# Unit-IV

## Time Base Generators or Sweep Circuits (Generators)

### 4.1 Time Base Generators:

A time-base generator is an electronic circuit which generates an output voltage or current waveform, a portion of which varies linearly with time. Ideally the output waveform should be a ramp. Time-base generators may be voltage time-base generators or current time-base generators. A voltage time-base generator is one that provides an output voltage waveform, a portion of which exhibits a linear variation with respect to time. A current time-base generator is one that provides an output current waveform, a portion of which exhibits a linear variation with respect to time. There are many important applications of time-base generators, such as in CROs, television and radar displays, in precise time measurements, and in time modulation. The most important application of a time-base generator is in CROs. For example, a linear time base voltage is required on the deflection plates of a CRO, to sweep the electron beam, from left to right across the screen. Similarly, a linear time base current waveform is required in the deflection coils of a television receiver. Because of the sweep applications, the circuits are also sometimes known as sweep circuits or sweep generators.

### 4.2 General Features of a Time-Base Signal:

Figure 4.1(a) shows the typical waveform of a time-base voltage. As seen the voltage starting from some initial value increases linearly with time to a maximum value after which it returns again to its initial value. The time during which the output increases is called the ***sweep time*** and the time taken by the signal to return to its initial value is called the ***restoration time, the return time, or the flyback time***. In most cases the shape of the waveform during restoration time and the restoration time itself are not of much consequence. However, in some cases a restoration time which is very small compared with the sweep time is required.

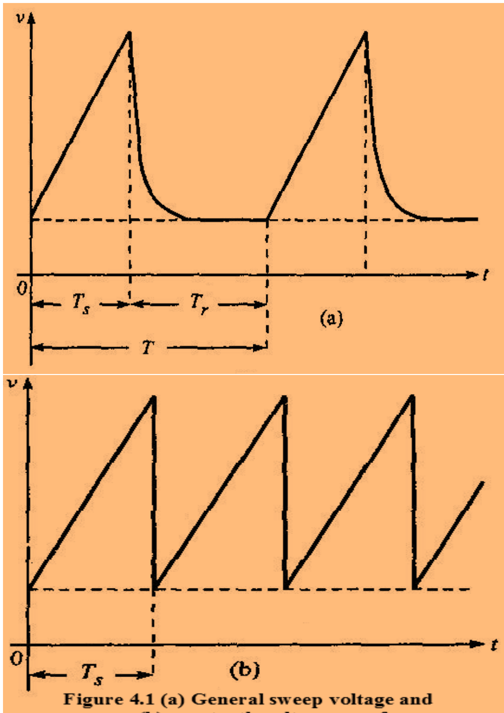


**Figure 4.1 (a) General sweep voltage and (b) saw-tooth voltage waveforms**

If the restoration time is the restoration time is almost zero and the next linear voltage is initiated the moment the present one is terminated then a saw-tooth waveform shown in Figure 4.1(b) is generated. The waveforms of the type shown in Figures 4.1 (a) and (b) are generally called sweep waveforms even when they are used in applications not involving the deflection of an electron beam. In fact, precisely linear sweep signals are difficult to generate by time-base generators and moreover nominally linear sweep signals may be distorted when transmitted through a coupling network.

It will be interesting to know that the circuits, which generate time base signals, do not ordinarily provide sweep voltages that are precisely linear. A most useful way of expressing the deviation from linearity is the slope error or sweep-speed error, which is given by the relation

$$e_S = \frac{\text{Difference in slope at the begining and end of sweep}}{\text{Initial value of slope}}$$

There is one another term called 'sweep speed', which is used to compare the performance of different sweep generating circuits. In all these circuits a capacitor is an essential element. The charging and discharging of a capacitor generates a sweep voltage.

Suppose a capacitor (C) is charged by a constant current (I). Then the voltage across the capacitor ($v_C$) at any time is given by the relation.

$$v_C = \frac{I}{C} \times t$$

The rate of change of capacitor voltage with time is known as sweep speed.

Thus, the sweep speed $= \dfrac{dv_C}{dt} = \dfrac{d}{dt}\left(\dfrac{I}{C}\right) \times t = \dfrac{I}{C}$ .

The sweep speed is required to be constant in most of the applications.

The deviation from linearity is expressed in three most important ways:

1. The slope or sweep speed error, $e_S$

2. The displacement error, $e_d$

3. The transmission error, $e_t$

### 4.2.1 The Slope-Error or Sweep-Speed Error $e_S$:

An important requirement of a sweep is that it must increase linearly with time, i.e. the rate of change of sweep voltage with time is a constant. The deviation from linearity is defined as Slope-error or Sweep-speed error $e_S$. It is defined as the ratio of difference in slope at beginning and end of sweep to initial value of slope. This error is considerable where constant sweep (i.e. rate of change of sweep voltage with time) is an important requirement as in the case of general purpose C.R.O's.

$\therefore$ Slope or sweep - speed error,

$$e_S = \frac{\textit{difference in slope at begining and end of sweep}}{\textit{initial value of slope}}$$

$$e_S = \frac{\left.\dfrac{dv_0}{dt}\right|_{t=0} - \left.\dfrac{dv_0}{dt}\right|_{t=T_S}}{\left.\dfrac{dv_0}{dt}\right|_{t=0}} \text{ ------------------------------------------ } 4.1$$

### 4.2.2The Displacement error $e_d$:

It is defined as the ratio of the maximum difference between the actual sweep voltage and the linear sweep voltage passing through the beginning and end points of the actual sweep to the maximum voltage attained by sweep as shown in Figure4.2 (a). It is used to define non-linearity of time base signal and is considerable in some timing applications.

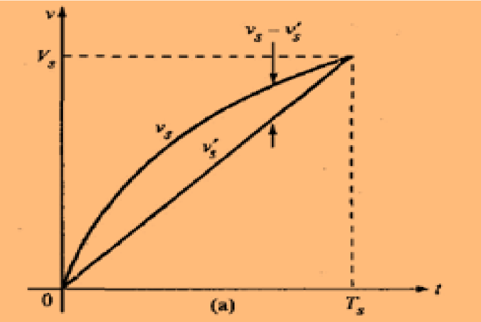

Figure 4.2 (a) Sweep for displacement error

As shown in Figure 4.2(a), $v_S$ is the actual sweep and $v^{|}_S$ is the linear sweep.

$$e_d = \frac{\text{Maximum difference between the actual sweep voltage and the linear sweep voltage which passes through the beginning and end points of the actual sweep.}}{\text{Amplitude of the sweep at the end of the sweep time}}$$

$$e_d = \frac{\left(v_S - v^{|}_S\right)_{\max}}{V_S} \text{ ------------------------------------------------------------------ } 4.2$$

### 4.2.3The transmission error, $e_t$:

When a ramp signal is transmitted through a high-pass circuit, the output falls away from the input as shown in Figure 4.2(b). This deviation is expressed as transmission error $e_t$ , defined as the difference between the maximum amplitude of input and the output divided by the maximum amplitude of input signal at the end of the sweep.

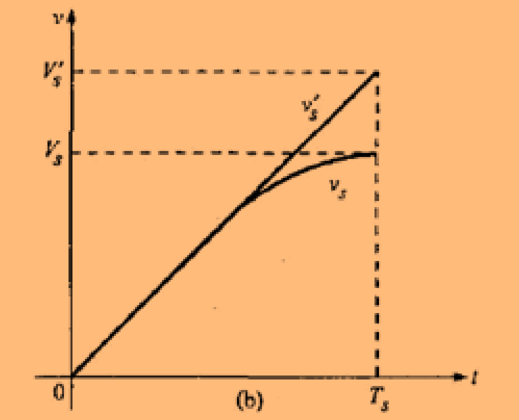

Figure 4.2 (b) sweep for transmission error.

$$e_t = \frac{V_S^{|} - V_S}{V_S^{|}} \text{ . ----------------------------------------------------- 4.3}$$

Where as shown in Figure 4.2(b), $V^{|}_S$ is the input and $V_S$ is the output at the end of the sweep, i.e. at $t$ = $T_S$.

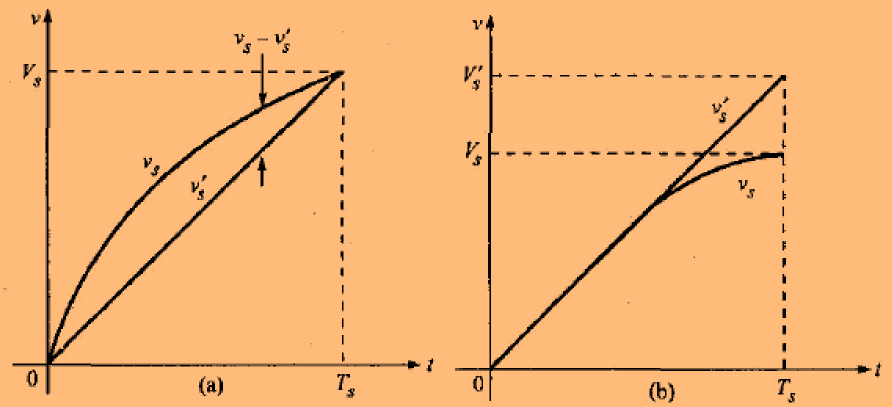

Figure 4.2 (a) Sweep for displacement error and (b) sweep for transmission error.

If the deviation from linearity is small so that the sweep voltage may be approximated by the sum of linear and quadratic terms in $t$, then the above three errors are related as

$$e_d = \frac{e_S}{8} = \frac{e_t}{4} \text{ ----------------------------------------------------- 4.4}$$

$$e_S = 2e_t = 8e_d \text{ ----------------------------------------------------- 4.5}$$

This implies that the sweep speed error is the more dominant one and the displacement error is the least severe one.

## 4.3 Types of Time Base Circuits:

**4.3.1 Free running time Base Generator: -** A circuit in which the periodic saw tooth wave form is generated, without the application of any signal is called a free running time base generator. Such a circuit is required to display a periodic waveform. It may be noted that in a free running time base generator, thus sweep time (Ts) must be larger than the period of the waveform to be displayed.

**4.3.2 Triggered time-Base generator:-** A circuit in which the linear wave form with a prescribed duration of time is generated by the application of a trigger signal, is called a triggered time base generator. Such a circuit is required to display widely separated narrow-width pluses or a waveform, which may not be periodic but may occur at irregular intervals.

