Time Base Generators

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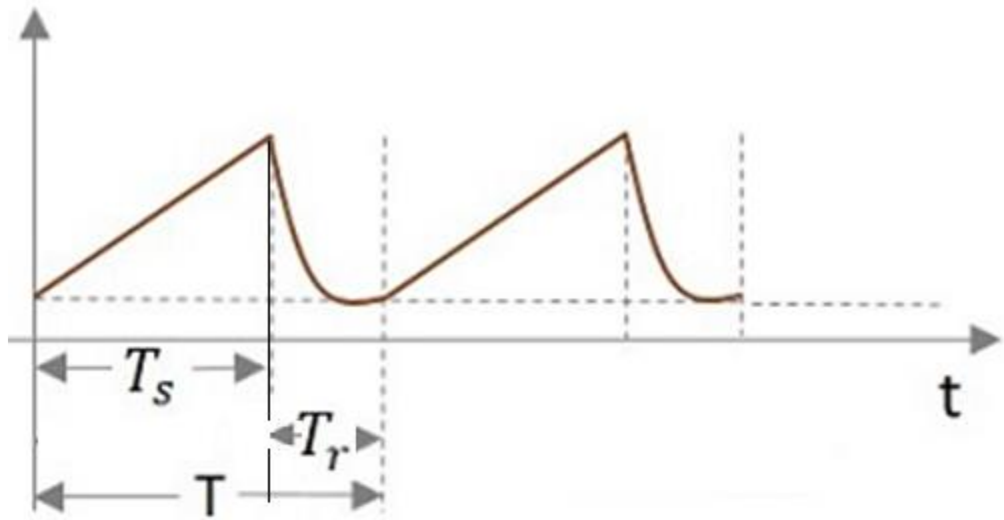
Time Base Generators

- 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
  - 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.

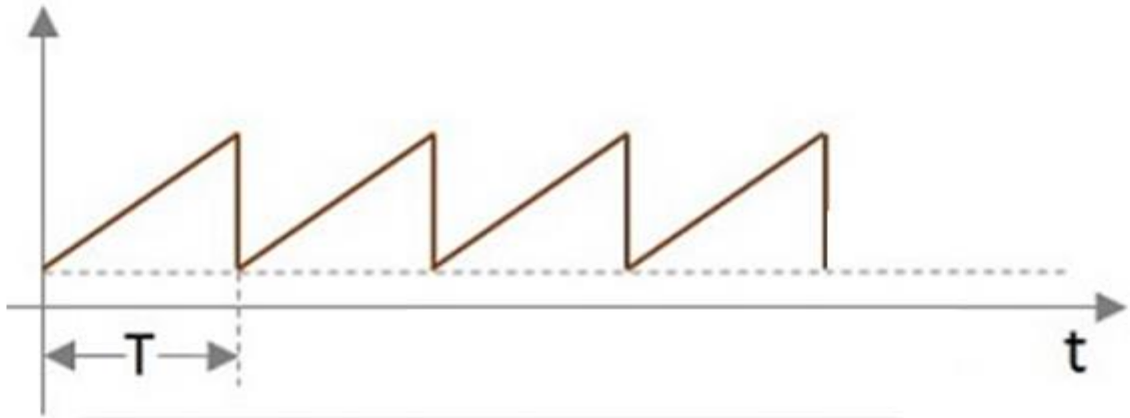
Applications

- There are many important applications of time-base generators
- such as in CROs, television and radar displays
- in precise time measurements
- in time modulation.
- The most important application of a time-base generator is in CROs.
- To display the variation with respect to time of an arbitrary waveform on the screen of an oscilloscope it is required to apply to one set of deflecting plates a voltage which varies linearly with time. Since this waveform is used to sweep the electron beam horizontally across the screen it is called the sweep voltage and the time-base generators are called the sweep circuits



A General sweep voltage

- 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**



A Saw tooth voltage waveform

- If 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 is generated.
- 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.

Errors of generation of sweep waveform

There are three most commonly used measures of sweep voltage:

1. Sweep speed error
2. Displacement error
3. Transmission error

These are called sweep parameters.

Sweep Speed Error (es):

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 be constant. This deviation from linearity is defined as

Slope or Sweep speed eror e_s = $$\frac{difference\ in\ slope\ at\ the\ beginning\ and\ end\ of\ sweep}{initial\ value\ of\ slope}$$

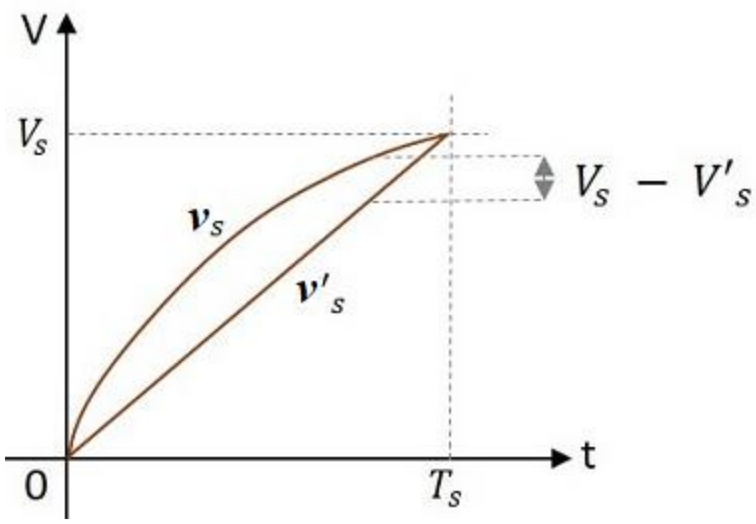
$$= \frac{\left(\frac{\mathrm{d}V_0}{\mathrm{d}t}\right)_{t=0} - \left(\frac{\mathrm{d}V_0}{\mathrm{d}t}\right)_{t=T_s}}{\left(\frac{\mathrm{d}V_0}{\mathrm{d}t}\right)_{t=0}}$$

The displacement error, ed

Another important criterion of linearity is the maximum difference between the actual sweep voltage and the linear sweep which passes through the beginning and end points of the actual sweep. The displacement error e_d is defined as

$$e_d = \frac{(actual\ speed) \sim (linear\ sweep\ that\ passes\ beginning\ and\ ending\ of\ actual\ sweep)}{amplitude\ of\ sweep\ at\ the\ end\ of\ sweep\ time}$$

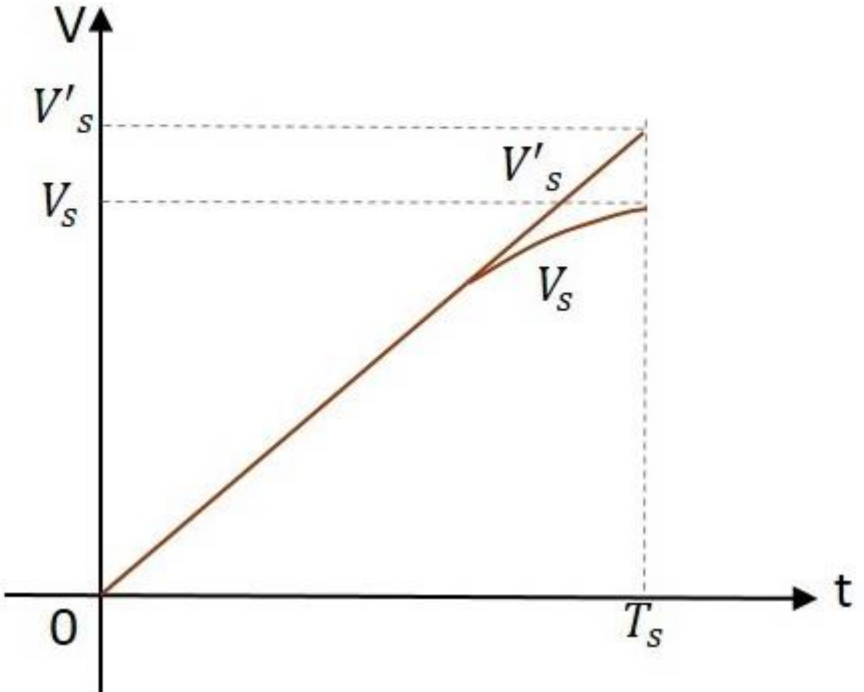
$$= \frac{(V_s - V'_s)_{max}}{V_s}$$



The Transmission Error (e_t)

