

LAGOS CITY POLYTECHNIC

LECTURE NOTE

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UNDERSTAND THE FEEDBACK EFFECTS IN ELECTRONIC CIRCUITS

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CHAPTER TWO:

UNDERSTAND THE PROPERTIES OF A PID CONTROLLER & APPLICATION

- understand the circuit of a simple PID controller as a Proportional, Integral and Derivative function
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EXPLAIN HOW OSCILLATORS CAN BE PRODUCED FROM AN AMPLIFIER WITH POSITIVE FEEDBACK

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CHAPTER ONE

THE FEEDBACK EFFECTS IN ELECTRONIC CIRCUITS

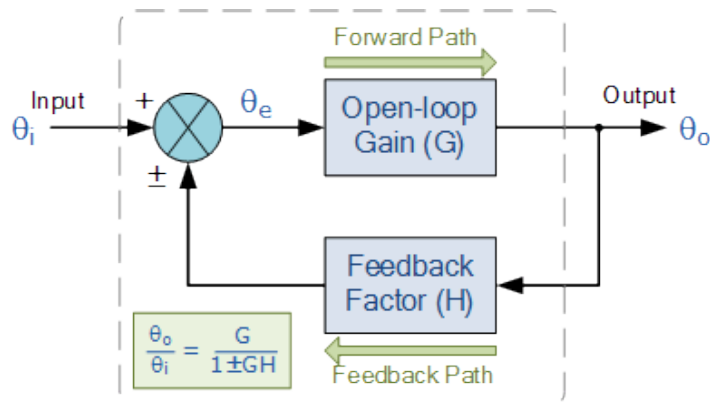
Feedback is the process whereby a signal derived in the output section of the amplifier is fed back into the input section. In this way, the amplifier can be used to provide characteristics which differ from those of the basic amplifier. The signal being fed back can either be a voltage or a current, being applied in series or shunt respectively with the input signal.

Feedback is one of the fundamental processes in nature. It is a mechanism of the control we use to drive an automobile at constant speed, of maintaining constant internal body temperature and of natural population control in an ecosystem.

Feedback Systems process signals and as such are signal processors. The processing part of a feedback system may be electrical or electronic, ranging from a very simple to a highly complex circuits.

Simple analogue feedback control circuits can be constructed using individual or discrete components, such as transistors, resistors and capacitors, etc, or by using microprocessor-based and integrated circuits (IC's) to form more complex digital feedback systems.

The basic model of a feedback system is given as:



Feedback System Block Diagram Model

As we have seen, open-loop systems are just that, open ended, and no attempt is made to compensate for changes in circuit conditions or changes in load conditions due to variations in circuit parameters, such as gain and stability, temperature, supply voltage variations and/or external disturbances. But the **effects of these** "open-loop" variations can be eliminated or at least considerably reduced by the introduction of **Feedback**.

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system.

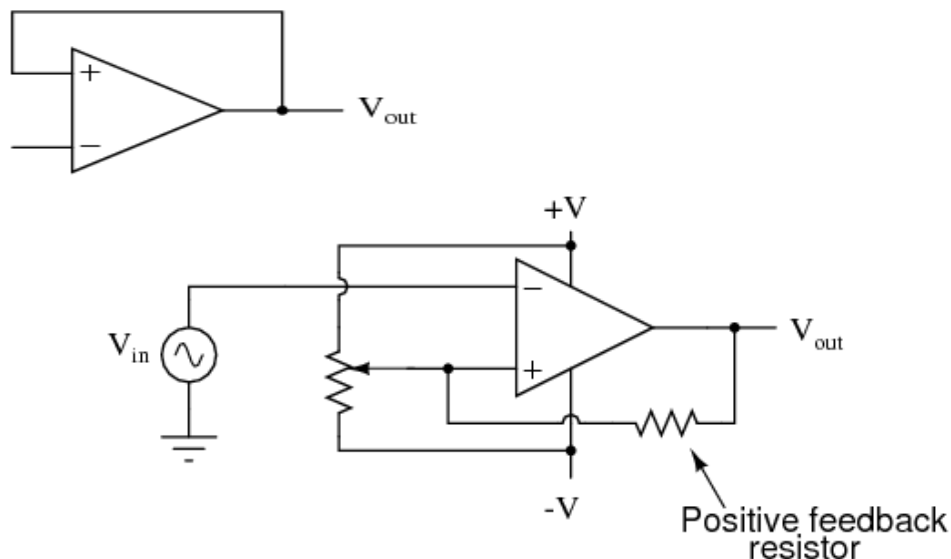
The feedback portion if appropriately applied, tends to make systems self-regulating. Depending on the relative polarity of the signal being fed back into a circuit, one may have **negative** or **positive** feedback.

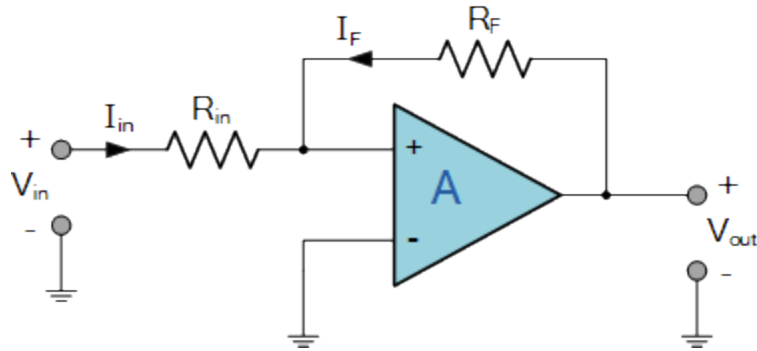
Feedback Systems are very useful and widely used in amplifier circuits, oscillators, process control systems as well as other types of electronic systems. But for feedback to be an effective tool it must be controlled as an uncontrolled system will either oscillate or fail to function.

POSITIVE FEEDBACK

It occurs when the feedback signal is in phase with the input signal i.e., the feedback signal will add to or “**regenerate**” the input signal. The result is a larger amplitude output signal than would occur without feedback. Positive Feedback (PFB) amplifies an effect by it having an influence on the process which gave rise to it. For example, when part of an electronic output signal returns to the input, and is in phase with it, the system gain is increased.

Positive feedback



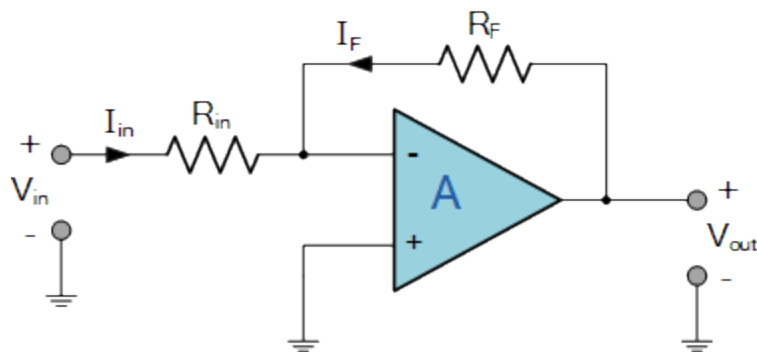


When the **feedback energy** (voltage or current) is **in phase** with the input signal and thus aids it, it is called **positive feedback**. This is illustrated in the figure above. Both amplifier and feedback network introduce a phase shift of 180° . The result is a 360° phase shift around the loop, causing the **feedback voltage V_f** to be in phase with the input signal **V_{in}** .