## 4.4 Methods of Generating a Time-Base Waveform:

In time-base circuits, sweep linearity is achieved by one of the following methods.

4.4.1 *Exponential charging*. In this method a capacitor is charged from a supply voltage through a resistor to a voltage which is small compared with the supply voltage.

4.4.2 *Constant current charging.* In this method a capacitor is charged linearly from a constant current source. Since the charging current is constant the voltage across the capacitor increases linearly.

4.4.3 *The Miller circuit.* In this method an operational integrator is used to convert an input step voltage into a ramp waveform.

4.4.4 *The Phantastron circuit.* In this method a pulse input is converted into a ramp. This is a version of the Miller circuit.

4.4.5 *The bootstrap circuit.* In this method a capacitor is charged linearly by a constant current which is obtained by maintaining a constant voltage across a fixed resistor in series with the capacitor.

4.4.6 *Compensating networks.* In this method a compensating circuit is introduced to improve the linearity of the basic Miller and bootstrap time-base generators.

4.4.7 *An inductor circuit.* In this method an *RLC* series circuit is used. Since an inductor does not allow the current passing through it to change instantaneously, the current through the capacitor more or less remains constant and hence a more linear sweep is obtained.

### 4.4.1 (A) Exponential Sweep Circuit:

Figure 4.3(a) shows an exponential sweep circuit. The switch S is normally closed and is open at $t = 0$. So for $t > 0$, the capacitor charges towards the supply voltage $V$ with a time constant $RC$. The voltage across the capacitor at any instant of time is given by.

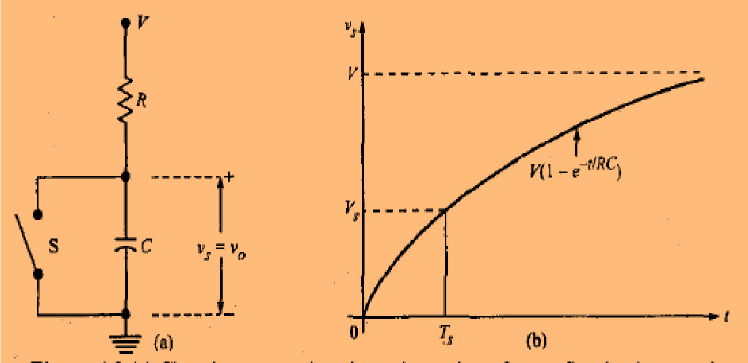


**Figure 4.3** (a) Charging a capacitor through a resistor from a fixed voltage and (b) the resultant exponential waveform across the capacitor.

$$v_o(t) = V\left(1 - e^{-t/RC}\right)$$

After an interval of time $T_S$ when the sweep amplitude attains the value $Vs$, the switch again closes. The resultant sweep waveform is shown in Figure 4.3(b).

The relation between the three measures of linearity, namely the slope or sweep speed error $e_S$, the displacement error $e_d$, and the transmission error $e_t$, for an exponential sweep circuit is derived below.

### Slope or Sweep Speed Error $e_S$ :

We know that for an exponential sweep circuit of Figure 4.3(a),

$$v_0(t) = V\left(1 - e^{-t/RC}\right) \text{ ------------------------------------------------------------- } 4.6$$

Rate of change of output or slope is

$$\frac{dv_o}{dt} = 0 - Ve^{-t/RC}\left(\frac{-1}{RC}\right) = \frac{Ve^{-t/RC}}{RC}$$

$$\text{Slope error}, e_S = \frac{\left.\frac{dv_0}{dt}\right|_{t=0} - \left.\frac{dv_0}{dt}\right|_{t=T_S}}{\left.\frac{dv_0}{dt}\right|_{t=0}} = \frac{\frac{V}{RC} - \frac{V\ e^{-T_S/RC}}{RC}}{\frac{V}{RC}}$$

Slope error, $e_S = 1 - e^{-T_S/RC}$

$$= 1 - \left(1 - \frac{T_S}{RC} + \frac{1}{2}\left(-\frac{T_S}{RC}\right)^2 + \ldots\ldots\ldots\right)$$

For small *Ts*, neglecting the second and higher order terms

$$e_S = \frac{T_S}{RC} \text{ ------------------------------------------------------------------------------ } 4.7$$

And also, $v_o = V\left(1 - e^{-t/RC}\right)$ ------------------------------------------------------ 4.8

At $t = T_s$, $v_o = V_s$

$$\therefore \quad V_s = V\left(1 - e^{-T_s/RC}\right) = V\left[1 - \left(1 - \frac{T_s}{RC} + \left(-\frac{T_s}{RC}\right)^2 \frac{1}{2!} + \ldots\ldots\right)\right] \text{ -------------- } 4.9$$

Neglecting the second and higher order terms, hence

$$V_s = V\frac{T_S}{RC} \quad \text{or} \quad \frac{V_S}{V} = \frac{T_S}{RC}$$

The slope error $e_s = \dfrac{V_S}{V} = \dfrac{T_S}{RC}$ ---------------------------------------------------- 4.10

So the smaller the sweep amplitude compared to the supply voltage, the smaller will be the slope error.

$\therefore$ Sweep speed error $e_S = \dfrac{V_s}{V} = \dfrac{T_s}{\tau}$

$e_S = \dfrac{T_s}{\tau}$ . Where τ is the time constant (RC) for good linearity i.e smaller sweep speed error the time constant τ must be very large as compared to sweep duration ($T_S$).

## The Transmission Error $e_t$:

From Figure 4.2(b),

$$v_s = V\left(1 - e^{-t/RC}\right)$$

At $t = T_s$, $\quad v_s = V_s = V\left(1 - e^{-T_s/RC}\right)$

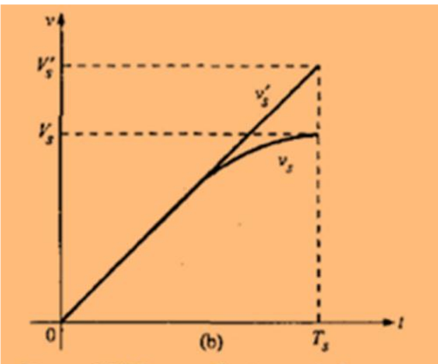

Figure 4.2 (b) sweep for transmission error.

$$V_s = V\left[1 - \left(1 - \frac{T_s}{RC} + \left(-\frac{T_s}{RC}\right)^2 \frac{1}{2!} + \ldots\ldots\right)\right]$$

$$V_s = V\left(\frac{T_S}{RC} - \frac{1}{2}\left(\frac{T_S}{RC}\right)^2\right) \text{-----------------------------------------------------} 4.11$$

The initial slope, $\left.\frac{dv_o}{dt}\right|_{t=0} = \frac{V}{RC}$

If the initial slope is maintained, the sweep is a linear sweep $\left(v_S^| = \alpha\, t = \frac{V}{RC} t\right)$ . Neglecting the second and higher order terms in the above equation 4.11, the input (linear sweep) is given by at $t = T_s$, $v_s = V_s^| = T_S \frac{V}{RC}$

The transmission error

$$e_t = \frac{V_S^| - V_S}{V_S^|} = \frac{T_s \frac{V}{RC} - V\left(\frac{T_s}{RC} - \frac{1}{2}\left(\frac{T_s}{RC}\right)^2\right)}{T_s \frac{V}{RC}} = \frac{T_S}{2RC} = \frac{e_S}{2}$$

$\therefore$ The transmission error $e_t = \frac{e_s}{2}$ or $e_s = 2e_t$ ------------------------ 4.12

## The Displacement Error $e_d$:

From Figure 4.2(a), we can see that the maximum displacement between the actual sweep and the linear sweep which passes through the beginning and end points of the actual sweep occurs at $t = T_S/2$.

At $t = \frac{T_S}{2}$, $\quad v_S^{|} = \frac{V_S}{2}$

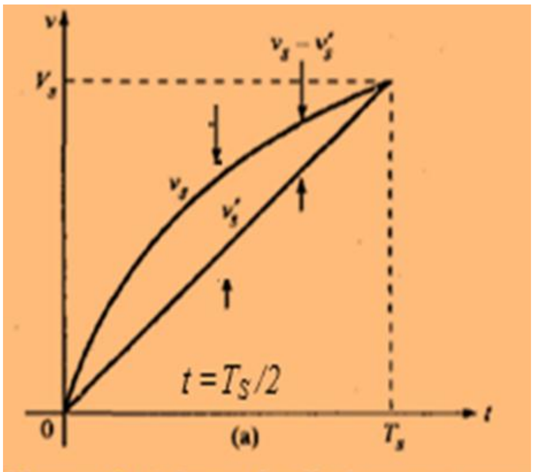

Figure 4.2 (a) Sweep for displacement error

The actual sweep $v_S$ is given by

$$v_S = V\left(1 - e^{-t/RC}\right)$$

At $t = \frac{T_S}{2}$,

$$v_S = V\left(1 - e^{-T_S/2RC}\right)$$

$$= V\left[1 - \left(1 - \frac{T_S}{2RC} + \left(-\frac{T_S}{2RC}\right)^2 \frac{1}{2!} + \ldots\ldots\right)\right]$$

$$\therefore v_S = V\left[\frac{T_S}{2RC} - \left(\frac{T_S}{2RC}\right)^2 \frac{1}{2}\right]$$

The input linear sweep is given by $\left(v_S^{|} = \alpha\, t = \frac{V}{\tau} t\right)$

At $t = \frac{T_S}{2}$, $\quad v_S^{|} = \frac{V}{\tau}\frac{T_S}{2}$ and at $t = T_S$, $V_S = V_S^{|}$

And is given by $\quad v_S^{|} = \alpha\, t = \frac{V}{\tau} T_S$

The displacement error $e_d$ is given by $e_d = \frac{\left(v_S - v_S^{|}\right)_{max}}{V_S}$ and substituting $V_S$ and the maximum values of $v_S$ *and* $v_S^{|}$ at $t = \frac{T_S}{2}$,

$$e_d = \frac{\left|\left(v_s - v_s'\right)_{\max}\right|}{V_s} = \frac{\left| V\left[\frac{T_s}{2RC} - \left(\frac{T_s}{2RC}\right)^2 \frac{1}{2}\right] - \frac{V}{RC}\frac{T_s}{2}\right|}{\frac{V}{RC}T_s}$$

$$= \frac{\left|\frac{V}{2}\left[-\left(\frac{T_s}{RC}\right)^2 \frac{1}{4}\right]\right|}{V\left(\frac{T_s}{RC}\right)}$$

$$= \frac{1}{2}\frac{\left[\left(\frac{T_s}{RC}\right)^2 \frac{1}{4}\right]}{\left(\frac{T_s}{RC}\right)} = \frac{1}{8}\frac{T_s}{RC} = \frac{e_s}{8}$$

$$\therefore \; e_d = \frac{e_s}{8}$$

This proves that $e_d = \frac{e_s}{8} = \frac{e_t}{4}$ or $e_s = 2\,e_t = 8\,e_d$ -------------------- 4.13

Suppose a capacitor (C) is charged by a constant current (I). Then the voltage across the capacitor ($v_C$) at any time is given by the relation.

$$v_C = \frac{I}{C} . t$$

Hence the rate of change of capacitor voltage with time is known as sweep speed.