Transmission Error = $\frac{(input) \sim (output)}{input\ at\ the\ end\ of\ the\ sweep}$

$$e_t = \frac{V'_s - V}{V'_s}$$



Where V'_s is the input and V_s is the output at the end of the sweep i.e. at $t = T_s$. If the deviation from linearity is very small and the sweep voltage may be approximated by the sum of linear and quadratic terms in t, then the above three errors are related as

$$e_d = \frac{e_s}{8} = \frac{e_t}{4}$$

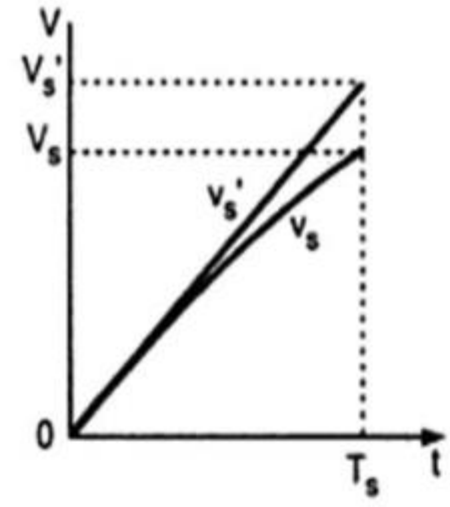
$$e_s = 2e_t = 8e_d$$

Transmission Error(et):

- When a ramp voltage is transmitted through a high pass rc circuit its output falls away from the input as shown.
- The transmission error is

defined as the difference b/w the input &o/p divided by i/p.

et=vs’-vs/vs’

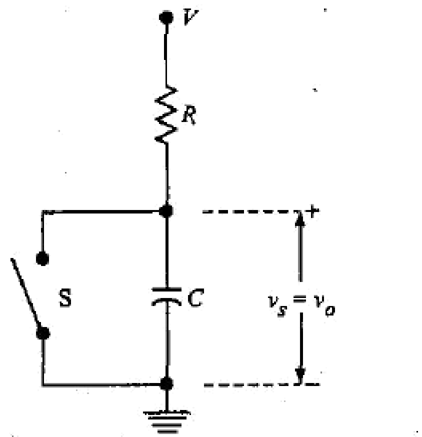


METHODS OF GENERATING A TIME-BASE WAVEFORM

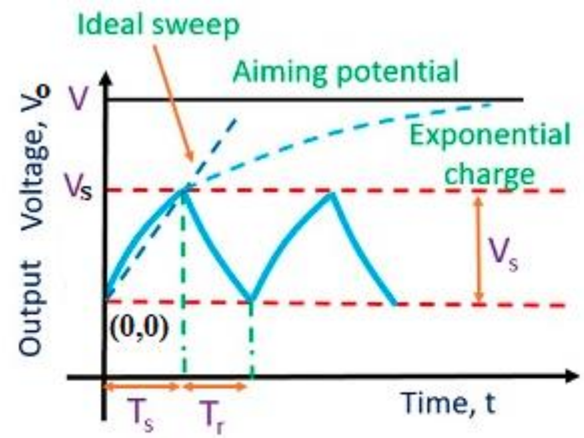
In time-base circuits, sweep linearity is achieved by one of the following methods.

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.
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.
3. **The Miller circuit:** In this method an operational integrator is used to convert an input step voltage into a ramp waveform.
4. **The Phantastron circuit:** In this method a pulse input is converted into a ramp. This is a version of the Miller circuit.
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.
6. **Compensating networks:** In this method a compensating circuit is introduced to improve the linearity of the basic Miller and bootstrap time-base generators.
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.

Exponential sweep circuit



(a)



- At t=0,the switch S is opened & the sweep voltage vs is

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

- If the switch is closed after time interval Ts,when the sweep value has attained the value Vs we get the sweep waveform.

Slope or sweep speed error, e_s

Slope or Sweep speed eror e_s = $\frac{\text{difference in slope at the beginning and end of sweep}}{\text{initial value of slope}}$

$$= \frac{\left(\frac{dV_0}{dt}\right)_{t=0} - \left(\frac{dV_0}{dt}\right)_{t=T_s}}{\left(\frac{dV_0}{dt}\right)_{t=0}}$$

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

$$e_s = 1 - e^{-T_s/RC}$$

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

For small Ts , neglecting the second and higher order terms $e_s = \frac{T_s}{RC}$

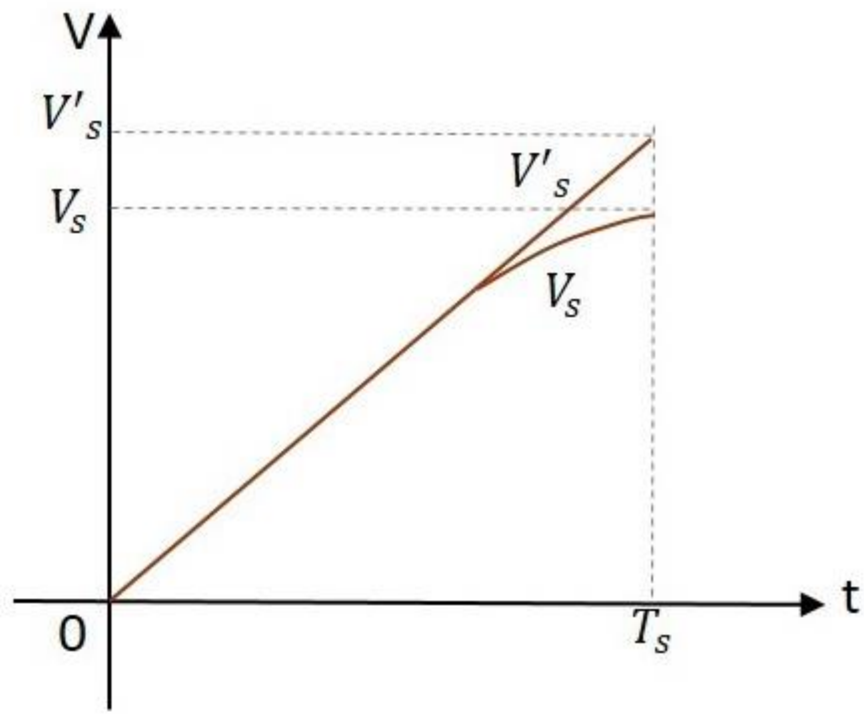
and $V_s = V\frac{T_s}{RC}$ or $\frac{V_s}{V} = \frac{T_s}{RC}$

$$\frac{V_s}{V} = \frac{T_s}{RC} = e_s$$

The transmission error, e_t

- $v_s = V\left(1 - e^{-t/RC}\right)$
- At $t=T_{s,}$
- $V_s = V\left(1 - e^{-Ts/RC}\right)$
- $V_S' = T_S \frac{V}{RC}$
- $e_t = \frac{V_{S'} - V_S}{V_{S'}}$

$$= \frac{\frac{VT_s}{RC} - \left(\frac{VT_s}{RC} - \frac{V}{2}\left(\frac{T_s}{RC}\right)^2\right)}{\frac{VT_s}{RC}} = \frac{T_s}{2RC} = \frac{e_s}{2}$$