The positive feedback increases the gain of the amplifier. However, it has the **disadvantages** of Increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in **oscillators**. As we shall see later, if positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

Negative feedback:

When the feedback energy (voltage or current) is **out of phase** with the input signal and thus opposes it, it is called **negative feedback**. This is illustrated in figure below.



As you can see, the amplifier introduces a **phase shift of 180°** into the circuit while the feedback network is so designed that it introduces no phase shift (*i.e.*, 0° phase shift). The result is that the **feedback voltage V_f** is 180° out of phase with the input signal **V_{in}** .

Negative feedback reduces the gain of the amplifier. However, the **advantages** of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances. It is due to these advantages that negative feedback is **frequently employed in amplifiers**.

A feedback amplifier has two parts viz an amplifier and a feedback circuit. The feedback circuit usually consists of resistors and returns a fraction of output energy back to the input.

Typical values have been assumed to make the treatment more illustrative. The output of the amplifier is 10 V. The fraction m_v of this output *i.e.* 100 mV is feedback to the input where it is applied in series with the input signal of 101 mV. As the feedback is negative, therefore, only 1 mV appears at the input terminals of the amplifier

Gain of amplifier without feedback,

$$A_v = \frac{10 \text{ V}}{1 \text{ mV}} = 10,000$$

Fraction of output voltage feedback, $m_v = \frac{100 \text{ mV}}{10 \text{ V}} = 0.01$

Gain of amplifier with negative feedback, $A_{vf} = \frac{10 \text{ V}}{101 \text{ mV}} = 100$

The following points are worth noting:

(i) When negative voltage feedback is applied, the gain of the amplifier is reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only 100.

(ii) When negative voltage feedback is employed, the voltage *actually* applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV so that voltage applied at the input of the amplifier is only 1 mV.

(iii) In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.

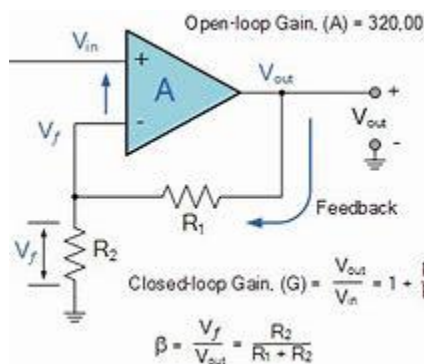
(iv) The gain with feedback is sometimes called *closed-loop gain* while the gain without feedback is called *open-loop gain*. These terms come from the fact that amplifier and feedback circuits form a “loop”. When the loop is “opened” by disconnecting the feedback circuit from the input, the amplifier's gain is A_v , the “open-loop” gain. When the loop is “closed” by connecting the feedback circuit, the gain decreases to A_{vf} , the “closed-loop” gain.

(Note that amplifier and feedback circuits are connected in *series-parallel*. The inputs of amplifier and feedback circuits are in *series* but the outputs are in *parallel*. In practice, this circuit is widely used).

(Since with negative voltage feedback the voltage gain is decreased and current gain remains unaffected, the power gain $A_p (= A_v \times A_i)$ will decrease. However, the drawback of reduced power gain is offset by the advantage of increased bandwidth.

Solved Problems Examples

1. In a negative voltage feedback amplifier (NVFB) amplifier shown below. If without feedback, $A_v = 10,000$, $Z_{in} = 10\text{k}\Omega$, $Z_{out} = 100\Omega$. If $R_1 = 10\text{k}\Omega$ and $R_2 = 90\text{k}\Omega$



Find:

- Feedback fraction
- Gain with feedback
- Input impedance with feedback\
- Output impedance with feedback

Solutions:

(a) Feedback fraction : $m_v = \frac{R_1}{R_1 + R_2} = \frac{10\text{k}\Omega}{(10 + 90)\text{k}\Omega} = 0.1$

(b) Gain with feedback : $A_{vf} = \frac{A_v}{1 + A_v m_v} = \frac{10,000}{1 + (10,000 \times 0.1)} = 10$

- (c) Input impedance increases with negative feedback and is given as :

$$Z_{in} = (1 + A_v m_v) Z_{in} = (1 + 10,000 \times 0.1) \times 10\text{k}\Omega = 10\text{M}\Omega$$

(d) Output impedance is decreased with NFB and is given by : $Z_{out} = \frac{Z_{out}}{1 + A_v m_v}$

$$= A_{vf} = \frac{100\Omega}{(1 + 10,000 \times 0.1)} = \frac{100}{1001} = 0.1$$

- The gain and distortion of an amplifier are 150 and 5% respectively without feedback. If the stage has 10% of its output voltage applied as negative FB. Find the distortion of the amplifier with feedback.

Solution:

Gain without FB: $A_v = 150$

Distortion without feedback : $D = 5\% = 0.05$

Feedback fraction, $m_v = 10\% = 0.1$

$$\text{If } D_{vf} \text{ is the distortion with negative FB, then } D_{vf} = \frac{D}{1 + A_v m_v}$$

$$= \frac{0.05}{1 + (150 \times 0.1)} = 0.00313 = 0.313\%$$

It may be seen that by the application of NFB voltage, the amplifier distortion is reduced from 5% to 0.313%

ASSIGNMENT

- State five application areas each, of negative feedback and positive feedback
- List five advantages of negative feedback over positive feedback
- An amplifier is required with a voltage gain of 100 which does not vary by more than 1%. If it is to use negative feedback with a basic amplifier the voltage gain of which can vary by 20%, determine the minimum voltage gain required and the feedback factor.

QUIZ

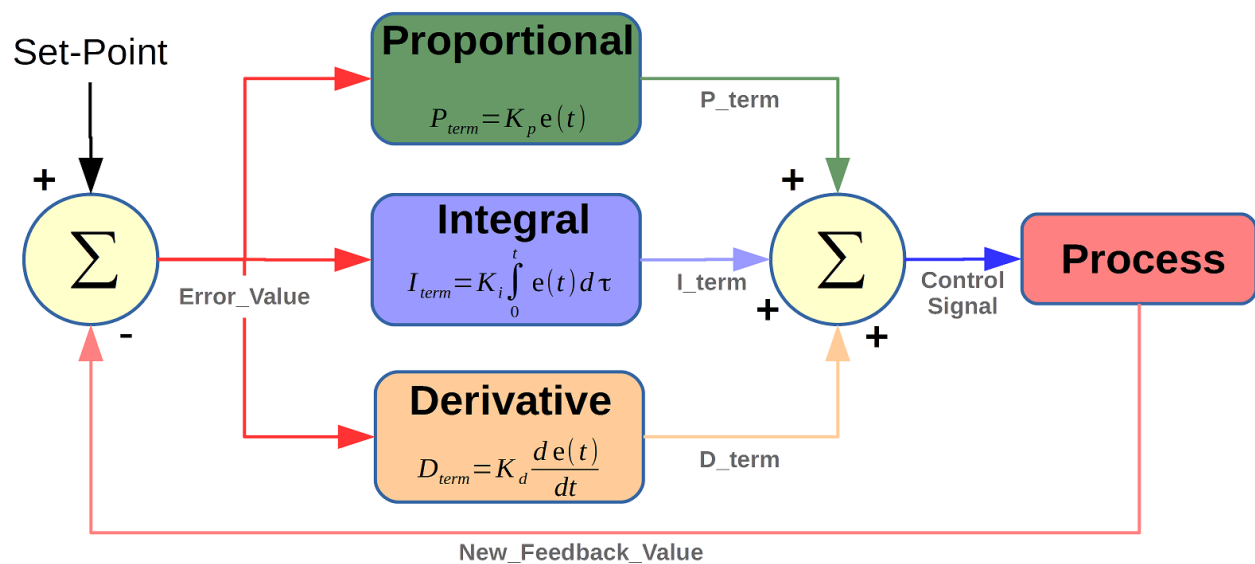
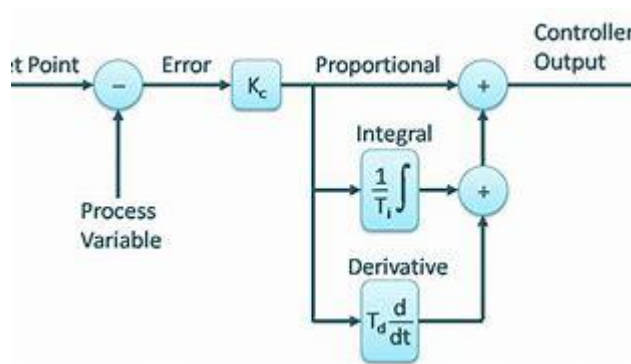
- The gain of an amplifier without feedback is 50 whereas with negative voltage feedback, it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.
- The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative voltage feedback is introduced in the circuit. Given that feedback fraction $m_v = 0.01$.