Thus, the sweep speed $= \frac{dV_C}{dt} = \frac{d}{dt}\left(\frac{I}{C}\right)\times t = \frac{I}{C}$ .

The sweep speed is required to be constant in most of the applications.

### 4.4.1 (B) Sweep Circuit Using Transistor Switch:

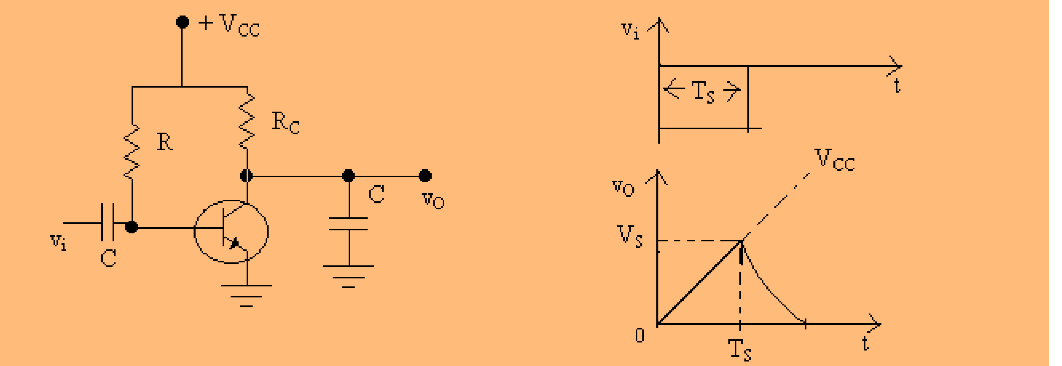


Figure 5(a) Transistor Switch Sweep Circuit Figure 5(b) Assoicted Input and Output Waveforms

Figure5.a shows a basic circuit of a transistor switch sweep circuit. This circuit requires a gating waveform $v_i$ as shown in Figure5.b.It may be obtained from a monostable multivibrator or an astable multivibrator. If the gating waveform is obtained from a monostable multivibrator, the sweep generated by the circuit is called triggered sweep and the circuit is known as triggered voltage time base generator. However, if the gating waveform is obtained from an astable multivibrator, the sweep generated by the circuit is called free running sweep and the circuit is known as free running voltage time base generator.

Initially, the transistor is biased ON and operates in the saturation region. Thus when there is no input (i.e. $v_i$ = 0) the output voltage is zero or $V_{CE(Sat)}$. When the gating pulse( i.e. a negative pulse) is applied, the transistor turns OFF. AS a result of this, the capacitor voltage rises toward $V_{CC}$ with a time constant $R_C C$. The charging voltage or the output voltage neglecting $V_{CE(Sat)}$ is given by

$v_0(t) = V_{CC}\,(1 - e^{-\frac{t}{\tau}})$, where $\tau = R_C\,C$ ---------------------------------------- 4.14

If $\tau$ << 1, then

$$v_O(t) = V_{CC}\left\{1-\left(1-\frac{t}{\tau}+\frac{1}{2}\left(\frac{t}{\tau}\right)^2 ---\right)\right\}$$

$$= V_{CC}\left\{\frac{t}{\tau}-\frac{1}{2}\left(\frac{t}{\tau}\right)^2\right\} \approx V_{cc}\frac{t}{\tau} = V_{CC}\frac{t}{\tau} = V_{CC}\frac{t}{RC}, \text{ where } \tau = RC.$$

At $t = T_S$, $v_0(t) = V_S$.

$\therefore V_S = \dfrac{V_{CC}\,T_S}{R_C\,C}$ ------------------------------------------------------------------- 4.15

The slope error or sweep speed error is given by

$$e_S = \frac{V_S}{V_{CC}} = \frac{T_S}{R_C C} \quad \text{------------------------------------------------------------} \quad 4.16$$

From the above Equation4.16, the output or sweep voltage ($V_S$) must be small fraction of the supply voltage ($V_{CC}$) in order to have small slope error.But this is not a desirable feature, if a certain sweep voltage level is desired. This shortcoming can be remedied by the Miller sweep and the Bootstrap sweep circuits.

It may be noted that the transistor switch is OFF only for the gating time ($T_S$). At the end of time $T_S$, the capacitor discharges, and the voltage is again zero. It is also possible to generate a negative going sweep using transistor switch, But in the case, we have to use a PNP instead of NPN transistors in the sweep circuit.

### 4.4.1 (C) Uni-Junction Transistor Switch:

As the name implies a UJT has only one p-n junction, unlike a BJT which has two p-n junctions. It has a p-type emitter alloyed to a lightly doped n-type material as shown in Figure 4.4(a). There are two bases: base $\mathbf{B_1}$ and base $\mathbf{B_2}$**,** base $\mathbf{B_1}$ being closer to the emitter than base $\mathbf{B_2}$. The p-n junction is formed between the p-type emitter and n-type silicon slab. Originally this device was named as double base diode but now it is commercially known as UJT. The equivalent circuit of the UJT is shown in Figure 4.4(b). $R_{B1}$ is the resistance between base $\mathbf{B_1}$ and the emitter, and it is basically a variable resistance, its value being dependent upon the emitter current $I_E$. $R_{B2}$ is the resistance between base $\mathbf{B_2}$ and the emitter, and its value is fixed.

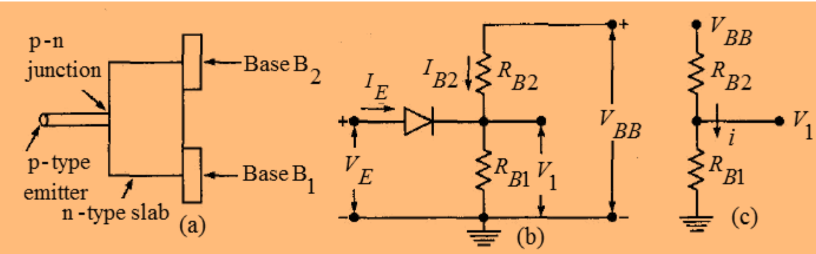


**Figure 4.4 (a) Construction of UJT, (b) equivalent circuit of UJT, and (c) circuit when $i_E = 0$.**

If $I_E = 0$, due to the applied voltage $V_{BB}$, a current *i* results as shown in Figure 4.4(c).

$$i = \frac{V_{BB}}{R_{B1} + R_{B2}} \text{ ------------------------------------------- } 4.17$$

$$V_1 = i \times R_{B1} = \frac{V_{BB}}{R_{B1} + R_{B2}} \times R_{B1} = \frac{R_{B1}}{R_{B1} + R_{B2}} \times V_{BB} \text{ -------- } 4.18$$

The ratio $\frac{R_{B1}}{R_{B1} + R_{B2}}$ is termed the intrinsic stand of ratio and is denoted by η. Therefore,

$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}, \text{ When } I_E = 0. \text{ -------------------------- } 4.19$$

From Equation 4.18, $V_1 = \eta \times V_{BB}$

From the equivalent circuit, it is evident that the diode cannot conduct unless the emitter voltage $V_E = V_\gamma + V_1$. Where, $V_\gamma$ is the cut-in voltage of the diode.This value of emitter voltage which makes the diode conduct is termed *peak voltage* and is denoted by $V_P$.

$V_P = V_\gamma + V_1 = V_\gamma + \eta \times V_{BB}$. Since $V_1 = \eta \times V_{BB}$

It is obvious that if $V_E < V_P$, the UJT is OFF and if $V_E > V_P$, the UJT is ON. The symbol of UJT is shown in Figure 4.5(a). The input characteristics of UJT (plot of $V_E$ versus $I_E$) are shown in Figure 4.5(b).

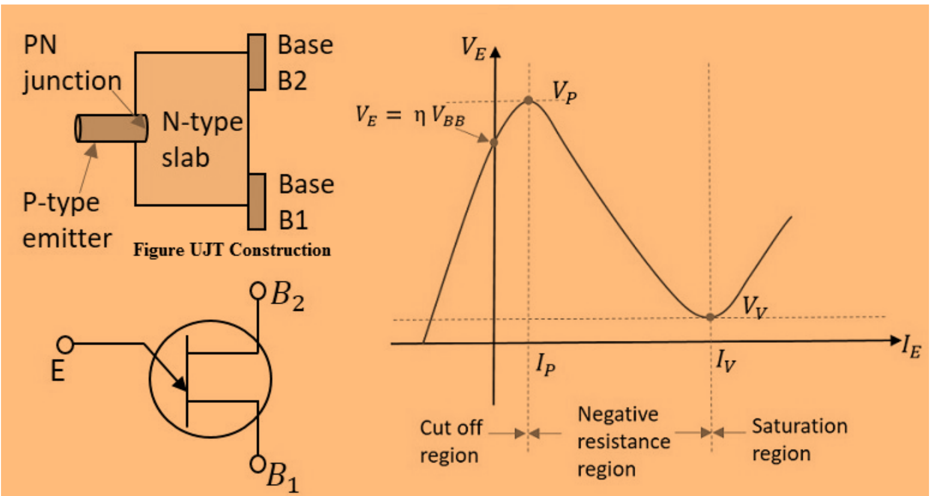


Figure 4.5 (a) UJT Symbol

Figure 4.5 (b) $V_E$ versus $I_E$ Charecteristics

The main application of UJT is in switching circuits wherein rapid discharge of capacitors is very essential. UJT sweep circuit is called as a relaxation oscillator.