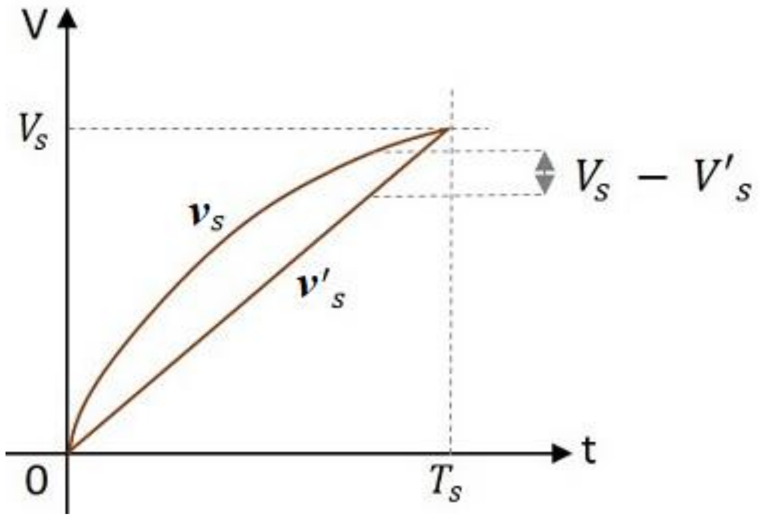


Displacement error

at t $= \frac{Ts}{2}$, vs'=$\frac{Vs}{2}$
$and\ v_s = V\left(1 - e^{-T_S/2RC}\right)$
$= V\left(T_S/2RC - \frac{1}{2}(T_S/2RC)^2\right)$

At t=T_S
v_S=V_S= $V\left(T_S/RC - \frac{1}{2}(T_S/RC)^2\right)$
so, vs'=$\frac{Vs}{2} = \frac{V}{2}\left(T_S/RC - \frac{1}{2}(T_S/RC)^2\right)$

$$e_d = \frac{(v_S - v_S')_{max}}{V_S} = \frac{1}{8}\frac{T_S}{RC}$$

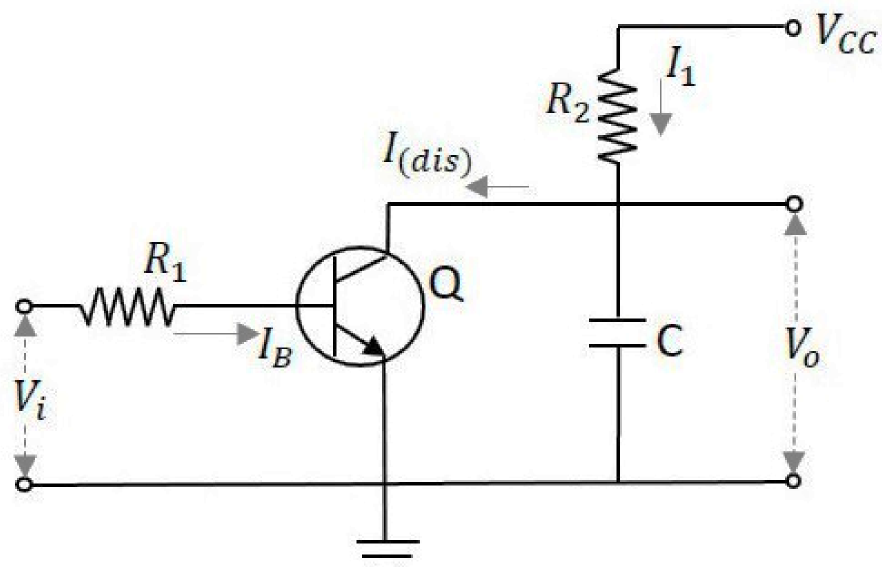


Sweep Circuit using a Transistor Switch

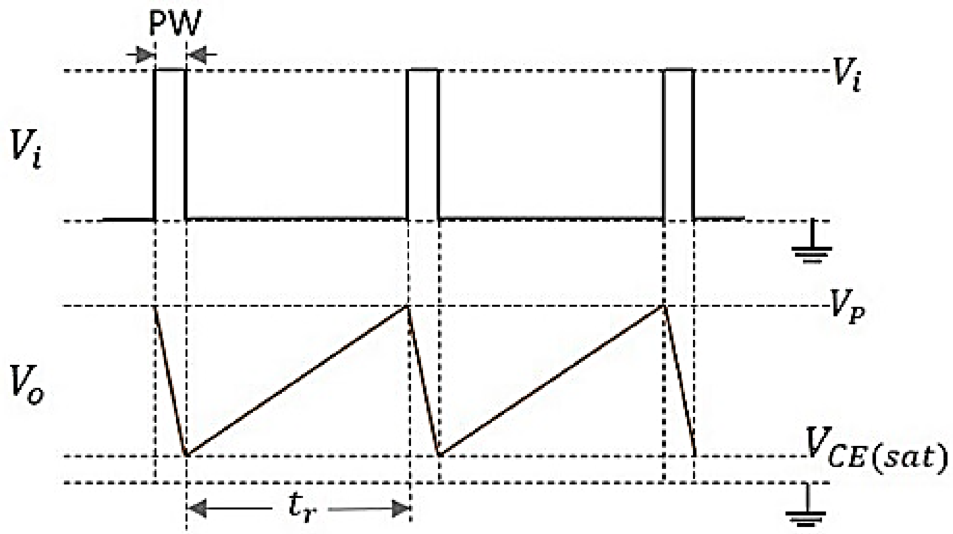
A Simple Voltage Time base Generator

A basic simple RC time base generator or a Ramp generator or a sweep circuit consists of a capacitor C which charges through V_{CC} via a series connected resistor R_2. It contains a BJT whose base is connected through the resistor R_1. The capacitor charges through the resistor and discharges through the transistor.

The following figure shows a simple RC sweep circuit.



By the application of a positive going voltage pulse, the transistor Q turns ON to saturation and the capacitor rapidly discharges through Q and R_1 to $V_{CE\ (sat)}$. When the input pulse ends, Q switches OFF and the capacitor C starts charging and continues to charge until the next input pulse. This process repeats as shown in the waveform below.



When the transistor turns ON it provides a low resistance path for the capacitor to discharge quickly. When the transistor is in OFF condition, the capacitor will charge exponentially to the supply voltage V_{CC}, according to the equation

$$V_0 = V_{CC}[1 - exp(-t/RC)]$$

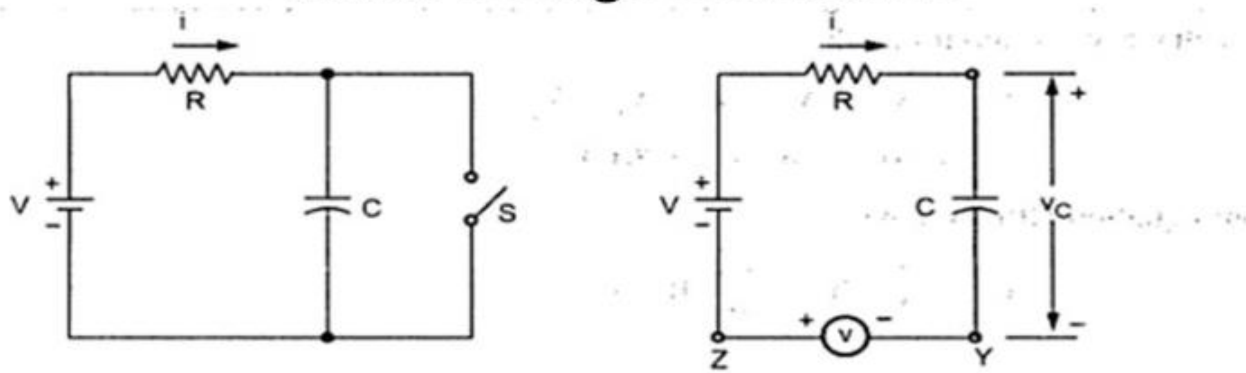
Where

- V_O = instantaneous voltage across the capacitor at time t
- V_{CC} = supply voltage
- t = time taken
- R = value of series resistor
- C = value of the capacitor

Let us now try to know about different types of time base generators.