CHAPTER TWO

THE PROPERTIES OF A PID CONTROLLER & APPLICATION

Reference: (<https://www.electricaltechnology.org/>)

A **proportional–integral–derivative controller** (PID controller or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control.

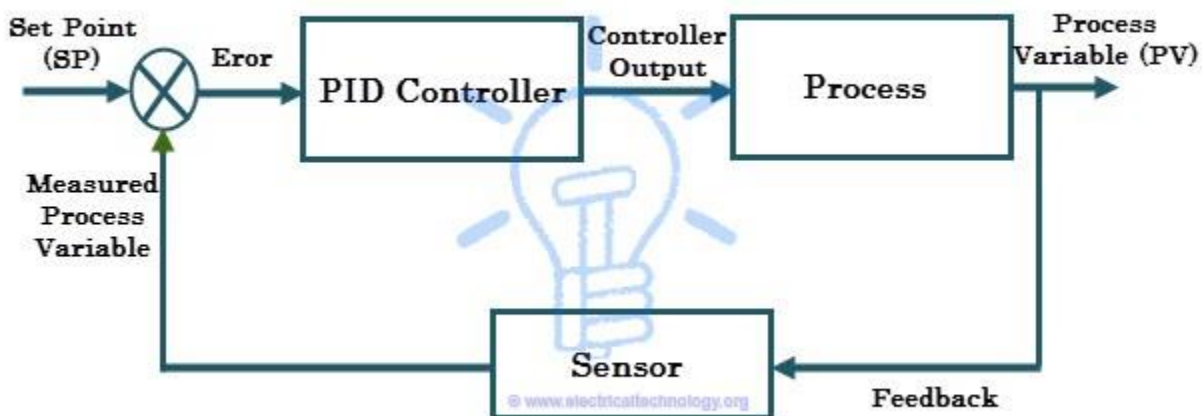


A PID controller continuously calculates an error value $\{e(t)\}$ as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name.

PID Controller is a most common control algorithm used in industrial automation & applications and more than 95% of the industrial controllers are of PID type. PID controllers are used for more precise and accurate control of various parameters.

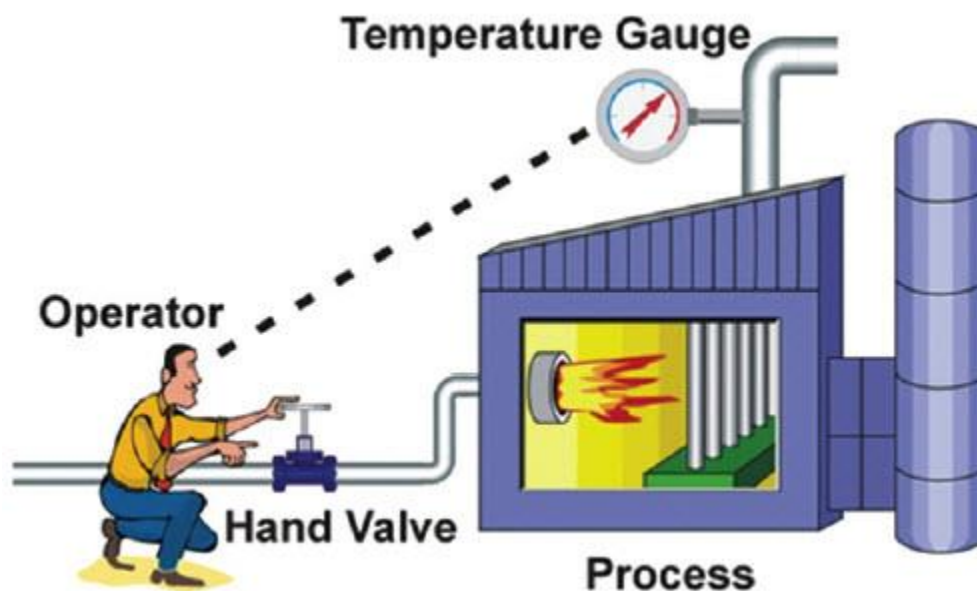
Most often these are used for the regulation of temperature, pressure, speed, flow and other process variables. Due to robust performance and functional simplicity, these have been accepted by enormous industrial applications where a more precise control is the foremost requirement.

It gets the input parameter from the sensor which is referred as actual process variable. It also accepts the desired actuator output, which is referred as set variable, and then it calculates and combines the proportional, integral and derivative responses to compute the output for the actuator.



Working of PID Controller

In manual control, the operator may periodically read the process variable (that has to be controlled such as temperature, flow, speed, etc.) and adjust the control variable (which is to be manipulated in order to bring control variable to prescribed limits such as a heating element, flow valves, motor input, etc.). On the other hand, in automatic control, measurement and adjustment are made automatically on a continuous basis.



made to produce one or combination of control actions. These control actions include

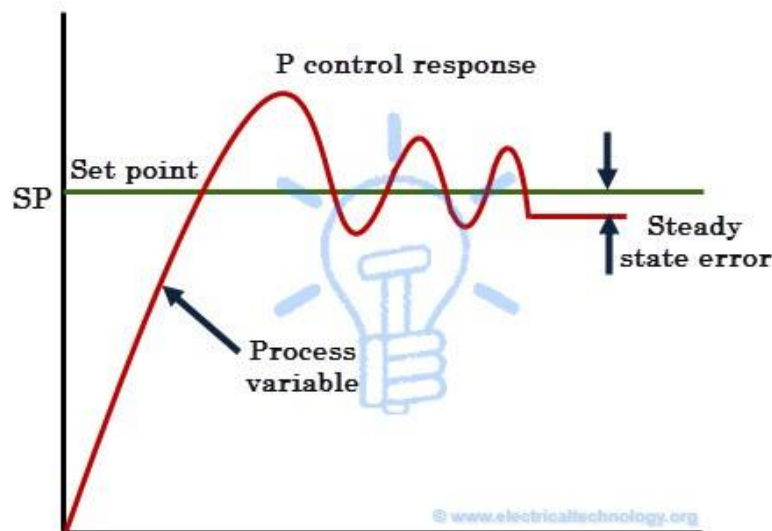
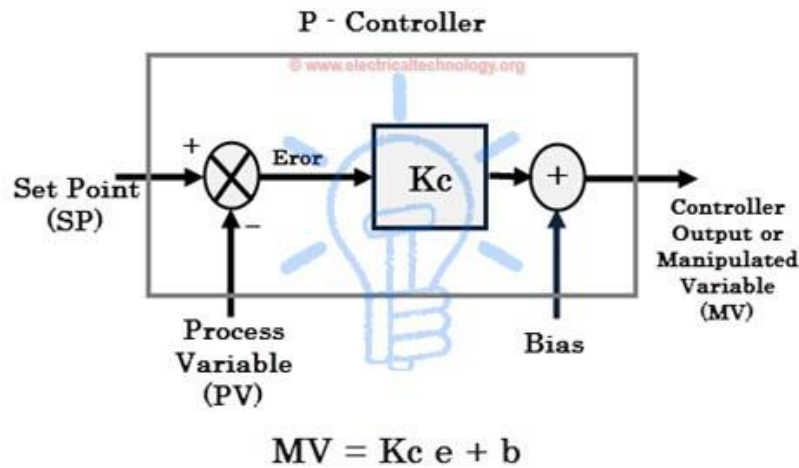
- **ON-OFF Controller**
- **Proportional Controller**
- **Proportional-Integral Controller**
- **Proportional-Derivative Controller**
- **Proportional-Integral-Derivative Controller**

