPES OF OSCILLATOR

There are several types of transistor oscillators commonly used in electronic circuits. Three important types of oscillators are

1. Hartley Oscillator,
2. RC Phase Shift Oscillator,
3. Crystal Oscillator

6.5.1. Crystal Oscillator

The transistor crystal oscillator resembles Colpitts oscillator modified to act as crystal oscillator. The only change is the addition of

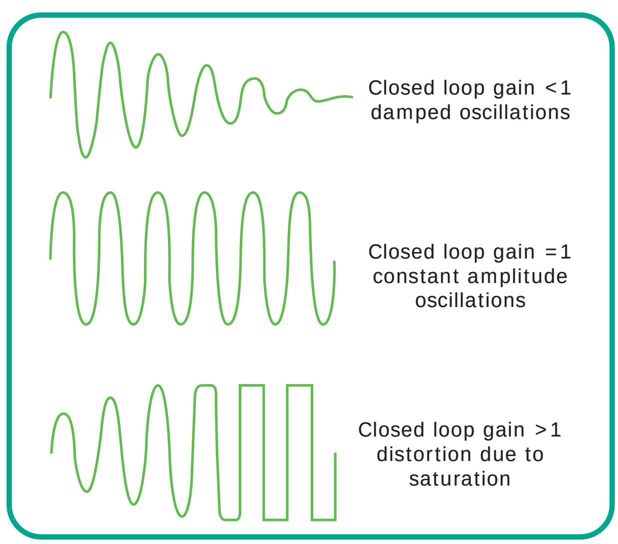

Figure 6.5 Constant Amplitude

the crystal (Y) in the feedback network. It replaces the LC resonant circuit.

History: Piezoelectricity was discovered by Jacques and Pierre Curie in 1880. Paul Langevin first investigated quartz resonators for use in sonar during World War I. The first crystal controlled oscillator using a crystal of Rochelle salt was built in 1917 and patented in 1918 by Alexander M. Nicholson at Bell Lab, although his priority was disputed by Walter Guyton Cady. Cady built first quartz crystal oscillator in 1921.


W. G. Cady

The crystal is a thin slice of piezoelectric material, such as quartz, tourmaline and Rochelle salt, which exhibits a property called piezoelectric effect. It means the crystal reacts to any mechanical stress by producing electric charge, in the converse effect, an electric field results in mechanical strain. The advantage of the crystal is its very high Q as a resonant circuit, which results in good frequency stability for the oscillator.

Circuit Description: In the circuit shown in Figure 6.6, the resistors R_1 and R_2 form the voltage divider network, while the emitter resistor R_E stabilizes the circuit. Further, C_E acts as an AC by pass capacitor, while the coupling capacitor C_i is used to block DC signal propagation between collector and base terminals. The RF coil in the circuit which offers dual advantages, as it provides even the DC bias and frees the circuit output from being affected by the AC signal on the power lines.

Working Principle: When the supply is switched 'ON', the capacitor C_1 is charged. It fully charged, then starts discharging through the crystal and produces oscillation. The frequency of the oscillation depends upon the values of C_1, C_2 and the RLC values of the crystal. If the frequency of the oscillation is equal to its crystal resonant frequency, the circuit produces more stable oscillations.