The circuit just we had discussed, is a voltage time base generator circuit as it offers the output in the form of voltage.

Miller Voltage Generators



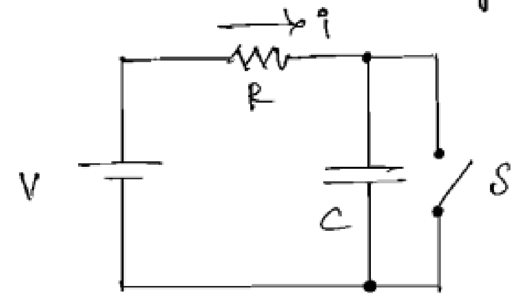
(a) Exponential charging of capacitor (b) Constant current charging of capacitor

- Fig (a) is the basic sweep circuit in which switch S opens to form the sweep. In fig (b) we introduce an auxiliary variable generator v & if v is always kept equal to the voltage drop across c, the charging current will be kept constant at i=V/R & perfect linearity can be achieved.

Miller and Bootstrap Time-Base Generators - Basic Principles

→ To improve the linearity of time-base waveforms, the feedbac[k]
is used.

→ The basic exponential sweep circuit in which S opens to form
the sweep is shown below fig(a).

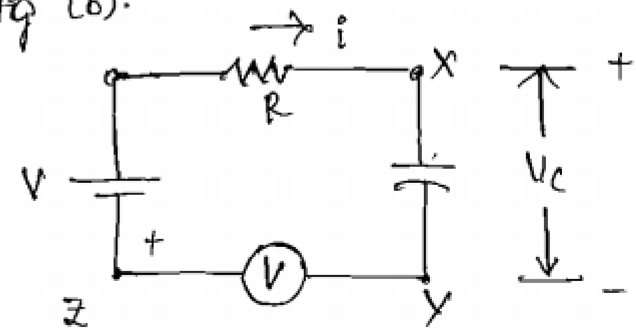


fig(a): Current decreases exponentially with time

→ A linear sweep cannot be obtained from this circuit b.cos
as the capacitor charges, the charging current decreases and
hence the rate at which the capacitor charges i.e, the slop[e]
of the output waveform decreases.

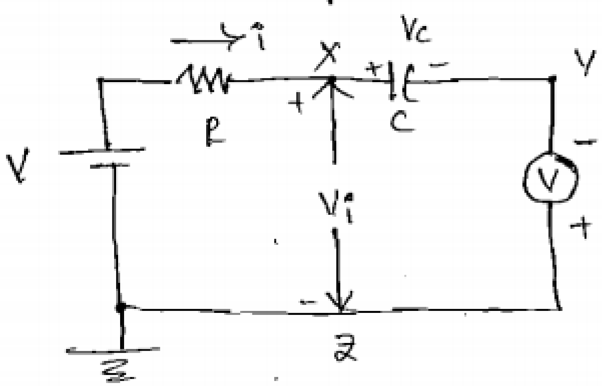
→ A perfectly linear output can be obtained if the initial
charging current $i = \frac{V}{R}$ is maintained constant.

→ 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, the charging current will be kept constant at $i = \frac{V}{R}$ and perfect linearity is achieved as shown in fig (b).



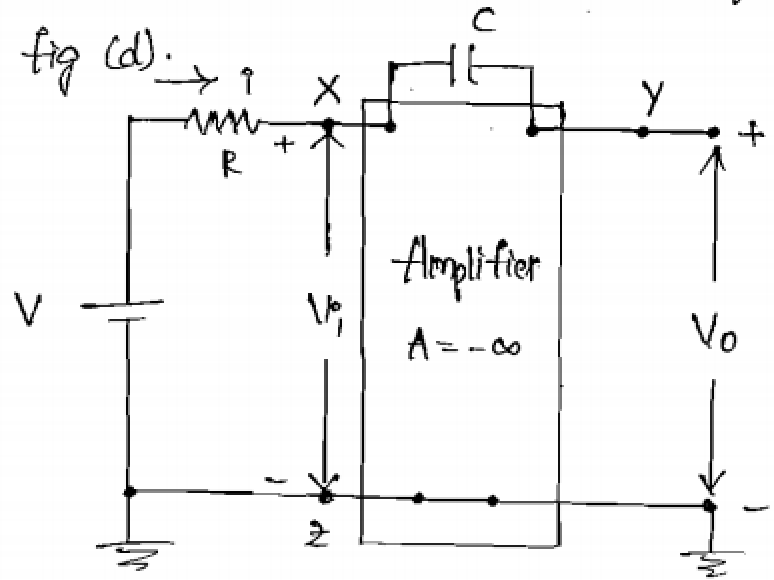
(b) Current remains constant

→ In fig (b), suppose the point Z is grounded as shown in fig (c).
A linear sweep will appear between the point Y and ground and will increase in negative direction.

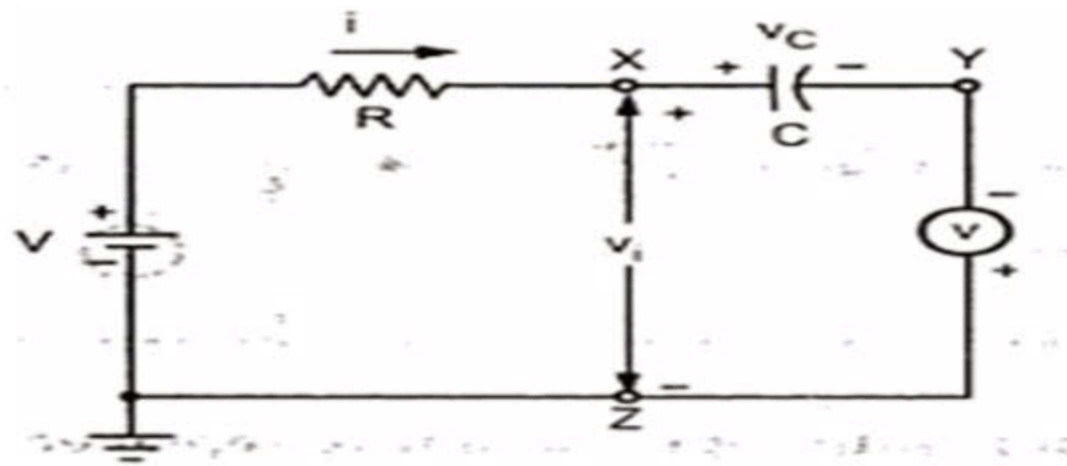


(c) With Z grounded

→ Let us now replace the fictitous (imaginary) generator by an amplifier with output terminals YZ and input terminal XZ as shown in fig (d).



(d) Miller Integrator Circuit



© Point Z is grounded

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- Let us consider the circuit shown in fig(b) with its Z terminal grounded as shown in fig©. With this circuit, linear sweep will appear between terminals Y & ground (Z terminal) & it will increase in the negative direction.
- Let us now replace the auxiliary variable generator by an amplifier with o/p terminals YZ & i/p terminals XZ, as shown in fig(d).