In case of ON-OFF controller, two states are possible to control the manipulated variable, i.e., either fully ON (when process variable is below the set point) or Fully OFF (when process variable is above the set point). So the output will be of oscillating in nature. In order to achieve the precise control, most industries use the PID controller (**or PI or PD** depends on the application). Let us look at these control actions.

P-Controller

Proportional control or simply **P-controller** produces the control output proportional to the current error. Here the error is the difference between the set point and process variable (i.e., $e = SP - PV$). This error value multiplied by the proportional gain (K_c) determines the output response, or in other words proportional gain decides the ratio of proportional output response to error value.

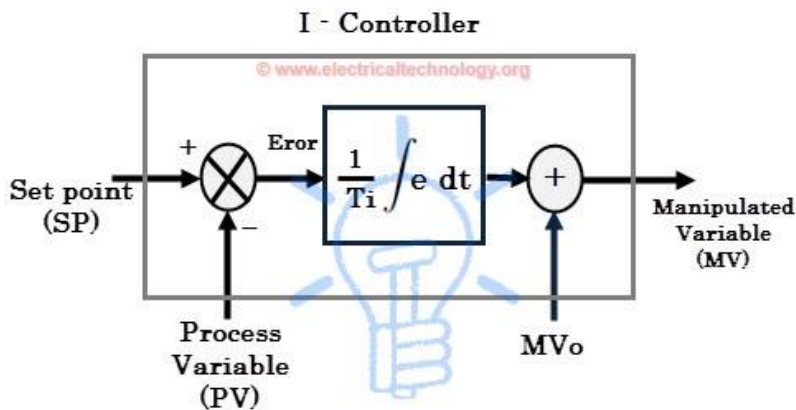
For example, the magnitude of the error is 20 and K_c is 4 then proportional response will be 80. If the error value is zero, controller output or response will be zero. The speed of the response (transient response) is increased by increasing the value of proportional gain K_c . However, if K_c is increased beyond the normal range, process variable starts oscillating at a higher rate and it will cause instability of the system.



Although P-controller provides stability of the process variable with good speed of response, there will always be an error between the set point and actual process variable. Most of the cases, this controller is provided with manual reset or biasing in order to reduce the error when used alone. However, zero error state cannot be achieved by this controller. Hence there will always be a steady state error in the p-controller response as shown in figure.

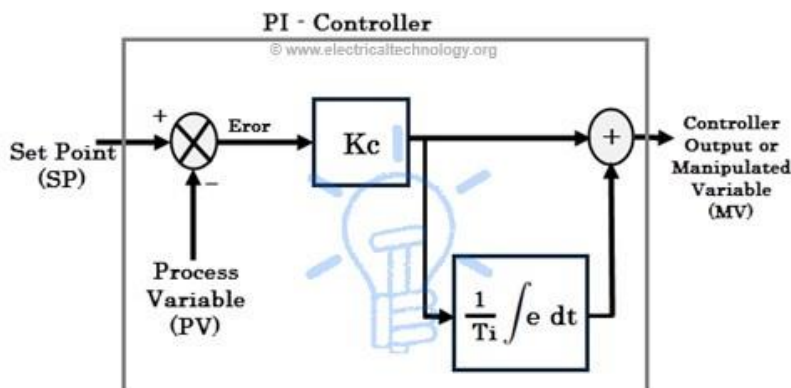
I-Controller

- **Integral controller or I-controller** is mainly used to reduce the steady state error of the system. The integral component integrates the error term over a period of time until the error becomes zero. This results that even a small error value will cause to produce high integral response. At the zero error condition, it holds the output to the final control device at its last value in order to maintain zero steady state error, but in case of P-controller, output is zero when the error is zero.



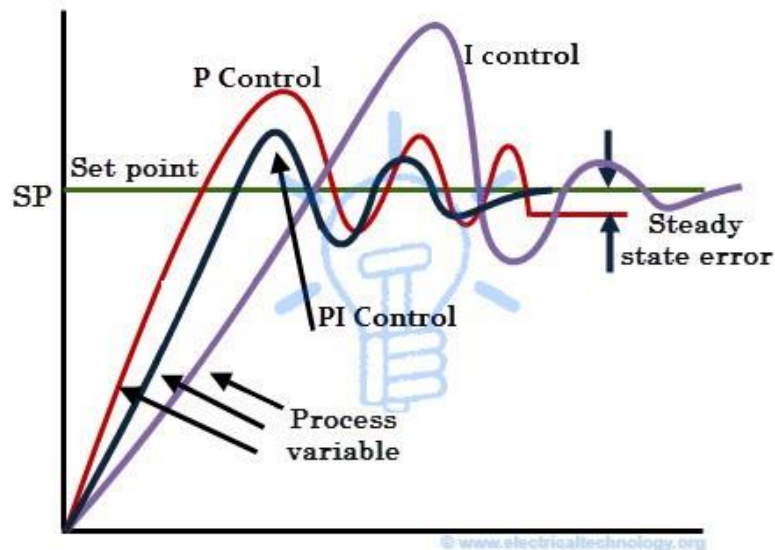
$$MV = \frac{1}{T_i} \int e \, dt + MV_o$$

If the error is negative, the integral response or output will be decreased. The speed of response is slow (means respond slowly) when I-controller alone used, but improves the steady state response. By decreasing the integral gain K_i , the speed of the response is increased.



$$MV = K_c e + \frac{1}{T_i} \int e \, dt$$

- For many applications, proportional and integral controls are combined to achieve good speed of response (in case of P controller) and better steady state response (in case of I controller). Most often **PI controllers** are used in industrial operation in order to improve transient as well as steady state responses. *The responses of only I-control, only p-control and PI*



control are shown

D- Controller Response

A **derivative controller** (or simply **D-Controller**) sees how fast process variable changes per unit of time and produce the output proportional to the rate of change. The derivative output is equal to the rate of change of error multiplied by a derivative constant. The D-controller is used when the processor variable starts to change at a high rate of speed.

In such case, D-controller moves the final control device (such as control valves or motor) in such direction as to counteract the rapid change of a process variable. It is to be noted that D-

$$\text{output} = T_d \frac{de}{dt}$$

controller alone cannot be used for any control applications.

The derivative action increases the speed of the response because it gives a kick start for the output, thus anticipates the future behavior of the error. The more rapidly D-controller responds to the changes in the process variable, if the derivative term is large (which is achieved by increasing the derivative constant or time T_d).