### 4.4.1(D) Sweep Time of UJT Sweep Circuit:

Many devices are available to serve as the switch S. Figure 4.6(a) shows the exponential sweep circuit in which the UJT serves the purpose of the switch. In fact, any current-controlled negative-resistance device may be used to discharge the sweep capacitor. The supply voltage $V_{YY}$ and the charging resistor $R$ must be selected such that the load line intersects the input characteristic in the negative-resistance region. Assume that the UJT is OFF. The capacitor $C$ charges from $V_{YY}$ through $R$. When it is charged to the peak value $\boldsymbol{V_P}$, the UJT turns ON and the capacitor now discharges through the UJT. When the capacitor discharges to the valley voltage $V_V$ the UJT turns OFF, and again the capacitor starts charging and the cycle repeats. The capacitor voltage appears as shown in Figure 4.6(b). The expression for the sweep time $T_S$ can be obtained as follows.

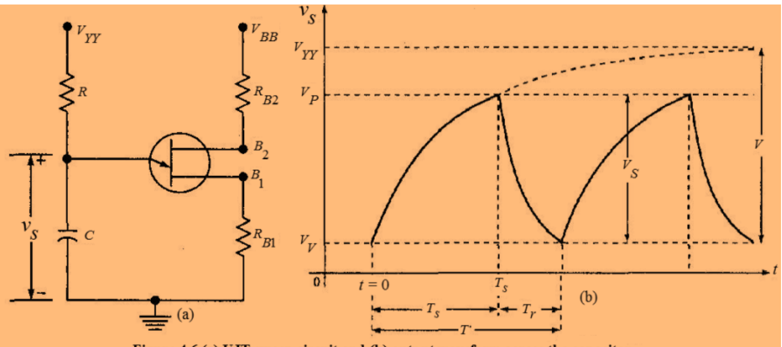

**Figure 4.6 (a) UJT sweep circuit and (b) output waveform across the capacitor.**

For $0 < t < T_S$, $v_s = V_f - \left(V_f - V_i\right)e^{-t/RC}$

$$= V_{YY} - \left(V_{YY} - V_V\right) e^{-t/RC}$$

At $t = T_S$, $v_o = v_s = Vp$

$$\therefore \; V_P = V_{YY} - \left(V_{YY} - V_V\right) e^{-T_s/RC}$$

i.e. $\left(V_{YY} - V_V\right) e^{-T_s/RC} = V_{YY} - V_P$

or $e^{T_s/RC} = \dfrac{V_{YY} - V_V}{V_{YY} - V_P}$

$$\therefore\ T_s = RC\ln\left(\frac{V_{YY}-V_V}{V_{YY}-V_P}\right) \text{ ------------------------------------------------ } 4.20$$

**Slope error:**

Consider $v_s = V_{YY} - (V_{YY} - V_V)\, e^{-t/RC}$

Neglecting the valley point voltage $V_V$

$$v_s = V_{YY}\left(1-e^{-t/RC}\right)$$

$$\frac{dv_s}{dt} = V_{YY}\times -e^{-t/RC}\times\frac{-1}{RC} = V_{YY}\times e^{-t/RC}\times\frac{1}{RC}$$

At t=0, $\left.\frac{dv_s}{dt}\right|_{t=0} = V_{YY}\times\frac{1}{RC}$

And at $t = T_S$ , $\left.\frac{dv_s}{dt}\right|_{t=T_S} = V_{YY}e^{-T_S/RC}\times\frac{1}{RC}$

The slope error or sweep speed error is given by

$$\text{Slope error}, e_S = \frac{\left.\frac{dv_s}{dt}\right|_{t=0} - \left.\frac{dv_s}{dt}\right|_{t=T_s}}{\left.\frac{dv_s}{dt}\right|_{t=0}}$$

$$= \frac{\frac{V_{YY}}{RC} - \frac{V_{YY}\ e^{-T_s/RC}}{RC}}{\frac{V_{YY}}{RC}} = 1-e^{-T_S/RC}$$

$$\approx 1-1+T_S/RC = \frac{T_S}{RC}$$

$$\therefore\ \textit{Slope error} = e_s = \frac{T_S}{RC}$$

In another way: consider $v_s = V_{YY}\left(1-e^{-t/RC}\right)$

At $t = T_S$ , $v_s = V_P$ and $V_P = V_{YY}\left(1-e^{-T_S/RC}\right)$

$$\frac{V_P}{V_{YY}} \approx \left(1 - 1 + T_S / RC\right)$$

$$\therefore slope\ \ errorr\ = \frac{V_P}{V_{YY}} = \frac{T_S}{RC}$$

## 4.4.1(E) Frequency of Uni-Junction Transistor Sweep Circuit:

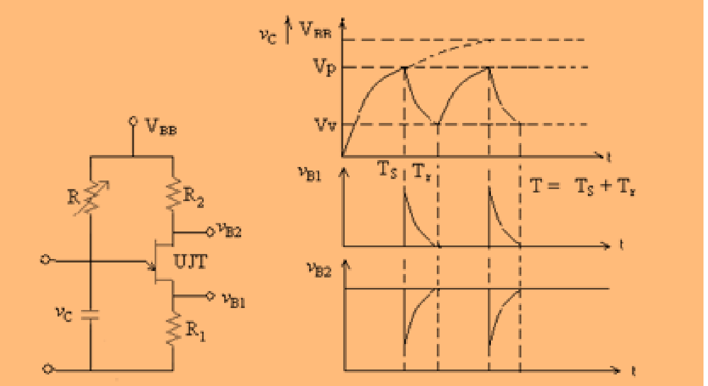


Figure 4.6(c) UJT Relaxation Oscillator (d) Associated Waveforms.

The circuit shown in Figure 4.6(c) is a sweep circuit using a UJT switch. The circuit is commonly known as UJT relaxation oscillator.

When the supply voltage $V_{BB}$ is switched ON, the capacitor (C) charges through resistor (R), till the capacitor voltage reaches the voltage level ( $V_P$) which is called peak point voltage,. At this voltage, the UJT turns ON. As a result of this, the capacitor (C) discharges rapidly through resistor ($R_1$). When capacitor voltage drops to a level $V_V$ called valley point voltage, the UJT switches OFF allowing the capacitor (C) to charge again.

Figure 4.6(d) shows the capacitor voltage ($v_C$), the base 1 voltage $V_{b1}$ and base 2 voltage *Vb2* waveforms during the capacitor charging and discharging interval. It may be noted that the voltage developed at base 1 terminal is in the form of narrow pulses commonly known as trigger pulses. The similar pulses but with opposite polarity are also available at the base terminal 2 of UJT.

Frequency of oscillations: Assuming that the capacitor is initially uncharged, the voltage across the capacitor prior to breakdown is given by

$v_C = v_f + ( v_i - v_f )\ e^{-\frac{t}{\tau}}$ , where $v_f = V_{BB}$, $v_i = V_v$ and $\tau = R.C$

$$v_C = V_{BB} + ( V_v - V_{BB} )\ e^{-\frac{t}{\tau}}$$

If $V_v = V_\gamma = 0$, at $t = T_S$, $v_C = V_P$

$$\therefore V_P = V_{BB}\left(1 - e^{-\frac{T_S}{\tau}}\right)$$

$$\frac{V_P}{V_{BB}} = \left(1 - e^{-\frac{T_S}{\tau}}\right)$$

$$\eta = \left(1 - e^{-\frac{T_S}{\tau}}\right)$$

$$e^{-\frac{T_S}{\tau}} = 1 - \eta$$

$$e^{\frac{T_S}{\tau}} = \frac{1}{(1-\eta)}$$

$$T_S = \tau \ln\frac{1}{(1-\eta)} = RC \ln\frac{1}{(1-\eta)}$$

$$T_S = 2.3\, RC \log_{10}\frac{1}{(1-\eta)}$$

If the discharge time of the capacitor is neglected, then $T = T_S + T_r = T_S$, the period of the wave, therefore frequency of oscillation of saw tooth wave is

$$T = \frac{1}{f} = 2.3\, RC \log_{10}\frac{1}{(1-\eta)} \text{ ------------------------------------------------------ } 4.21$$

$$f = \frac{1}{2.3RC\log_{10}\frac{1}{(1-\eta)}} \text{ --------------------------------------------------------------- } 4.22$$

It will be interesting to know that the sweep period, also called period of oscillation, depends up on time constant ($\tau$ = RC) and the type of UJT used in the circuit.

However, it is independent of the supply voltage ($V_{CC}$) and the temperature.

The sweep period is given by

$$T = 2.3\, RC \log_e\frac{1}{(1-\eta)} = RC \log_{10}\frac{1}{(1-\eta)}$$

Where $\eta$ is an intrinsic standoff ratio. Its value is approximately equal to the ratio of peak point voltage to the supply voltage i.e. $\eta = \frac{V_P}{V_{BB}}$.

The sweep frequency or the frequency of oscillation is the reciprocal of sweep period. i.e.

$$f = \frac{1}{T} = \frac{1}{2.3\,RC\,\log_{10}\frac{1}{(1-\eta}} \text{ ---------------------------------------------------- } 4.23$$

The sweep frequency can be varied by changing values of either resistance (R) or capacitor (C).

However, it is more convenient to change the value of R than C. It is due to this fact that the resistor R is shown as a variable resistor.