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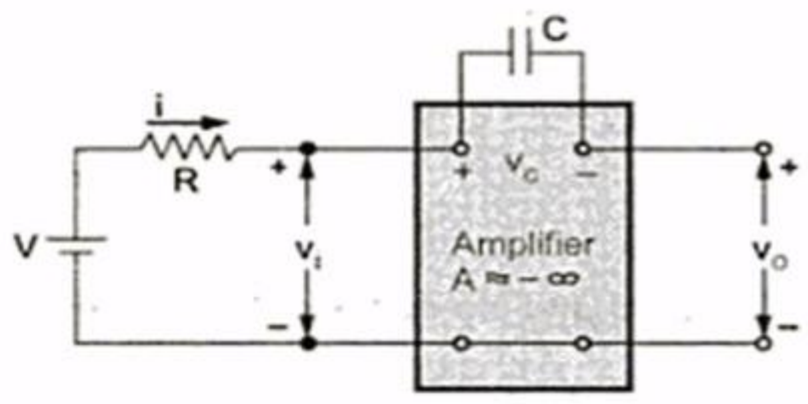

Basic Miller circuit

- Since we have assumed that the magnitude of voltage v equals the voltage Vc across the capacitor at every instant of time, then the input vi to the amplifier is zero. We can say that point X behaves as a virtual ground.
- With this situation if we want to obtain finite o/p, the amplifier gain A should be ideally be infinite.

(Recall OPAMP integrator)

- Such a need of amplifier can be satisfied by using operational amplifier & circuit is recognized as the operational integrator amplifier. It is referred as **Miller integrator** or **Miller sweep**.

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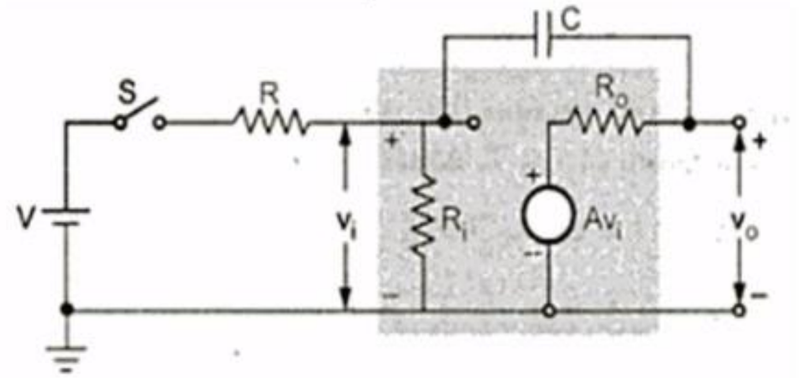

(e) Miller circuit with amplifier equivalent circuit

In Fig(e) Ri = input impedance of the amplifier,

A =open circuit voltage gain , Ro = o/p resistance.

Here, switch is added at the closing of which the time base waveform will start.

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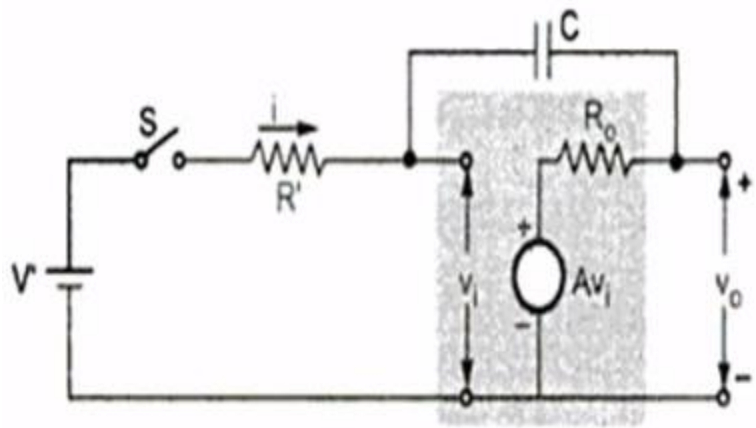

Fig(f) Miller circuit with i/p circuit is replaced by a Thevenin's equivalent

- The input circuit V,R,Ri are replaced by V',R' as follows.

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$$v_i\,(t = 0^+) = \Delta V_i = v_o\,(t = 0^+) = \Delta V_o$$

$$= \frac{(R_0 / R')V'}{1 - A + R_0 / R'} \quad \dots (9)$$

Since $R_o << R'$ and $|A| >> 1$ we have

$$v_i\,(t = 0^+) \approx \frac{R_0 V'}{R'|A|} \quad \dots (10)$$

Thus when R_o is considered, the output voltage of a Miller integrator continues to be a simple exponential but it starts at $v_o = \Delta V_o$ rather than at zero. Thus, there is a negative going ramp preceded by a positive jump. Due to this positive jump, the total path of the exponential curve is slightly larger than before, improving the linearily.

Sweep Speed of Miller Circuit

Looking at Fig. 5.12 (c) charging i is given as

$$i = \frac{V'}{R'} \quad \text{... (11)}$$

We know that, if a capacitor C is charged by a constant current i, then the voltage across C is (i × t) /C. Hence, the rate of change of voltage with time is given by

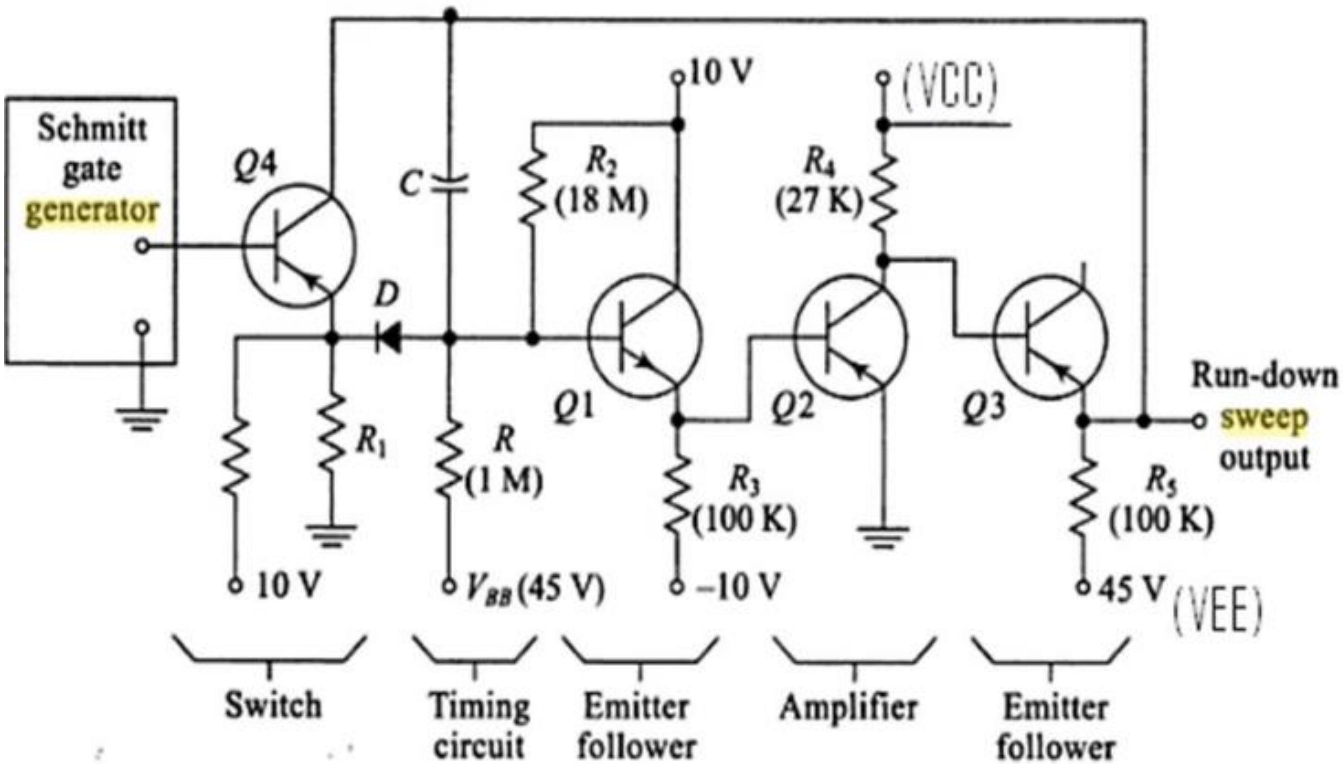
$$\text{Sweep speed} = \frac{i}{C} \quad \text{... (12)}$$

Substituting values of I from equation (11) we get

Sweep speed= V'/R'C=V/RC

Thus the sweep speed for miller circuits is same as in the case where the capacitor charges through R directly from the source V.