In most of the PID controllers, D-control response depends only on process variable, rather than error. This avoids spikes in the output (or sudden increase of output) in case of sudden set point change by the operator. And also most control systems use less derivative time t_d , as the

derivative response is very sensitive to the noise in the process variable which leads to produce extremely high output even for a small amount of noise.

Real-Time PID Controllers

There are different types PID controllers available in today's market, which can be used for all industrial control needs such as level, flow, temperature and pressure. When deciding on controlling such parameters for a process using PID, options include use either PLC or standalone PID controller.

Standalone PID controllers are used where one or two loops are needed to be monitored and controlled or in the situations where it difficult to access with larger systems. These dedicated control devices offer a variety of options for single and dual loop control. Standalone PID controllers offer multiple set point configurations and also generates the independent multiple alarms.

Some of these standalone controllers include Yokogava temperature controllers, Honeywell PID controllers, OMEGA auto tune PID controllers, ABB PID controllers and Siemens PID controllers.

Most of the control applications, **PLCs** are used as PID controllers. PID blocks are inbuilt in PLCs/PACs and which offers advanced options for a precise control. PLCs are more intelligent and powerful than standalone controllers and make the job easier. Every PLC consist the PID block in their programming software, whether it can Siemens, ABB, AB, Delta, Emersion, or Yokogava PLC.

ASSIGNMENT

1. Explain the principle of operation of PID
2. Differentiate between PLC and PID? And what are the similarities among the two?
3. State five application of PID controller

QUIZ

1. State the different types of real time PID
2. Sketch a diagram to display how a PID functions

CHAPTER THREE

OSCILLATORS (TYPES & APPLICATIONS)

Many electronic devices require a source of energy at a specific frequency which may range from a **few Hz** to **several MHz**. This is achieved by an electronic device called an **oscillator**. Oscillators are extensively used in electronic equipment. For example, in radio and television receivers, oscillators are used to generate high frequency wave (called carrier wave) in the tuning stages. Audio frequency and radio-frequency signals are required for repair of radio, television and other electronic equipment. Oscillators are widely used in radar, electronic computers and other electronic devices.

An **electronic oscillator** may be defined in any one of the following four ways :

1. It is a circuit which converts dc energy into ac energy at a very high frequency;
2. It is an electronic source of alternating current or voltage having sine, square or sawtooth or pulse shapes;
3. It is a circuit which generates an ac output signal without requiring any externally applied input signal;
4. It is an unstable amplifier.

These definitions exclude electromechanical alternators producing 50 Hz ac power or other devices which convert mechanical or heat energy into electric energy.

Although we speak of an oscillator as “generating” a frequency, it should be noted that it does not create energy, but merely acts as an energy converter. It receives dc energy and changes it into a.c. energy of desired frequency. The frequency of oscillations depend on the constants of the device.

An oscillator is different from an alternator based on the following points:

- (i) An alternator is a mechanical device having rotating parts, whereas an oscillator is a non-rotating electronic device
- (ii) An alternator converts mechanical energy into a.c. energy whereas an oscillators converts dc energy into a.c. energy
- (iii) An alternator cannot produce high frequency oscillations whereas an oscillator can produce oscillations ranging from a few Hz to several MHz

An oscillator has a **good frequency stability** i.e. frequency once set, remains constant for a considerable period of time. An oscillator also has a **very high efficiency**

An **oscillator differs from an amplifier** in one basic aspect : the **oscillator does not require an external signal** either to start or maintain energy conversion process. It keeps producing an output signal so long as the dc power source is connected. Moreover, the frequency of the output signal is determined by the passive components used in the oscillator and can be varied at will.

Classification of Oscillators

Electronic oscillators may be broadly divided into following two groups :

- (i) Sinusoidal (or harmonic) oscillators—which produce an output having sine waveform;
- (ii) Non-sinusoidal (or relaxation) oscillators—they produce an output which has square, rectangular or sawtooth waveform or is of pulse shape.

Sinusoidal oscillators may be further subdivided into :

- (a) Tuned-circuits or LC feedback oscillators such as Hartley, Colpitts and Clapp etc.;
- (b) RC phase-shift oscillators such as Wien-bridge oscillator;
- (c) Negative-resistance oscillators such as tunnel diode oscillator;
- (d) Crystal oscillators such as Pierce oscillator;
- (e) Heterodyne or beat-frequency oscillator (BFO).

The **active devices** (bipolars, FETs or unijunction transistors) in the above mentioned circuits may be biased class-A, B or C. Class-A operation is used in high-quality audio frequency oscillators. However, radio frequency oscillators are usually operated as class-C.

Non-sinusoidal Waveforms

Any waveform whose shape is different from that of a standard sine wave is called **non-sinusoidal waveform**. Examples are : square, rectangular, sawtooth, triangular waveforms.

Damped and Undamped Oscillations

Sinusoidal oscillations produced by oscillators may be (i) damped or (ii) undamped.

(i) Damped Oscillations

Oscillations whose amplitude keeps decreasing (or decaying) with time are called **damped** or **decaying** oscillations. The waveform of such oscillations is shown in . These are produced by those oscillator circuits in which $I^2 R$ losses take place continuously during each oscillation without any arrangement for compensating the same. Ultimately, the amplitude of the oscillations decays to zero when there is not enough energy to supply circuit losses. However, the frequency or time-period remains constant because **it is determined by the circuit parameters**.

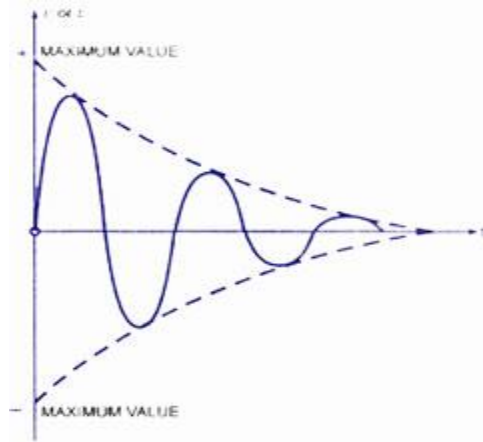
Sinusoidal oscillators serve a variety of functions in telecommunications and in electronics.

The most important application in telecommunication is the use of sine waves as carrier signal in both radio and cable transmissions.

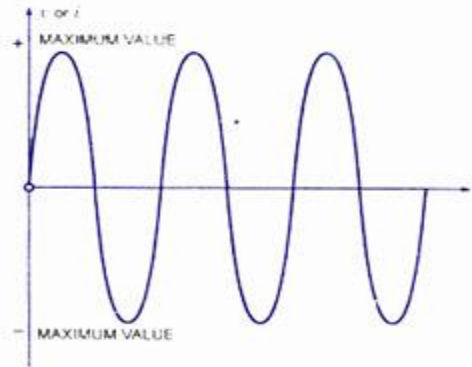
Sine wave signals are also used in frequency response testing of various types of systems and equipment including analogue communication channels, amplifiers and filters and closed-loop control systems.

(ii) Undamped Oscillations

Oscillations whose amplitude remains constant *i.e.* does not change with time are called undamped oscillations. These are produced by those oscillator circuits which have no losses or if they have, there is provision for compensating them. The constant-amplitude and constant-frequency sinusoidal waves shown in Fig. 65.2 (b) are called **carrier waves** and are used in communication transmitters for transmitting low-frequency audio information to far off places.