## 4.5 A Transistor Constant Current Sweep:

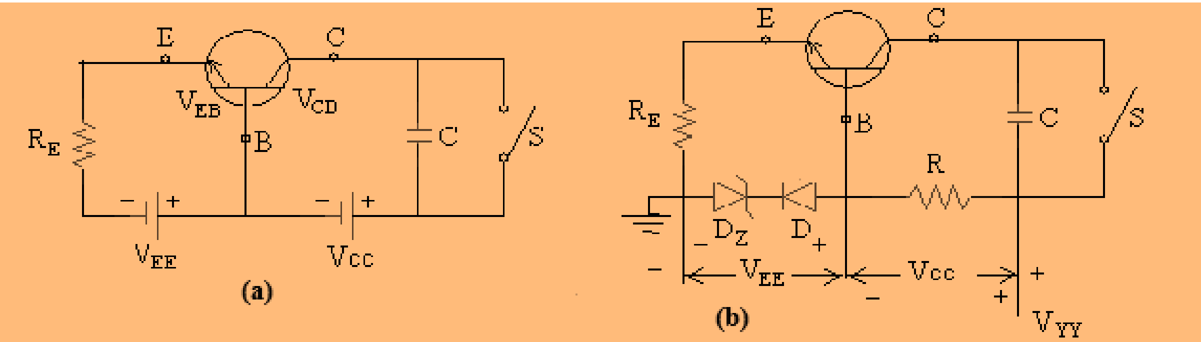


**Figure 4.7 (a) A Transistor Constant Current Sweep Circuit**

**Figure 4.7 (b) A Transistor Constant Current Sweep Circuit Using Single Supply $V_{YY}$**

Figure7 (a) shows a circuit to generate a sweep using constant current obtained from a common base transistor. We know that except for small values of collector to base voltage, the collector current of a transistor in the common base configuration is very nearly constant, when the emitter current is held fixed. This characteristic may be used to generate a quite linear sweep by causing a constant current flow into a capacitor. The value of emitter current in Figure7 (a) is given by the expression

$$I_E = \frac{V_{EE} - V_{EB}}{R_E} \text{ ----------- } 4.24$$

If the emitter to base voltage ($V_{EB}$) remains constant with times after the switch (S) opened, then the collector current will be a constant whose nominal value is $I_C = h_{FB}.\ I_E = \alpha.\ I_E$, where $h_{FB}$ ($\alpha$ ) is the common base current gain of the transistor.

The constant current sweep circuit discussed above has one drawback, that it makes the sweep rate as function of temperature. Since the emitter base junction voltage ($V_{BE}$) for fixed current decreases by about 2mV/$^{o}$C, therefore the sweep speed increases with the temperature.

We know sweep speed = $\frac{I}{C}$. Here $I = I_C = \alpha . I_E$

$$\therefore \text{Sweep speed} = \frac{\alpha\, I_E}{C}.$$

$$\text{Since } I_E = \frac{V_{EE} - V_{EB}}{R_E}$$

$$\therefore \text{Sweep speed} = \frac{\alpha\ (V_{EE} - V_{EB})}{C\, R_E} \text{ ------------------------------------------------- } 4.25$$

Here $V_{EB}$ decreases with increase in temperature. Hence sweep speed increases with increase in temperature.

Figure7 (b) shows a constant current sweep circuit, which employs a single supply $V_{YY}$ and provides a considerable temperature compensation. The emitter supply voltage is now equal to the voltage $V_Z$ across the zenor diode ($D_Z$) plus the drop ($V_D$) across the diode D. The collector supply voltage $V_{CC}$ is now equal to the drop across resistor R, i.e. $V_{CC} = (V_{YY} - V_{EE})$. The diode D is made of the same material as that of the transistor ( i.e. both silicon or germanium). Hence the diode (D) serve to compensate for the temperature dependent emitter to base voltage ($V_{EB}$). If the drops across diode and emitter base junction are always the same, then the voltage across resistor ($R_E$) remains equal to $V_Z$ and the emitter current is equal to $\frac{V_Z}{R_E}$ which is constant. Thus the sweep speed is essentially independent of temperature.

## 4.6 Miller and Bootstrap Time-Base Generators-Basic Principles:

The linearity of the time-base waveforms may be improved by using circuits involving feedback. Figure 4.8(a) shows the basic exponential sweep circuit in which S opens to form the sweep. A linear sweep cannot be obtained from this circuit because as the capacitor charges, the charging current decreases and hence the rate at which the capacitor charges, i.e. the slope of the output waveform decreases. A perfectly linear output can be obtained if the initial charging current $I = V/R$ is maintained constant. This can be done by introducing an auxiliary variable generator $v$ whose generated voltage $v$ is always equal to and opposite to the voltage across the capacitor as shown in Figure 4.8(b). Two methods of simulating the fictitious generator are discussed below.

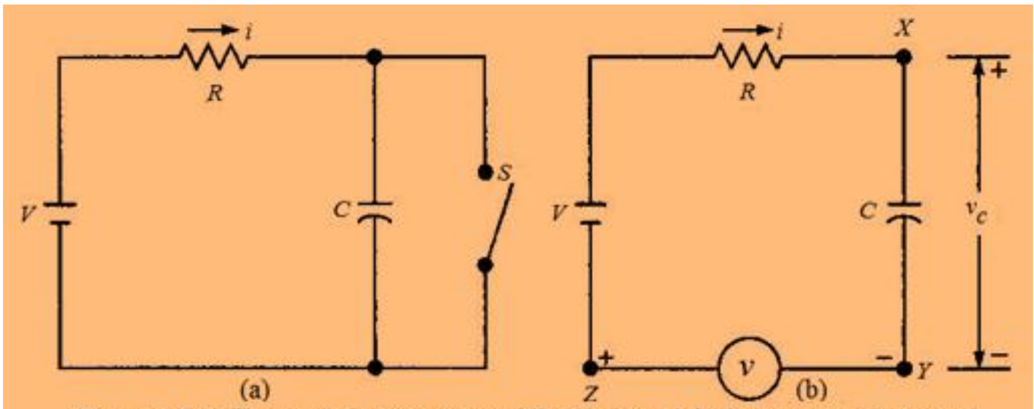

**Figure 4.8** (a) The current decreases exponentially with time and (b) the current remains constant.

In the circuit of Figure 4.8(b) suppose the point Z is grounded as in Figure 4.9(a), a linear sweep will appear between the point Y and ground and will increase in the negative direction. Let us now replace the fictitious (imaginary) generator by an amplifier with output terminals YZ and input terminals XZ as shown in Figure 4.9(b). Since we have assumed that the generated voltage is always equal and opposite to the voltage across the capacitor. The voltage between X and Z is equal to zero. Hence the point X acts as a virtual ground. Now for the amplifier, the input is zero volts and the output is a finite negative value. This can be achieved by using an operational integrator with a gain of infinity. This is normally referred to as the Miller integrator circuit or the Miller sweep.

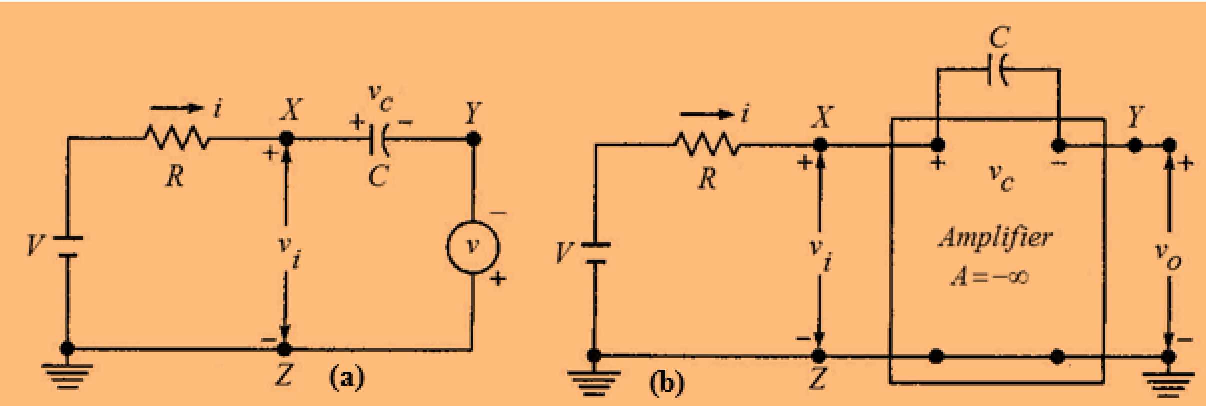

**Figure 4.9(a) Figure 4.8(b) with Z grounded and (b) Miller Integrator Circuit**

Suppose that the point Y in Figure 4.8(b) is grounded and the output is taken at Z. A linear sweep will appear between Z and ground and will increase in the positive direction. Let us now replace the fictitious generator by an amplifier with input terminals XY and output terminals ZY as shown in Figure 4.10. Since we have assumed that the generated voltage *v* at any instant is equal to the voltage across the capacitor $v_C$, then $v_0$ must be equal to $v_i$, and the amplifier voltage gain must be equal to unity. The circuit of Figure 4.10 is referred to as the Bootstrap sweep circuit.

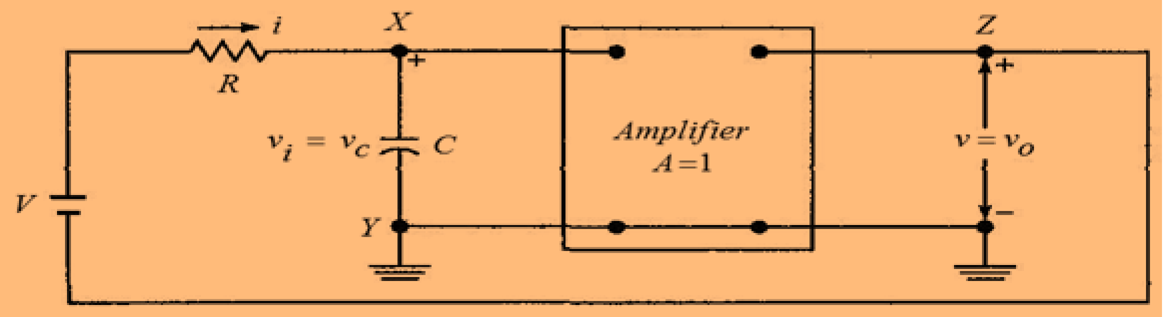


**Figure 4.10 Bootstrap Sweep circuit**

## 4.6.1 The Miller Sweep:

The Miller integrating circuit of Figure 4.9(b) is redrawn in Figure 4.10(a). A switch S at the closing of which the sweep starts is included. The basic amplifier has been replaced at the input side by its input resistance and on the output side by its Thevenin's equivalent. $R_O$ is the output resistance of the amplifier and $A$ its open circuit voltage gain. Figure 4.10(b) is obtained by replacing $V$, $R$ and $R_i$, in the input side by a voltage source $V'$ in series with a resistance $R'$ where

$$V' = V\frac{R_i}{R_i + R} = \frac{V}{1+\frac{R}{R_i}} \quad and \quad R' = R||R_i = \frac{RR_i}{R+R_i} \text{-----------------------} \; 4.26$$