Transistorized Miller Sweep Generator



Operation:

→ When V_i = positive

Q_1 becomes ON and goes into saturation.

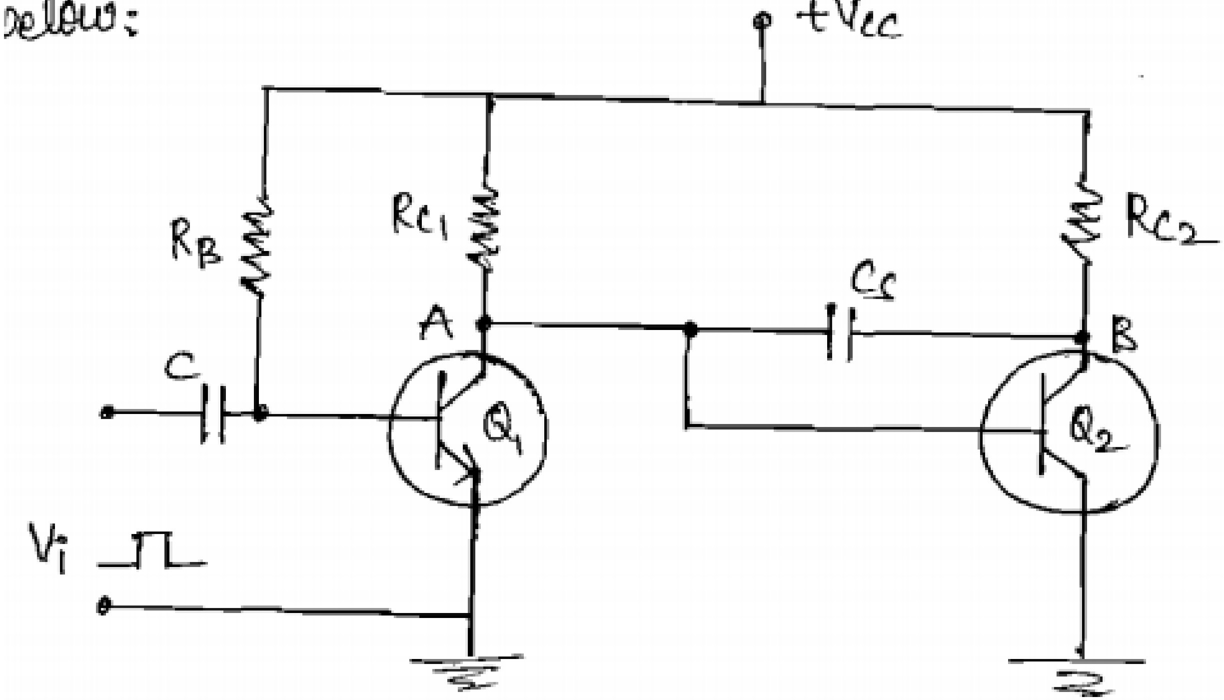
→ The potential at point A, V_A becomes minimum.

$$V_A = V_{CE(sat)} = \begin{matrix} 0.3 \text{ for Si} \\ 0.1 \text{ for Ge} \end{matrix}$$

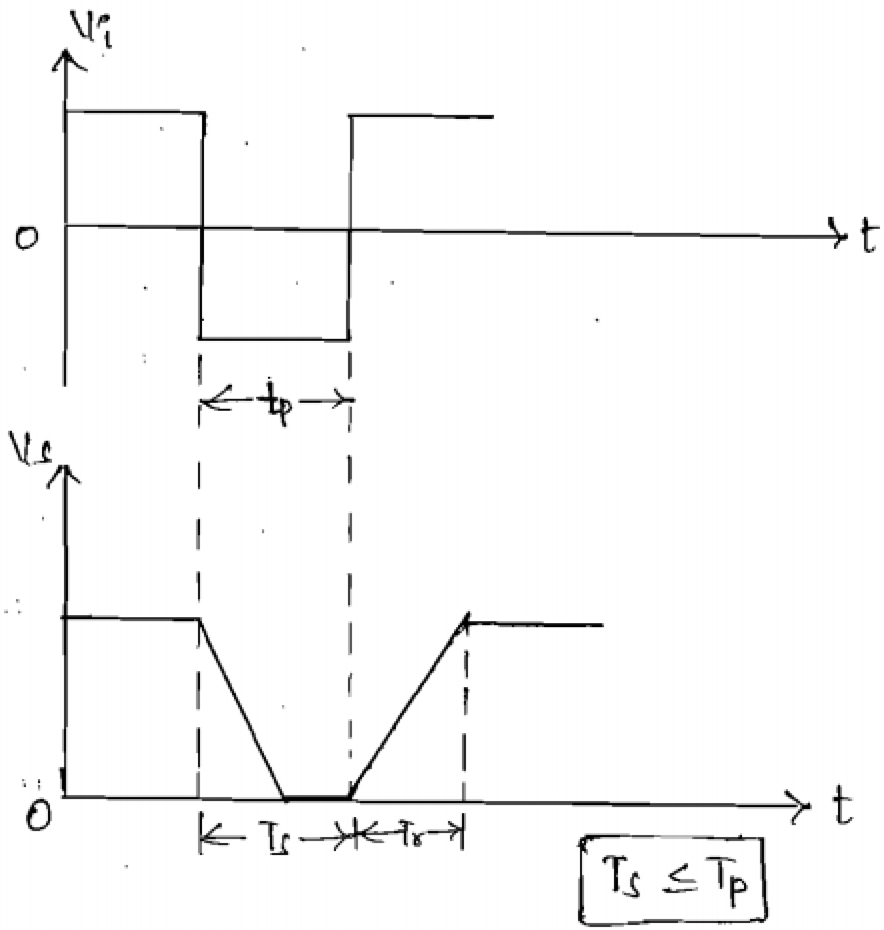
and since this $V_{CE(sat)}$ is connected to base of Q_2 which is not sufficient to drive the transistor Q_2.

→ So, Q_2 remains OFF and expotential at point B is maximum and collector current (I_c) is zero.