(a) Damped Oscillations



(b) Undamped or Sustained Oscillations

Figures 3. 1a and b: Damped and Undamped Oscillations

The Oscillatory Circuit

It is also called **LC circuit** or **tank circuit**. The oscillatory circuit (Fig.) consists of two reactive elements *i.e.* **an inductor** and **a capacitor**. Both are capable of storing energy. The capacitor stores energy in its electric field whenever there is potential difference across its plates. Similarly, a coil or an inductor stores energy in its magnetic field whenever current flows through it. Both L and C are supposed to be loss-free (*i.e.* their Q -factors are infinite). As shown in Fig. (a), suppose the capacitor has been fully-charged from a dc source.

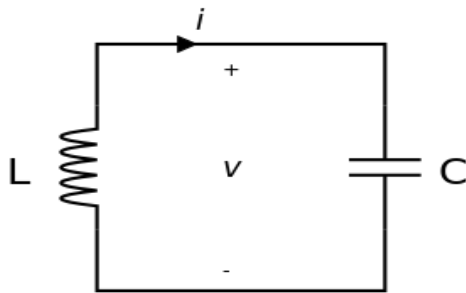


Figure 3.2 : Tank/LC Circuit

Different types of Transistor Oscillators

A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it. All oscillators under different names have similar functions *i.e.* they produced continuous *undamped* output. However the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses.

The following are the transistor oscillators commonly used at various places in electronic circuits ;

- (i) Tuned collector oscillator
- (ii) Hartley oscillator
- (iii) Collpitt's oscillator
- (iv) Phase shift oscillator
- (v) Wein Bridge oscillator
- (vi) Crystal oscillator

LC Oscillator Example 1

An inductance of 200mH and a capacitor of 10pF are connected together in parallel to create an LC oscillator tank circuit. Calculate the frequency of oscillation.

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{200\text{mH} \times 10\text{pF}}} = 112.5 \text{ kHz}$$

Then we can see from the above example that by decreasing the value of either the capacitance, C or the inductance, L will have the effect of increasing the frequency of oscillation of the LC tank circuit.

LC Oscillators Summary

The basic conditions required for an **LC oscillator** resonant tank circuit are given as follows.

- For oscillations to exist an oscillator circuit **MUST** contain a reactive (frequency-dependant) component either an “Inductor”, (L) or a “Capacitor”, (C) as well as a DC power source.
- In a simple inductor-capacitor, LC circuit, oscillations become damped over time due to component and circuit losses.
- Voltage amplification is required to overcome these circuit losses and provide positive gain.
- The overall gain of the amplifier must be greater than one, unity.
- Oscillations can be maintained by feeding back some of the output voltage to the tuned circuit that is of the correct amplitude and in-phase, (0°).
- Oscillations can only occur when the feedback is “Positive” (self-regeneration).
- The overall phase shift of the circuit must be zero or 360° so that the output signal from the feedback network will be “in-phase” with the input signal.

The RC Oscillator Circuit

RC Oscillators use a combination of an amplifier and an RC feedback network to produce output oscillations due to the phase shift between the stages

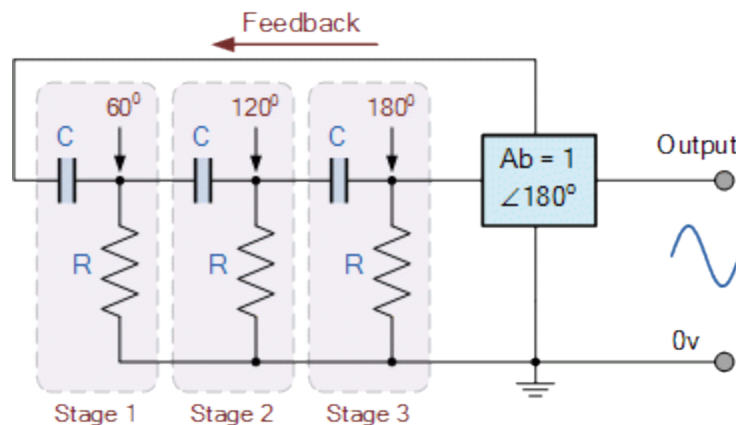


Figure 3.3 : RC Oscillator Circuit

For an RC oscillator to sustain its oscillations indefinitely, sufficient feedback of the correct phase, that is positive (in-phase) Feedback must be provided along with the voltage gain of the single transistor amplifier being used to inject adequate loop gain into the closed-loop circuit in order to maintain oscillations allowing it to oscillates continuously at the selected frequency.

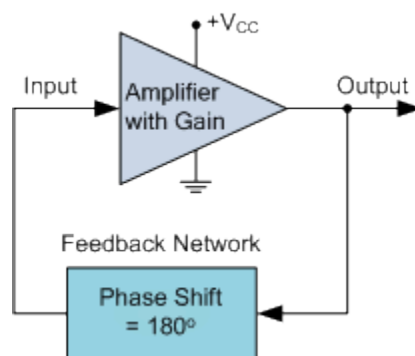


Figure 3.4: Feedback Network in RC Network

In an **RC Oscillator** circuit the input is shifted 180° through the feedback circuit returning the signal out-of-phase and 180° again through an inverting amplifier stage to produces the required positive feedback. This then gives us " $180^\circ + 180^\circ = 360^\circ$ " of phase shift which is effectively the same as 0° , thereby giving us the required positive feedback. In other words, the total phase shift of the feedback loop should be "0" or any multiple of 360° to obtain the same effect.

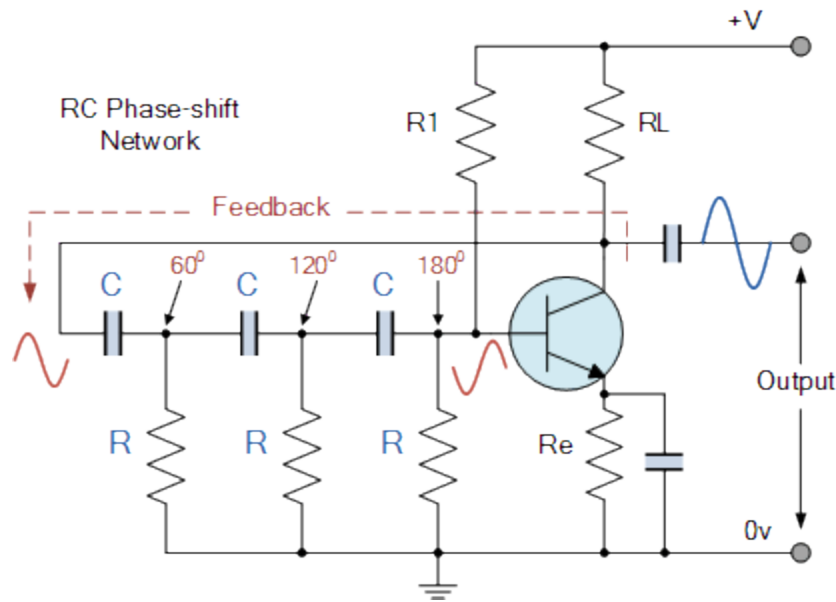


Figure 3.5: RC Phase-Shift Network

The basic **RC Oscillator** which is also known as a **Phase-shift Oscillator**, produces a sine wave output signal using regenerative feedback obtained from the resistor-capacitor (RC) ladder network. This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).

$$f_r = \frac{1}{2\pi RC\sqrt{2N}}$$

Where:

- f_r is the oscillators output frequency in Hertz
- R is the feedback resistance in Ohms
- C is the feedback capacitance in Farads
- N is the number of RC feedback stages.