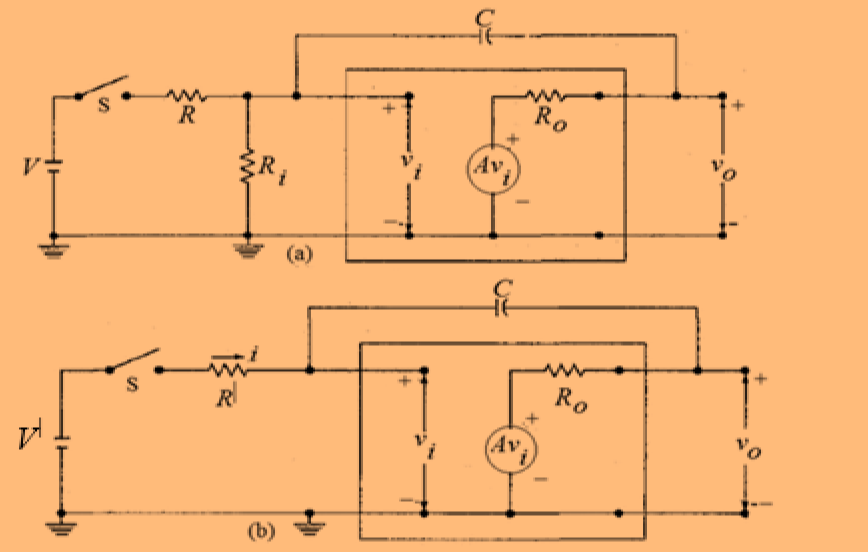


**Figure 4.10 (a) A Miller integrator with switch S, input resistance $R_i$ and Thevenin's equivalent on the output side and (b) Figure 4.10(a) with input replaced by Thevenin's equivalent.**

Neglecting the output resistance in the circuit of Figure 4.10(b), if the switch is closed at $t$ = 0 and if the initial voltage across the capacitor is zero, then $v_o$ (t = $0^+$) = 0,because at t = $0^+$, $Vi \approx 0$ and since the voltage across the capacitor cannot change instantaneously.

$$At \quad t=0^+, \quad v_i - Av_i = 0 \quad or \quad v_i = Av_i = v_o = 0 \text{----------------------} 4.27$$

This indicates that the sweep starts from zero.At $t$ = ∞, the capacitor acts as an open-circuit for dc.So no current flows and therefore

$$v_i = V^| \quad and \quad v_o = AV^|$$

This indicates that the output is exponential and the sweep is negative-going since $A$ is a negative number.

$$\text{Slope error,} \quad e_s = \frac{V_s}{\mathrm{V_o}} \text{------------------------------------------------------} 4.28$$

Where $Vs$ is the sweep amplitude and $V_O$ is the peak-to-peak value of the output.

$$e_s(miller) = \frac{V_s}{|A|V^|} = \frac{V_s}{|A|} \times \frac{R_i + R}{V\, R_i} = \frac{V_s}{V} \times \frac{1+\frac{R}{R_i}}{|A|} \text{----------------------} 4.29$$

The deviation from linearity is $\frac{1+\frac{R}{R_i}}{|A|}$ times that of an $RC$ circuit charging directly from a source $V$. If $R_0$ is taken into account, the final value attained by $v_o$ remains as before and $AV$ = - $|A|V$.

The initial value however is slightly different. To find $v_o$ at $t$ = 0+, writing the KVL around the mesh in Figure 4.10(b), assuming zero voltage across the capacitor, we have

$$V^| - R^| i - R_o i - Av_i = 0 ---- (a)$$

$$\text{and} \quad v_i = V^| - R^| i$$

From the above equation $v_i$, we find $i=\dfrac{V^{\prime}-v_i}{R^{\prime}}$ and substituting this in equation (a), we get

$$V^{\prime}-R^{\prime}\frac{V^{\prime}-v_i}{R^{\prime}}-R_o\frac{V^{\prime}-v_i}{R^{\prime}}-Av_i=0 \text{ and solving this we get}$$

$$v_i\left(t=0^{+}\right)=\Delta v_i=v_o\left(t=0^{+}\right)=\Delta v_o=\frac{\left(\dfrac{R_o}{R^{\prime}}\right)V^{\prime}}{1-A+\dfrac{R_o}{R^{\prime}}}$$

$$v_i\left(t=0^{+}\right)\approx\frac{R_o V^{\prime}}{R^{\prime}\left|A\right|} \text{ ------------------------------------------------------------ } 4.30$$

Therefore, if $R_0$ is taken into account, $v_0(t = 0+)$ is a small positive value and still it will be a negative going sweep with the same terminal value. Thus the negative-going ramp is preceded by a small positive jump. Usually this jump is small compared to the excursion $AV^{\prime}$. Hence, improvement in linearity because of the increase in total excursion is negligible.

## 4.6.2 The Bootstrap Sweep:

Figure 4.11 shows the bootstrap circuit of Figure 4.10. The switch S at the opening of which the sweep starts is in parallel with the capacitor $C$. Here, $R_i$ is the input resistance, $A$ is the open-circuit voltage gain, and $R_o$ is the output resistance of the amplifier.

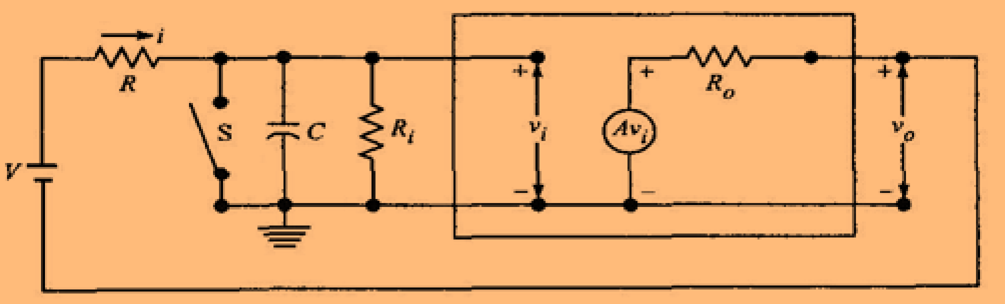


**Figure 4.11 Bootstrap circuit of Figure 4.9 with switch S which opens at t = 0, input resistance *Rf*, and Thevenin's equivalent of the amplifier on the output side.**

At $t$ = 0 the switch was closed and so $v_i$ = 0. Since the voltage across the capacitor cannot change instantaneously, at $t$ = $0^+$ also, $v_i$=0 and hence $Av_i$ = 0, and the circuit shown in Figure 4.12 results.

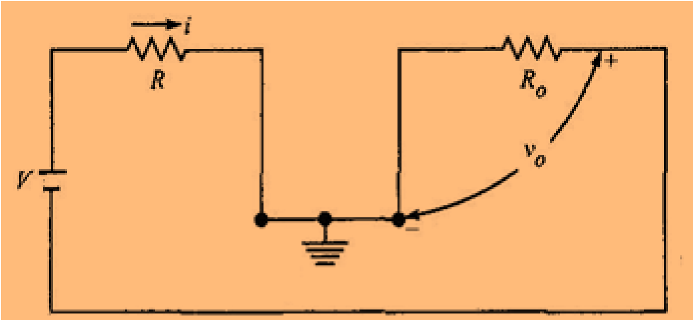

**Figure 4.12 Equivalent Circuit of Figure 4.11 at t=0**

From the Figure 4.12, at $t=0^+$, $v_O = -V\dfrac{R_O}{R+R_O}$

The output has the same value at $t$ = 0 and hence there is no jump in the output voltage at $t$ = $0^+$.

At $t$ =∞ , the capacitor acts as an open-circuit and the equivalent circuit shown in Figure 4.13 results.

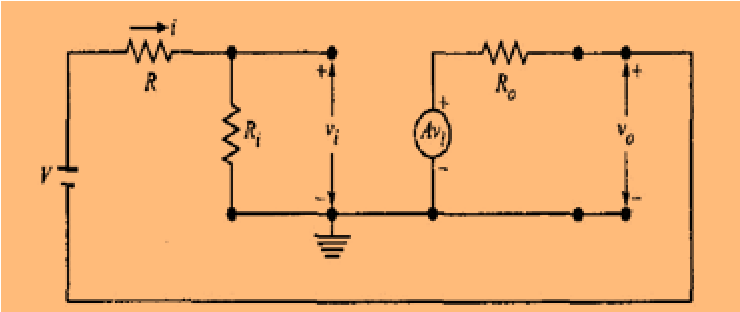

**Figure 4.13 Equivalent Circuit of Figure 4.12 at t = ∞**

$$v_O(\infty) = Av_i - i\times R_O = A\times i\times R_i - i\times R_O = i\left(AR_i - R_O\right) \text{----------------- } 4.31$$

Writing KVL around the circuit of Figure 4.13, we get

$$V - i\times R - i\times R_i + Av_i - i\times R_O = 0$$

$$V - i\times R - i\times R_i + A\times i\times R_i - i\times R_O = 0 \text{, and solving for } i$$

$$i.e \quad i = \frac{V}{R+R_O+R_i(1-A)} \text{ and substituting this value in equation 4.31, we get}$$

$$\therefore \quad v_O(t=\infty) = \frac{V(AR_i - R_O)}{R+R_O+R_i(1-A)}$$

Since $A\approx 1$, and if $R_O$ is neglected, we get

$$v_o(t=\infty)=\frac{V}{(1-A)+R/R_i} \text{ ------------------------------------------------- } 4.32$$

Since $R_0 <<1$, $v_0$ at $t=0$ can be neglected compared to the value of $v_0$ at $t=\infty$.

Then the total excursion of the output is given by

$$v_o(t=\infty)-v_o(t=0)=\frac{V}{(1-A)+R/R_i} \text{ -------------------------------- } 4.33$$

and the slope error is

$$e_s(bootstrap)=\frac{Sweep\ \ amplitude}{Total\ \ excursion\ \ of\ \ output}=\frac{V_s}{\dfrac{V}{(1-A)+R/R_i}}=\frac{V_s}{V}\left((1-A)+R/R_i\right)$$

$$e_s(bootstrap)=\frac{V_s}{V}\left((1-A)+R/R_i\right) \text{ --------------------------------- } 4.34$$

This shows that the slope error is $\left((1-A)+R/R_i\right)$ times the slope error that would result if the capacitor is charged directly from $V$ through a resistor.