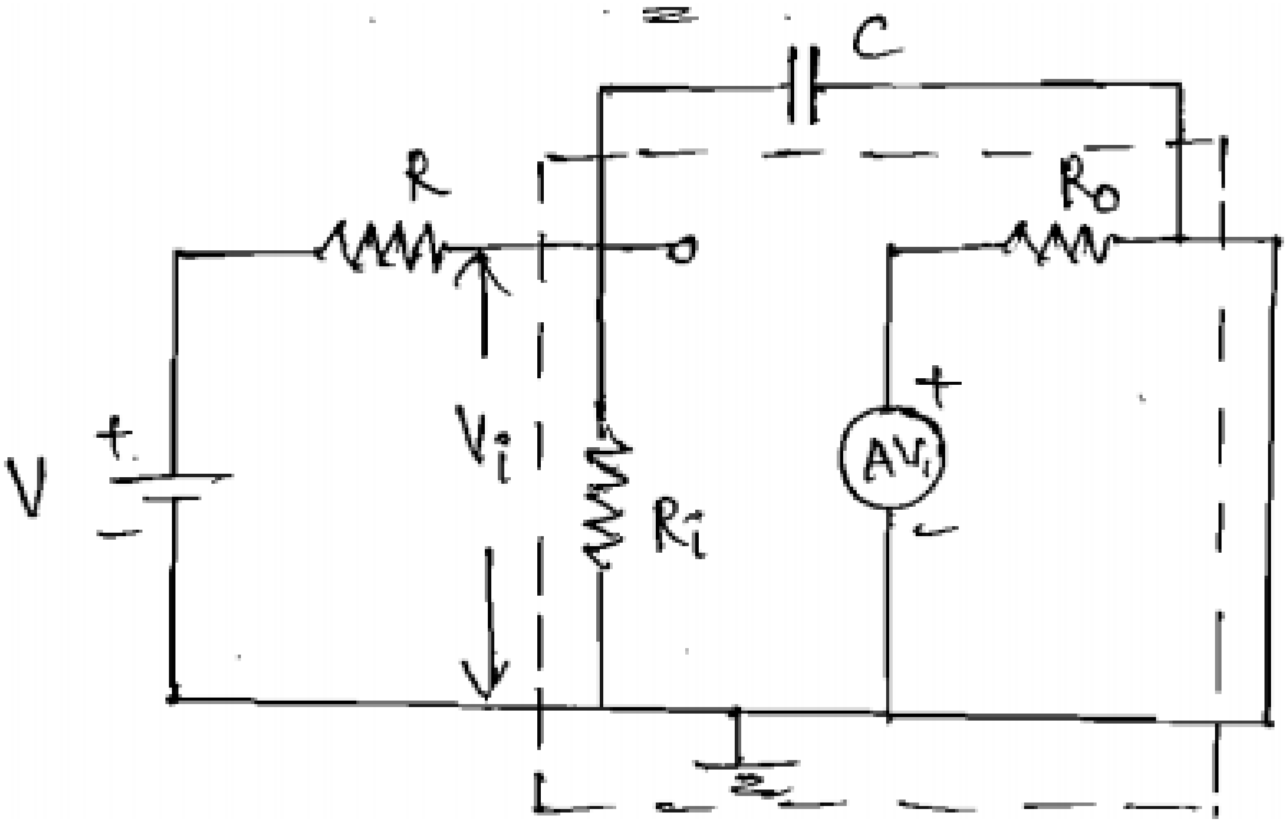
below:



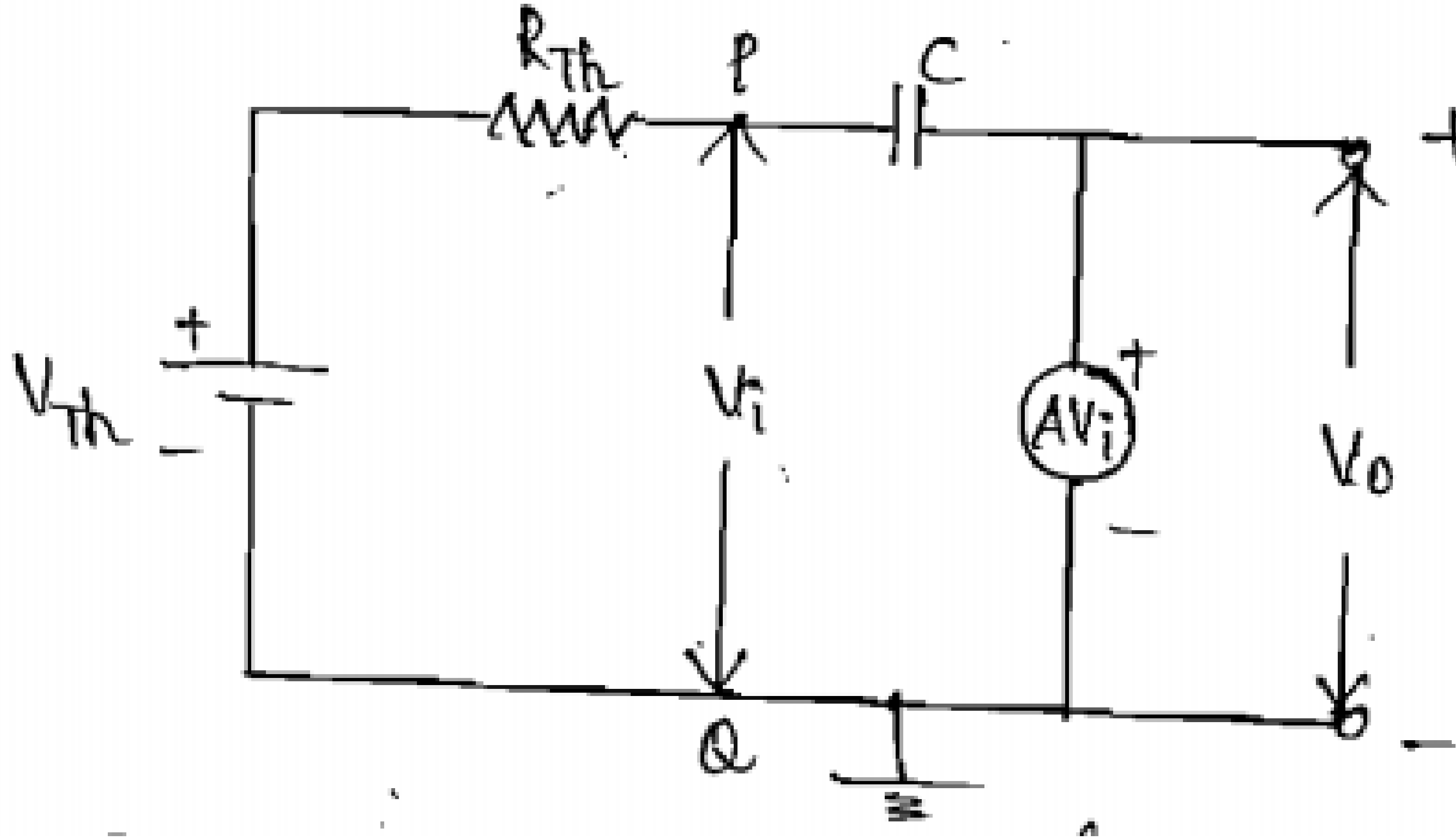
← Switch → | ← High Gain Amplifier →



Vi
0
t
tp
Vc
0
t
Ts
Tr
Ts ≤ Tp



fig(b).