Crystals

For an exceptionally high degree of frequency stability, use of crystal oscillators is essential. The crystal generally used is a finely-ground wafer of translucent quartz (or tourmaline) stone held between two metal plates and housed in a package about the size of a postal stamp. The crystal wafers are cut from the crude quartz in two different ways. The method of ‘cutting’ determines the crystal’s natural resonant frequency and its temperature coefficient. When the wafer is cut so

that its flat surface are perpendicular to its **electrical axis**, it is called an **X-cut** crystal (Fig. 65.14). But if the wafer is so cut that its flat surfaces are perpendicular to its **mechanical axis**, it is called **Y-cut** crystal.

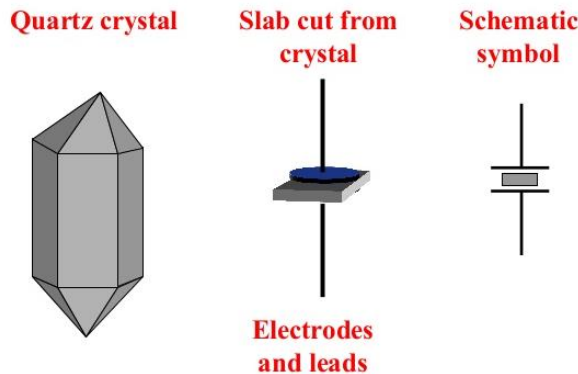


Figure 3.6: Quartz Crystal

(a) Piezoelectric Effect

The quartz crystal described above has peculiar properties. When mechanical stress is applied across its two opposite faces, **a potential difference is developed across them**. It is called **piezoelectric effect**. Conversely, when a potential difference is applied across its two opposite faces, it causes the crystal to **either expand or contract**. If an alternating voltage is applied, the crystal wafer is set into vibrations. The frequency of vibration is equal to the resonant frequency of the crystal as determined by its structural characteristics. Where the frequency of the applied ac voltage equals the natural resonant frequency of the crystal, the amplitude of vibration will be maximum. As a general rule, thinner the crystal, **higher its frequency of vibration**.

Frequency Stability of an Oscillator

The ability of an oscillator to maintain a constant frequency of oscillation is called its frequency stability. The following factors affect the frequency stability:

1. Operating Point of the Active Device

The Q -point of the active device (*i.e.* transistor) is so chosen as to confine the circuit operation on the linear portion of its characteristic. Operation on non-linear portion varies the parameters of the transistor which, in turn, affects the frequency stability of the oscillator.

2. Inter-element Capacitances

Any changes in the inter-element capacitances of a transistor particularly the collector- to-emitter capacitance cause changes in the oscillator output frequency, thus affecting its frequency stability. The effect of changes in inter-element capacitances, can be neutralized by adding a swamping capacitor across the offending elements—the added capacitance being made part of the tank circuit.

3. Power Supply: Changes in the dc operating voltages applied to the active device shift the oscillator frequency. This problem can be avoided by using regulated power supply.

4. Temperature Variations: Variations in temperature cause changes in transistor parameters and also change the values of resistors, capacitors and inductors used in the circuit. Since such changes take place slowly, they cause a slow change (called drift) in the oscillator output frequency.

5. Output Load

A change in the output load may cause a change in the Q -factor of the LC tuned circuit thereby affecting the oscillator output frequency.

6. Mechanical Vibrations

Since such vibrations change the values of circuit elements, they result in changes of oscillator frequency. This instability factor can be eliminated by isolating the oscillator from the source of mechanical vibrations.

The figure below shows the use of a crystal to stabilise the frequency of a tuned-collector oscillator which has a crystal (usually quartz) in the feedback circuit. The LC tank circuit has a frequency of oscillation

$$f = 1 / 2\pi \sqrt{LC} \quad i.e.$$

Resonant Frequency Formula

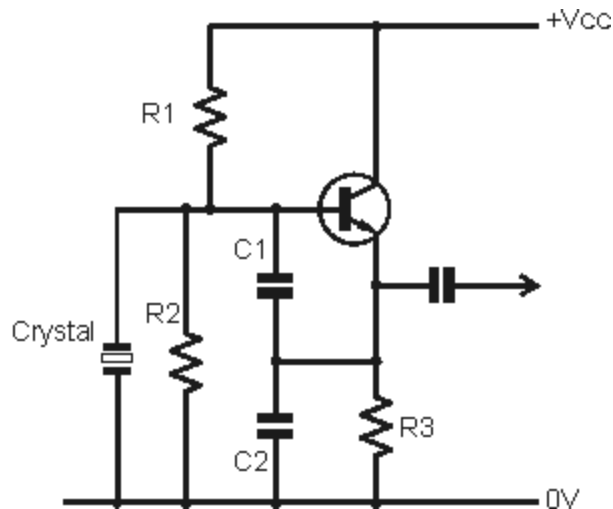
$$f = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

where 'f' = frequency in hertz
'L' = inductance in henrys
'C' = capacitance in farads

The formula also holds true if used with the units of megahertz, microhenries and microfarads and many other combinations of units.

The circuit is adjusted to have a frequency near about the desired operating frequency but the exact frequency is set by the crystal and stabilized by the crystal.

For example, if natural frequency of vibration of the crystal is 27 MHz, the LC circuit is made to resonate at this frequency.



As usual, resistors **R1, R2 and R3** provide a voltage-divider stabilised dc bias circuit. Capacitor C1 by-passes R3 in order to maintain large gain. *RFC* coil L1 prevents ac signals from entering dc line whereas RC is the required dc load of the collector.

The coupling capacitor C2 has negligible impedance at the operating frequency but prevents any dc link between collector and base. Due to extreme stability of crystal oscillations, such oscillators are widely used in communication transmitters and receivers where frequency stability is of prime importance.

Here, the crystal is excited in the series resonance mode because it is connected as a series element in the feedback path from collector to the base. Since, in series resonance, crystal impedance is the smallest, the amount of positive feedback is the largest. The crystal not only provides the feedback but also the necessary phase shift.

As usual, R1, R2 and R3 provide a voltage-divider stabilized dc bias circuit. C2 bypasses R3 to avoid degeneration. The *RFC* coil provides dc collector load and also prevents any ac signal from entering the dc supply. The coupling capacitor C1 has negligible reactance at circuit operating frequency but **blocks any dc flow between collector and base**. The oscillation frequency equals the series-resonance frequency of the crystal and is given by:

Advantages of crystal oscillator

1. It is a very simple circuit because no tuned circuit other than the crystal itself is required.
2. Different oscillation frequencies can be obtained by simply replacing one crystal with another. It makes it easy for a radio transmitter to work at different frequencies.
3. Since frequency of oscillation is set by the crystal, it remains unaffected by changes in supply voltage and transistor parameters etc.

ASSIGNMENT

1. State three definitions of an oscillator?
2. Differentiate between oscillator and alternator?
3. In an RC oscillator having three RC stages, if $R = 10\text{k}\Omega$ and $C = 15\text{nanoFarad}$, draw the circuit and then calculate the frequency of oscillation.
4. Under which conditions would a negative feedback result in positive feedback?