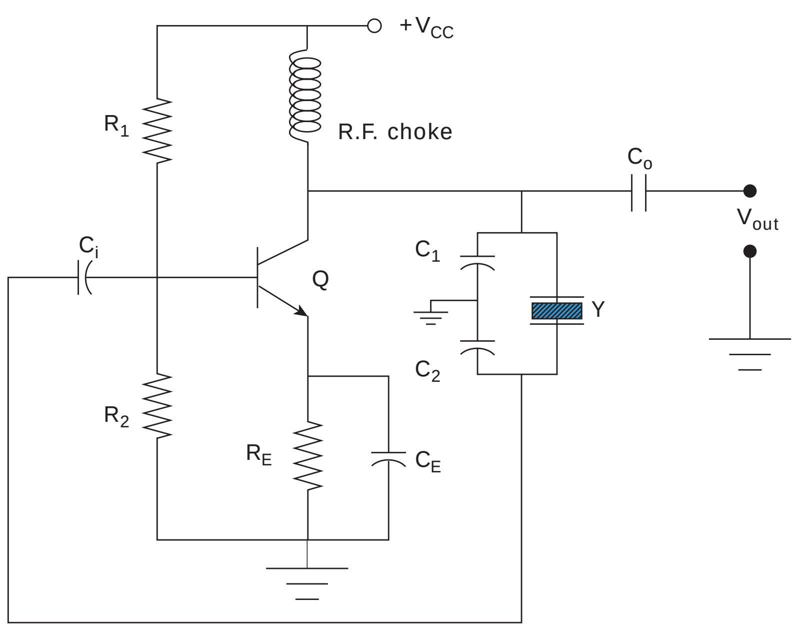

Figure 6.6 Crystal Oscillator

The crystal frequency is dependent on temperature.

Advantages

1. High 'Q' factor
2. Excellent frequency stability
3. Simple circuit

Disadvantages

1. Not to be used as tuned oscillators
2. Crystal is fragile type, hence it is used only in low power circuits

6.5.2. Application of crystal oscillator

Crystal oscillators are used in the microprocessor and microcontroller for providing the clock signals. It generates clock pulses required for the synchronization of all the internal operations. The use of crystal oscillator in military and aerospace is to establish an efficient communication system for navigation purpose in the guidance systems.

The oscillator is used in research and measurement of celestrial navigation, space tracking purpose, and the timing signal in the measuring instruments and medical devices. There is variety of industrial applications of crystal oscillator such as computers, digital systems, marine, modems, sensors, telecommunications and disk drives. It is used in automotive field by engine controlling, stereo and in GPS system. It is also used in consumer applications like TV systems, PCs, video games, toys, radio systems and cellular phones.

6.6. MULTIVIBRATORS

Multivibrators are two stage switching circuits in which the output of the first stage is fed to the input of the second stage and vice versa. The outputs of the two stages are complementary (high or low). A specific characteristic of multivibrator is that it uses passive elements like resistor and capacitor to determine the output state.

Multivibrators are of three types namely

1. Astable multivibrator
2. Monostable multivibrator
3. Bistable multivibrator

6.6.1. Astable Multivibrator

The astable or free running multivibrator generates square wave without any external triggering pulse. It has no stable states, i.e. it has two quasi-stable states. It switches back and forth from one state to the other, remaining in each state for a time depending upon the discharging of a capacitive circuit.

6.6.2. Monostable Multivibrator

Monostable multivibrator has one stable and one quasi-stable. It is also known as one- shot multivibrator. In this, the output pulse duration is determined by the RC time constant and is given as $1.11 * R * C$. This multivibrator cannot generate square waves of its own like an astable multivibrator. One external triggering pulse will cause it to generate the rectangular waves.

6.6.3. Bistable Multivibrator

The bistable multivibrator has two stable states. A triggering pulse is applied to the circuit causes it to switch from one state to other. Another trigger pulse is then required to switch the circuit back to its original state.

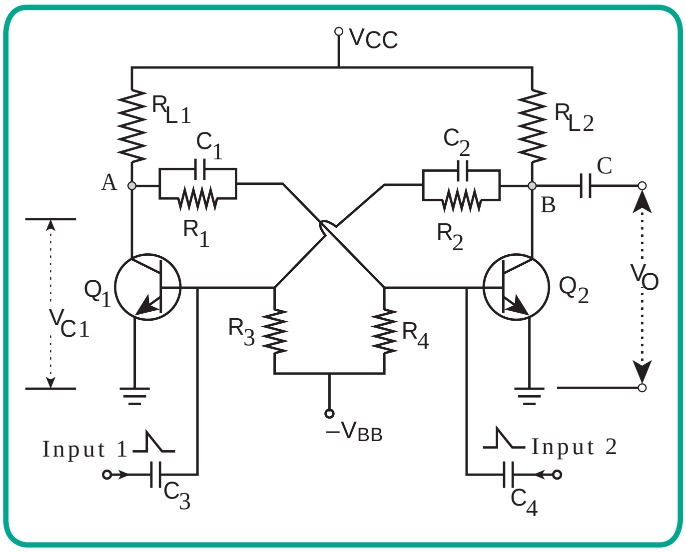

Figure 6.7 Bistable Multivibrator

Construction: Figure 6.7 shows the circuit of a bistable multivibrator using two NPN transistors. In this circuit, the output of a transistor Q_2 is coupled to the base of transistor Q_1 through a resistor R_2. Similarly, the output of Q_1 is coupled to the base of Q_2 through resistor R_1. The main purpose of capacitors C_1 and C_2 is to improve the switching characteristic of the circuit by passing the high frequency components of the square wave pulses. This allows fast rise and fall times, so that these square waves will not be distorted. C_1 and C_2 are called commutating capacitors or speed up capacitors.