Comparing the expressions for the slope error of Miller and bootstrap circuits, we can see that it is more important to keep $R/R_i$ small in the bootstrap circuit than in the Miller circuit.

Therefore, the Miller integrator has some advantage over the bootstrap circuit in that in the Miller circuit a higher input

## 4.6.3 Miller Sweep Circuit

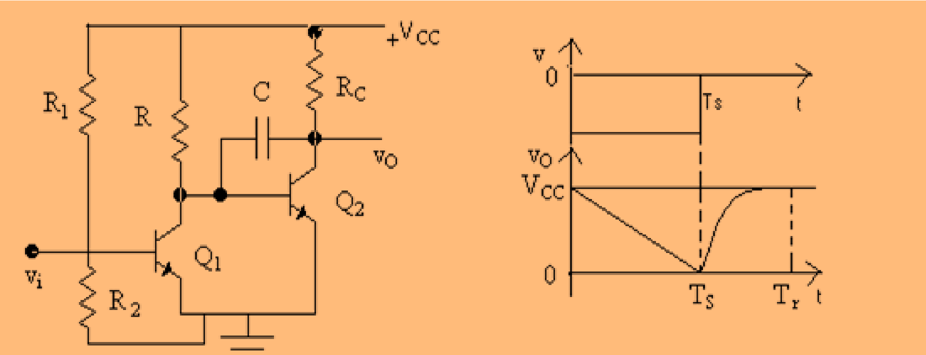


Figure 4.14(a) Miller sweep circuit Figure 4.14(b) The input and output waveform

It is also called Miller integrator. In Figure 4.14(a) the transistor $Q_1$ acts as a switch and transistor $Q_2$ is a common emitter amplifier i.e. a high gain amplifier. The operation of the circuit may be understood from the condition that, initially, the transistor $Q_1$ is ON and $Q_2$ is OFF. At this instant, the voltage across the capacitor and the output voltage equal to $V_{CC}$.

Now suppose a pulse $v_i$ of negative polarity as shown in Figure 4.14(b) is applied at the base of $Q_1$, the emitter base junction of $Q_1$ is reverse biased and it turns OFF $Q_1$. This causes the $Q_2$ to turn ON. As the $Q_2$ conducts, the output voltage begins to decrease towards zero. Since the capacitor C is coupled to the base of $Q_2$, therefore the rate of decrease of the output voltage is controlled by the rate of discharge of capacitor C. The time constant of the discharge is given by the relation = $R_B C$.

Since the value of time constant is very large, therefore the discharge current practically remains constant. As a result of this, the rundown of the collector voltage is linear. When the input pulse is removed, the transistor $Q_1$ turns ON and $Q_2$ turns OFF. It will be interesting to know that as the $Q_2$ turns OFF, the capacitor C charges quickly, through resistor $R_C$ to $V_{CC}$ with a time constant $\tau = R_C C$ . The waveform of the generated sweep or the output voltage $v_O$ is shown in Figure 4.14(b)

It may be noted from the circuit that we have shown only one stage of amplification. But in actual practice more than one stage of amplification is used. Usually the amplifier stage uses emitter followers at the input and output to increase the low frequency input and output resistances (i.e. $R_i$ and $R_O$). Sometimes the resistor $R_C$ in the Miller sweep circuit is replaced by a diode. The diode forward resistance $R_F$ helps the capacitor to charge quickly from $V_{CC}$.

This reduces the fly back time $T_r$ of the generated sweep. The Miller sweep circuit provides excellent sweep linearity as compared to other sweep circuits.

### 4.6.4 Bootstrap Sweep Circuit:

Figure 4.15(a) shows a practical form of a Bootstrap sweep circuit. Here the transistor $Q_1$ acts as a switch and $Q_2$ as an emitter follower (i.e. a unity gain amplifier). The operation of the circuit may be explained as follows.

Initially $Q_1$ is ON and $Q_2$ is OFF. Therefore, the capacitor $C_1$ is charged to $V_{CC}$ through the diode forward resistance $R_F$. At this instant the output voltage $V_O$ is zero. When a negative pulse $v_i$ as shown in Figure 4.15(b)is applied to the base of transistor $Q_1$, it turns OFF. Since $Q_2$ is an emitter follower, therefore the output voltage $V_O$ is the same as the base voltage of $Q_2$. Thus as the transistor $Q_1$ turns OFF, the capacitor $C_1$ starts charging the capacitor C through resistor R. As a result of this both the base voltage of $Q_2$ and the output voltage begins to increase from zero. As the output voltage increases, the diode D becomes reverse biased. It is because of the fact that the output voltage is coupled through the capacitor $C_1$ to the diode. Since this value of capacitor $C_1$ is much larger than that of capacitor C, therefore the voltage across capacitor $C_1$ practically remains constant. Thus the voltage drop across the resistor R also remains constant. Because of this, the current $i_R$ through the resistor R also remains constant. It means that the capacitor C is charged with a constant current. This causes the voltage across the capacitor C and hence the output voltage to increase linearly with time.

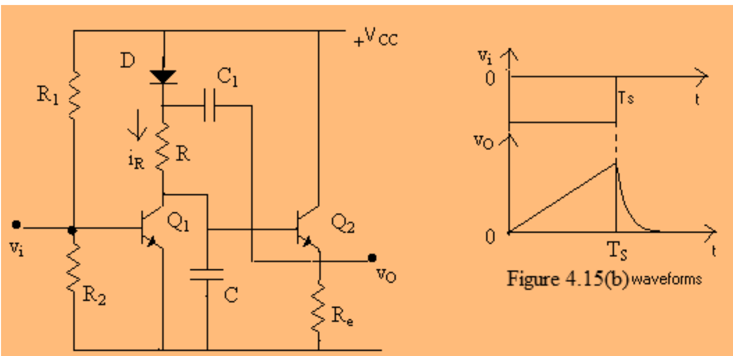


Figure 4.15(a) Bootstrap sweep circuit

Figure 4.15(b) waveforms

It is evident from the above discussion that the circuit pulls itself up by its own bootstrap and hence it is known as Bootstrap sweep circuit. When the negative pulses removed from the input of $Q_1$, the capacitor C discharges rapidly through

$Q_1$ and the output voltage returns to zero. Then capacitor $C_1$ again charges to voltage $V_{CC}$ through diode D. The output waveform is shown in Figure 4.15(b)

## 4.7 Current Time Base Generator:

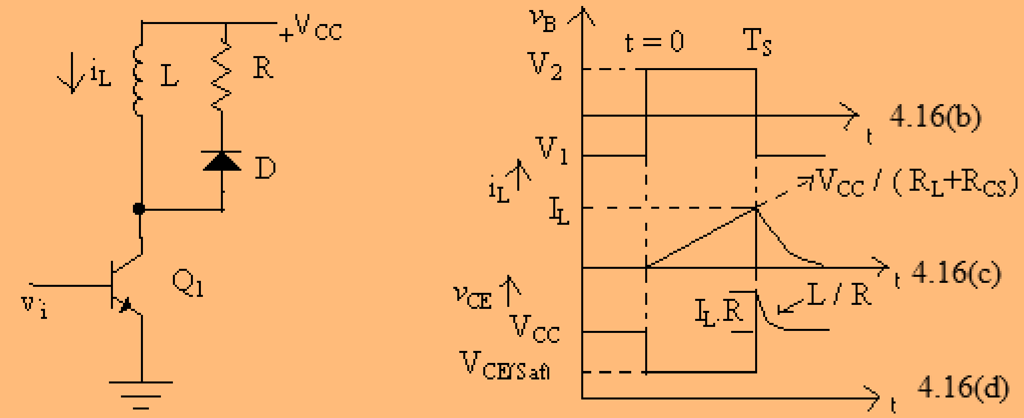


Figure 4.16(a) A Current Time Base Circuit Figure 4.16(b) ,(c) and (d) Waveforms

Figure 4.16 A Current Time Base Circuit

We have already discussed the methods and circuits by means of which we can generate a voltage that varies linearly with the time. Such a voltage may be applied to resistor, there by generating a current that increases linearly with time. However, the more accurate method is to cause a linearly time varying current to flow through an inductor L. Such circuits are used in Radar and Television displays.

Figure 4.16(a) shows a simple circuit of a current time base generator. Here an inductor L in series with a transistor is connected across the $V_{CC}$ supply. The transistor operates as a switch in this circuit. The gating waveform $v_B$ at the base operates between two levels $V_1$ and $V_2$ as shown in Figure 4.16(b).The lower level $V_1$ keeps the transistor in cut off, while the upper level $V_2$ drives the transistor into saturation.

The operation of the circuit may be understood from the condition that when the transistor switch is turned ON, then neglecting the effect of small saturation resistance $R_{CS}$, the current $i_L$ through an inductor increases linearly with the time. The diode D does not conduct during the sweep, because it is reverse biased. The growth of current through an inductor L is given by the relation

$$i_L = \frac{V_{CC}}{R_L + R_{CS}} \times \left(1 - e^{-\frac{(R_L + R_{CS})}{L} \times t}\right) \text{------------------------------------------ } 4.35$$

where $R_L$ is the coil resistance.

$$i_L = \frac{V_{CC}}{R_L + R_{CS}} \times \left(1 - e^{-\frac{(R_L + R_{CS})}{L} \times t}\right) \approx \frac{V_{CC}}{R_L + R_{CS}} \times \left(1 - 1 + \frac{(R_L + R_{CS})}{L} \times t\right)$$

Here higher orders are neglected i.e. $t << \frac{L}{R_L + R_{CS}}$. And the above expression may be approximated as

$$i_L = \frac{V_{CC}}{L} \times t \text{ ------------------------------------------------------------------ } 4.36$$

At $t = T_S$, $i_L = I_L$

$$\therefore\ I_L = \frac{V_{CC}}{L} \times T_S \text{ ------------------------------------------------------------- } 4.37$$

It may be noted that the sweep terminates at $t = T_S$, then the gating signal drives the transistor to cut off. The inductor current then continues to flow through the diode D and resistor R, until it reduces to zero as shown in Figure 4.16(c)

Figure 4.16(d) shows the waveform of the collector to emitter voltage $v_{CE}$ of a transistor. It may be noted that the transistor is turned ON and sometime after it has been turned OFF, the voltage $v_{CE} = V_{CC}$. But during the time interval, in which the transistor is ON the voltage $v_{CE}$ is quite low i.e. equal to $v_{CE(sat)}$. It may be noted that at the moment the transistor turned OFF, a large spike of amplitude $I_L$ .R appears across the inductor. This voltage must be kept below the break down voltage, so that it does not damage the transistor.