QUIZ

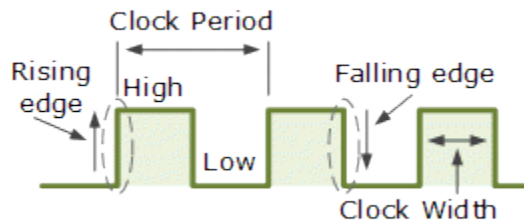
1. Differentiate between oscillator and amplifier
2. Under which condition would a negative feedback results into a positive feedback
3. Differentiate between RC and LC Oscillators
4. What are the advantages of crystal oscillator over RC and LC oscillator

CHAPTER FOUR

THE OPERATION OF MULTIVIBRATORS

Multivibrators (MV)

Multivibrators are **sequential logic circuits** that operate continuously between two distinct states of **HIGH** and **LOW**. These devices are very useful as pulse generating, storing and counting circuits. They are basically **two-stage amplifiers with positive feedback from the output of one amplifier to the input of the other**. This feedback is supplied in such a manner that one transistor is driven to saturation and the other to cut-off. It is followed by new set of conditions in which the saturated transistor is driven to cut-off and the cut-off transistor is driven to saturation.



- Active HIGH – if the state change occurs from a “LOW” to a “HIGH” at the clock’s pulse rising edge or during the clock width.
- Active LOW – if the state change occurs from a “HIGH” to a “LOW” at the clock’s pulses falling edge.
- Duty Cycle – this is the ratio of the clock width to the clock period.
- Clock Width – this is the time during which the value of the clock signal is equal to a logic “1”, or HIGH.
- Clock Period – this is the time between successive transitions in the same direction, ie, between two rising or two falling edges.
- Clock Frequency – the clock frequency is the reciprocal of the clock period,

$$\text{frequency} = 1/\text{clock period. } (f = 1/T)$$

Clock pulse generation circuits can be a combination of analogue and digital circuits that produce a continuous series of pulses (these are called astable multivibrators) or a pulse of a specific duration (these are called monostable multivibrators). Combining two or more multivibrators provides generation of a desired pattern of pulses (including pulse width, time between pulses and frequency of pulses).

Some Uses of Multivibrators

1. as frequency dividers,
2. as sawtooth generators,
3. as square wave and pulse generators,
4. as a standard frequency source when synchronized by an external crystal oscillator,
5. for many specialised uses in radar and TV circuits,

6. as memory elements in computers.

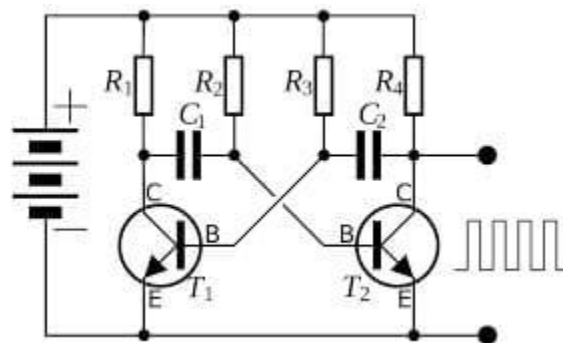
There are three basic types of *MVs* distinguished by the type of coupling network employed.

1. Astable multivibrator (*AVM*),
2. Monostable multivibrator (*MMV*),
3. Bistable multivibrator (*BMV*).

The first one is the **non-driven** type whereas the other two are the **driven** type (also called triggered oscillators).

1. Astable Multivibrator (AMV)

It is also called **free-running relaxation oscillator**. It has no stable state but only two quasistable (half-stable) states between which it keeps oscillating continuously of its own accord without any external excitation. In this circuit, neither of the two transistors reaches a stable state. When one is ON, the other is OFF and they continuously switch back and forth at a rate depending on the *RC* time constant in the circuit. Hence, it oscillates and produces pulses of certain mark-to-space ratio. Moreover, two outputs (180° out of phase with each other) are available. It has two energy-storing elements *i.e. two capacitors*.



Applications of Astable multivibrator

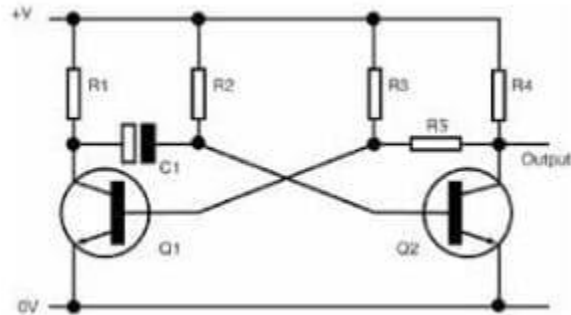
- The astable or free running multivibrator is used as a square wave frequency generator
- As a timing oscillator or clock of a computer system.
- It is also used for a flashing lights, switching and power supply circuits.

2 . Monostable Multivibrator (MMV)

It is also called a **single-shot** or **single swing** or a **one-shot** multivibrator. Other names are : **delay multivibrator and univibrator**. It has:

- (i) one absolutely stable (stand-by) state and
- (ii) one quasistable state.

It can be **switched** to the quasi-stable state by an external trigger pulse but it returns to the stable condition after a time delay determined by the value of circuit components. It supplies a single output pulse of a desired duration for every input trigger pulse. It has one energy-storing element *i.e.* **one-capacitor**.

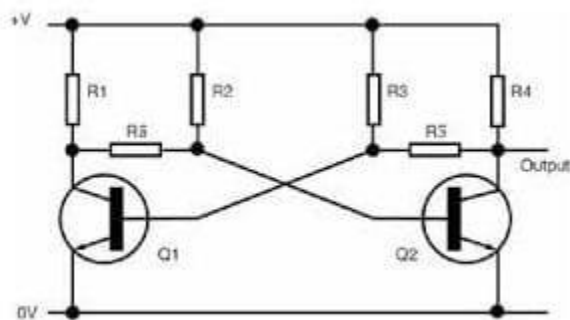


Applications of mono stable multivibrator

- The monostable multivibrator is used as delay and timing circuits.
- It is also used for temporary memories.
- It is often used to trigger another pulse generator.
- It is used for regenerating old and worn out pulses.

3. Bistable Multivibrator (BMV)

It is also called **Eccles-Jordan** or **flip-flop** multivibrator. It has **two absolutely stable states**. It can remain in either of these two states unless an external trigger pulse switches it from one state to the other. Obviously, *it does not oscillate*. It has **no energy storage element**.



Applications of Bistable Multivibrator

- The bistable multivibrator or Flip Flop is of great importance in digital operation in computers, digital communications.
- It is also used for reversing the supply to a given circuit or change supply to two circuits at regular intervals.

Example:

In the Astable MV shown in figure above, if $R_2 = R_3 = 10\text{k}\Omega$, and $C_1 = C_2 = 0.01\mu\text{F}$. Determine the time period and frequency of the square wave.

Solution:

$$R = 10\text{k}\Omega, C = 0.01\mu\text{F} = 10^{-8}\text{F}$$

Time Period of the Square wave is:

$$T = 1.4 \times RC = 1.4 \times 10^{-4} \times 10^{-8} \text{ second} \\ = \mathbf{0.14\text{msec}}$$

Frequency of the square wave is

$$F = \frac{1}{T} = \frac{1}{1.4 \times 10^{-4}} = 7\text{kHz}$$

ASSIGNMENT

1. Sketch a simple circuit of Astable MV. In your diagram, if $R_2 = R_3 = 20\text{k}\Omega$, and $C_1 = C_2 = 0.05\mu\text{F}$. Determine the time period and frequency of the square wave.
2. State three application each, of the three types of multivibrators
3. Differentiate between multivibrator and oscillator

QUIZ

1. What are the limitations of multivibrators?
2. **LAB/PRACTICAL:** students in two/three groups are to get an **IC 555 Timer**. Each group to study the pins configuration, draw it, use an oscilloscope to get the waveform when a +5v input signal is applied. And also state the different functions of the IC 555 Timer. All report/results are to be done on graph book.