Working Principle: When the circuit is switched-ON, one of the transistors will start conduct slightly higher than the other. This transistor is thus driven into saturation (i.e. ON). Then, because of the regenerative feedback action, the other transistor is taken into cut-off (i.e. OFF) state. Let us consider transistor Q_1 is ON and Q_2 is OFF. It is a stable state of the circuit and will remain in this state till a trigger pulse is applied from outside. A positive triggering pulse applied to the reset input (base of Q_2) increases its forward bias, thereby turning transistor Q_2 ON, and there is an increase in collector current and decrease in collector voltage occur. The fall in the collector voltage is coupled to the base of Q_1, which in turn turned OFF. The circuit is then in its second stable state until a positive trigger pulse is applied to the base of Q_1.

A similar action can be achieved by applying a negative pulse at the set input for transition from the first stable state to the second stable state and by applying a negative pulse at the reset input, reverse transition can be obtained.

Applications

1. It is used in computer memory circuits.
2. It is used as memory element in shift registers, counters and so on.
3. It can also be used as a frequency divider.

LEARNING OUTCOMES

Through this Chapter, the student will

1. **Acquire basic knowledge in sinusoidal and non sinusoidal waves.**
2. **Understand how the oscillator circuit is essential for communication equipment.**
3. **Understand the use of positive feedback in an oscillator.**
4. **Understand bistable multivibrator as the foundation of digital electronics.**

QUESTIONS

PART A

I Choose the correct answer 1Mark

1. An oscillator converts ………………..
   a) AC power into DC power
   b) DC power into AC power
   c) Mechanical power into AC power
   d) AC power into Mechanical power

2. In an LC transistor oscillator, the active device is …………
   a) LC tank circuit b) Biasing circuit
   c) Transistor d) RC circuit

3. An oscillator produces ………… oscillations
   a) Damped b) Undamped
   c) Modulated d) None of the above

4. Crystal oscillator is commonly used in ……………..
   a) Radio receivers b) Radio transmitters
   c) TV receivers d) TV transmitters

5. In a crystal, the piezoelectric effect causes …………..
   a) A voltage is developed because of mechanical stress
   b) A change in resistance occurs because of temperature
   c) change in frequency occurs because of temperature
   d) None of the above

6. The crystal oscillator frequency is very stable due to ………. of the crystal.
   a) Rigidity b) Vibrations
   c) Low Q d) High Q

7. Astable multivibrator is ………. in any state.
   a) Stable b) Unstable
   c) Saturated d) Unsaturated

8. Bistable multivibrator is ………… in any state.
   a) Stable b) Unstable
   c) Saturated d) Independent

9. A monostable multivibrator has ……….
   a) Unstable state b) One stable state
   c) Two stable state d) Tristable state

10. Circuit which consists of a quasi-stable state is called ………………
    a) Bistable circuit b) Monostable circuit
    c) Tristable circuit d) Tristate circuit

PART B

II Answer in few sentences 3 Marks

1. What is an oscillator? How is it classified?
2. What is meant by piezoelectric effect?
3. How will you produce square wave?
4. What are the types of transistor oscillator?
5. What is positive feedback in an oscillator?
6. What is multivibrator? Give its types.
7. Give merits and demerits of crystal oscillator.

PART C

III Explain the following questions 5 Marks

1. Explain damped and undamped oscillation with waveform diagram.
2. Draw and explain the essentials parts of an oscillator.
3. Write short notes on Astable and Monostable multivibrators.
4. Why positive feedback is much needed in an oscillator function? Justify it.

PART D

IV Answer the following questions in detail 10 Marks

1. Draw and explain the working functions of crystal oscillator.
2. Explain the construction and working principle of bistable multivibrator with circuit diagram.

ANSWERS

1. (b) 2. (c) 3. (b) 4.(a) 5. (a)

6. (d) 7. (b) 8. (a) 9. (b) 10. (b)