The sweep speed error for the current time base circuit is given by

$$e_s = \frac{Sweep\ \ amplitude}{Total\ \ excursion\ \ of\ \ output}$$

$$= \frac{I_L}{\dfrac{V_{CC}}{R_L + R_{CS}} - 0}$$

$$e_S = I_L \frac{R_L + R_{CS}}{V_{CC}} \text{ but } \mathrm{I_L} = \frac{V_{CC}}{L} T_S$$

$$\therefore\ e_S = \frac{V_{CC}}{L} T_S \times \frac{R_L + R_{CS}}{V_{CC}}$$

$$e_S = T_S \times \frac{R_L + R_{CS}}{L} \quad \text{-------------------------------------------------------- 4.38}$$

It is evident from the above expression that to maintain linearity the time constant $\tau = \dfrac{L}{R_L + R_{CS}}$ must be kept large enough as compared to the sweep time $T_S$.

## 4.8 Linearity Correction through the Adjustment of Driving Waveform:

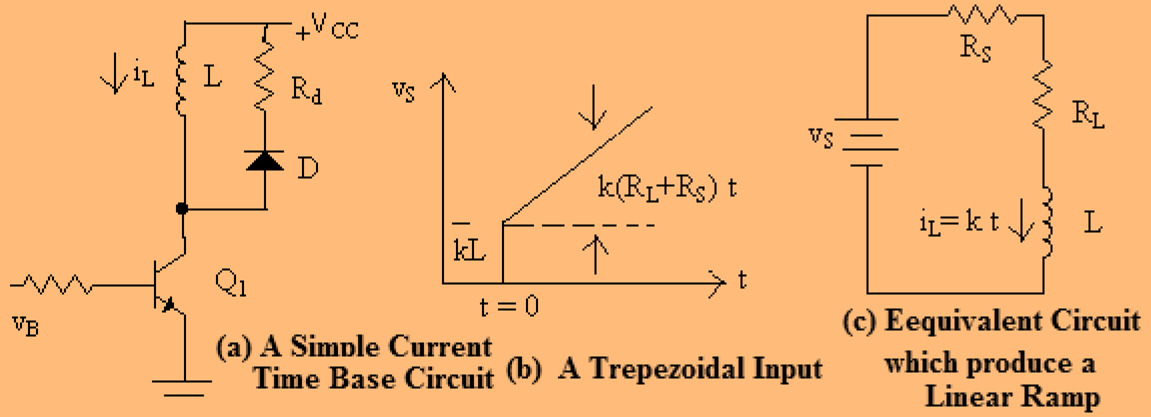


**Figure 4.17 Linearity Correction through the Adjustment of Driving Waveform. The Trapezoidal Voltage Waveform Shown in Figure4.17(b) Produces a Linear Ramp in the Circuit of Figure 4.17(c)**

The non-linearity encountered in the above circuit results from the fact that as yoke (inductor) current increases, so also does the current in the series resistance. Consequently the voltage across the yoke decreases and the rate of change of current decreases as well. We may compensate for the voltage developed across the resistor in the manner indicated in Figure 4.17(b) and

Figure 4.17(c).The driving voltage source has a Thevenins resistance $R_S$, and the total circuit resistance is $R_S + R_L$. If the current is to be $i_L = k.t$, then the voltage source waveform must be

$$v_S = L\frac{di}{dt} + (R_S + R_L)\, i \text{ ------------------------------------------------------- } 4.38$$

$$v_S = L\,k + (R_S + R_L)\,kt \text{ ----------------------------------------------------- } 4.39$$

This applied waveform consists of a step followed by a ramp. Such a waveform is called trapezoid.

We may find it more convenient to use a Nortans representation for the driving source as shown in Figure 4.18.

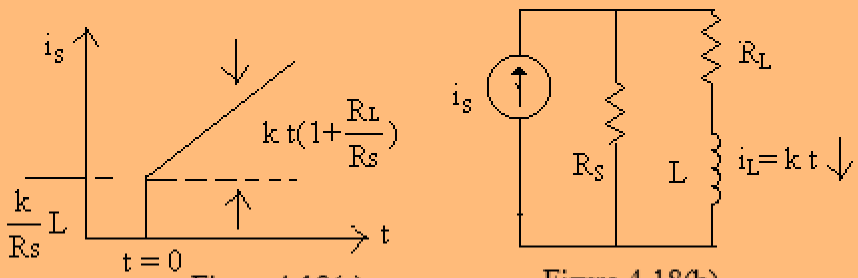


Figure 4.18(a) Figure 4.18(b)

Figure 4.18 The trapezoidal current waveform in Figure 4.18(a) produces a linear current ramp in the inductor of the circuit of Figure 4.18(b)

In this case the current source must furnish a current,

$$i_S = \frac{v_S}{R_S} = \frac{kL + k\left(R_L + R_S\right)\times t}{R_S}$$

$$i_S = \frac{k}{R_S}L + k\left(1 + \frac{R_L}{R_S}\right)\times t \text{ ------------------------------------------------------- } 4.40$$

The waveform of the current source is also trapezoidal, being a step followed by a ramp.

At the end of the sweep the current will return to zero exponentially with a time constant $\tau = \frac{L}{(R_S + R_L)}$.

Often we find that $R_S >> R_L$, so that $\tau \approx \frac{L}{R_S}$. If $R_S$ is small, the current will decay slowly and a correspondingly long period will elapse before another sweep will be possible.

But as compensation, the peak voltage developed across the current source (which may be well being a transistor) will be small.

Alternatively, if $R_S$ is large, the current will decay rapidly but a large peak voltage will appear across the source.

To limit this peak voltage, it is necessary to bridge a damping resistor $R_d$ across the yoke (inductor).

Let R be the parallel combination of $R_S$ and $R_d$. Then the retrace time constant is $\tau = \frac{L}{R}$

The trapezoidal waveform required is generated by a voltage sweep circuit modified as in Figure 4.19(a), by the addition of a resistor $R_1$ in series with the sweep capacitor $C_1$.

If the switch S is opened at t = 0 the output is given by

$$v_0 = V - iR_2 = V - \frac{R_2 V}{(R_1 + R_2)} e^{-\frac{t}{(R_1+R_2)C_1}} \quad \text{-------------------------- 4.41}$$

If $R_2 >> R_1$, then

$$v_0 \approx V - \frac{R_2 V}{(R_1 + R_2)}\left(1 - \frac{t}{R_2 C_1} + \frac{1}{2}\left(\frac{t}{R_2 C_1}\right)^2\right)$$

$$v_0 \approx V - \frac{R_2 V}{(R_1 + R_2)} + \frac{R_2 V}{(R_1 + R_2)}\left(\frac{t}{R_2 C_1} - \frac{1}{2}\left(\frac{t}{R_2 C_1}\right)^2\right)$$

$$v_0 \approx \frac{R_1 V}{R_2} + \frac{V \times t}{R_2 C_1}\left(1 - \frac{t}{2R_2 C_1}\right) \quad \text{------------------------------------------ 4.42}$$

If $\frac{t}{2R_2 C_1} << 1$, then

$v_0 \approx \frac{R_1 V}{R_2} + \frac{V}{R_2 C_1} \times t$. Here the output is a step followed by a ramp.

As long as $\frac{t}{2R_2C_1} << 1$, the waveform $v_O$ is trapezoidal, consisting of a step of amplitude $\frac{R_1 V}{R_2}$ on which is superimpose a ramp of slope $\frac{V}{R_2C_1}$.

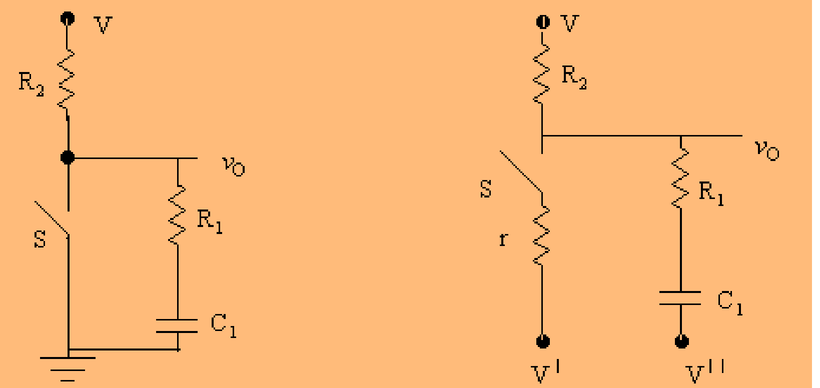


Figure 4.19(a) Figure 4.19(b)

Figure 4.19(a) A Circuit for Generating a Trapezoidal Viltage Waveform.
Figure 4.19(b) A More General Circuit

A more general form of trapezoidal waveform generator is shown in Figure 4.19(b).Here a switch resistor r has been included, and the switch and capacitor C1 have been returned to arbitrary voltages $V^1$and $V^{11}$ respectively. Equations 24 and 25 continue to apply. However provided that V is taken to be the quiescent voltage across R2 and that $v_O$ is interpreted as the departure of the output voltage from its quiescent value.

If the inductor were placed directly across the output terminals of Figure 4.19, the signal $v_O$ would no longer be given by equation 24. therefore the signal generated by the circuit of Figure 4.19 is not to be applied directly to the yoke but rather through an active device (tube or transistor). If the input impedance of the device is $R_i$, then a Thevinins equivalent can be made for $V_1$, $R_2$ and Ri. It is then found that equation 4.42 remains valid, except that the second term in the parenthesis is changed to $\frac{t}{2 R_2 C_1}\left(1+ \frac{R_2}{R_i}\right)$

Hence, $R_i$ must be larger than $R_2$ if the linearity of the trapezoidal is not to suffer appreciably.