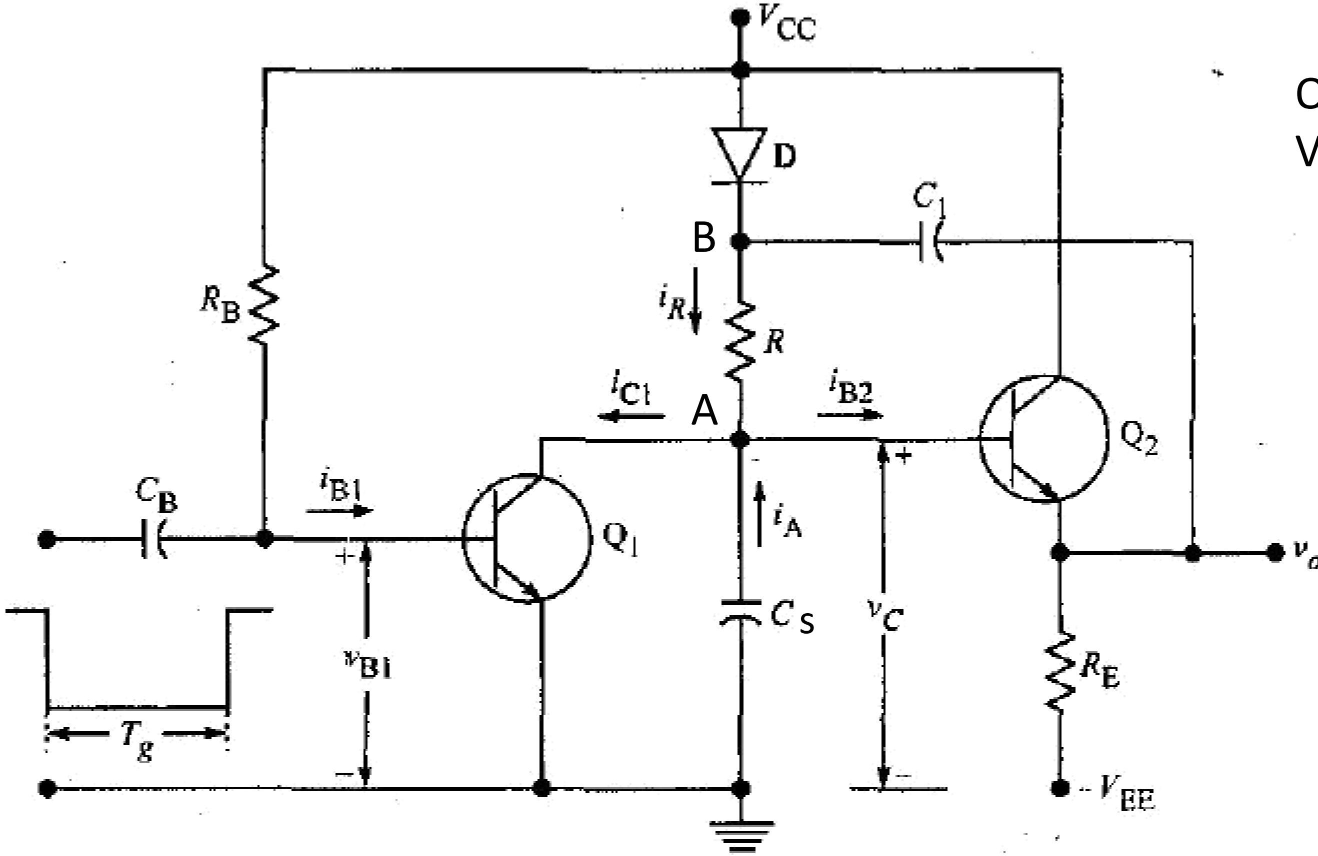
R_{Th}
P
C
+
V_{Th}
+
−
V_i
AV_i
+
−
V_0
Q
−

$$\text{Sweep Error } (e_s) = \frac{\text{Maximum Sweep Amplitude}}{\text{Maximum Output (at } t=\infty)}$$

$$e_s = \frac{V_s}{V_o(\text{at } t=\infty)} = \frac{V_s}{\frac{AVR_i}{R+R_i}} = \frac{V_s(R+R_i)}{AVR_i}$$

$$e_s = \frac{V_s}{AV}\left[\frac{R}{R_i}+1\right]$$

$$\therefore \boxed{e_s = \frac{V_s}{AV}\left[1+\frac{R}{R_i}\right]}$$



$Q_1 \rightarrow$ ON

$V_A = V_{CEsat} = V_{Cs} \rightarrow Q_2$ OFF

$(V_o) = V_A - V_{BE(Q_2)}$

$= 0.3 - 0.6$

$V_o = -0.3V$

$V_D = 0.6V$

$V_B = V_{CC} - V_D$

$V_B - V_A = V_{CC} - V_D - V_A$

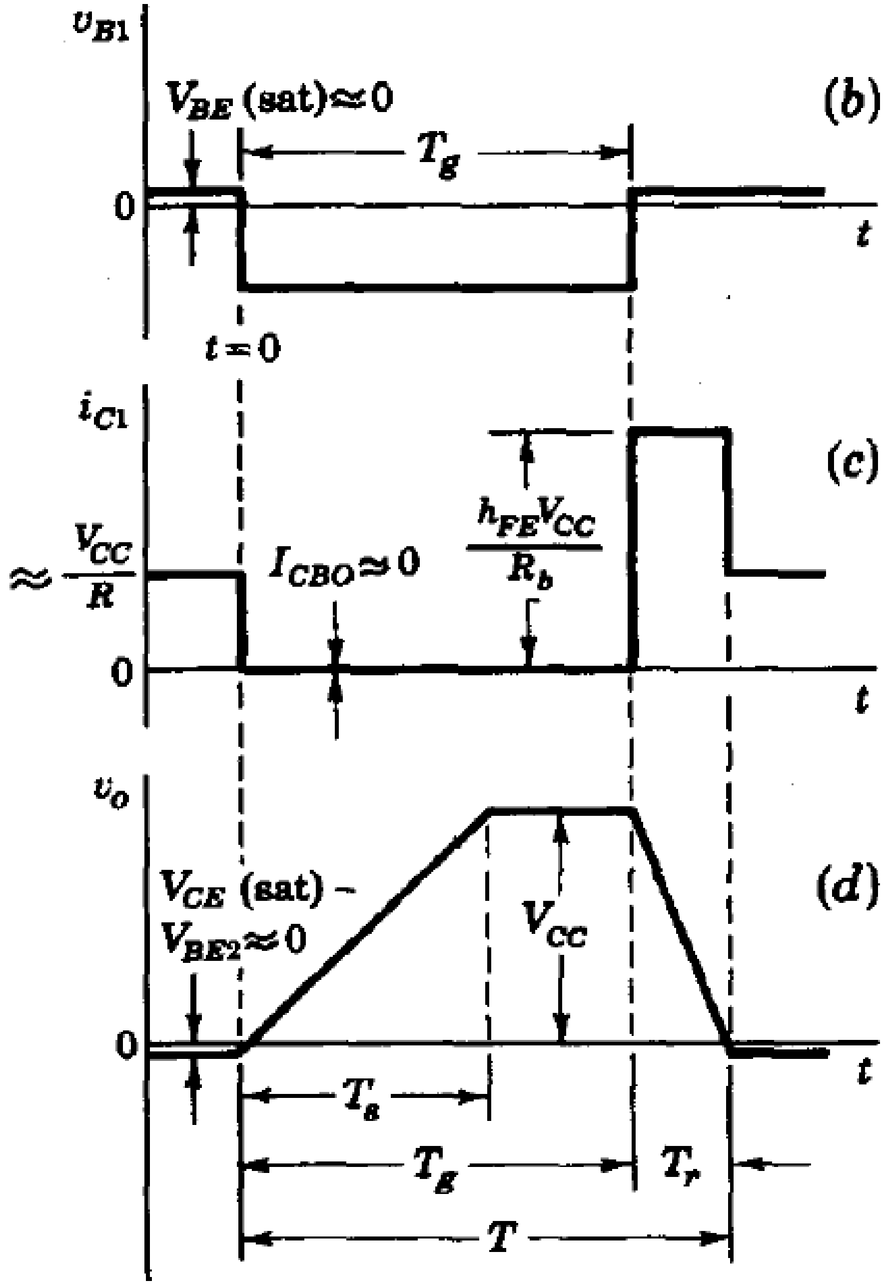
$= V_{CC}$

$$I_R = \frac{V_B - V_A}{R} = \frac{V_{CC}}{R} = I_{C1}$$

In order that $Q1$ should indeed be in saturation for $t < 0$ it is necessary that its base current ($\approx V_{CC}/R_b$) be at least equal to i_{C1}/h_{FE}, so that

$$\frac{V_{CC}}{R_b} > \frac{V_{CC}}{h_{FE}R} \qquad \text{or} \qquad R_b < h_{FE}R$$

- At t=0, gated waveform is applied at base of Q_1 → OFF
- i_R flows through C_s → V_{CS} increases linearly
- $V_{CS}(t)$=



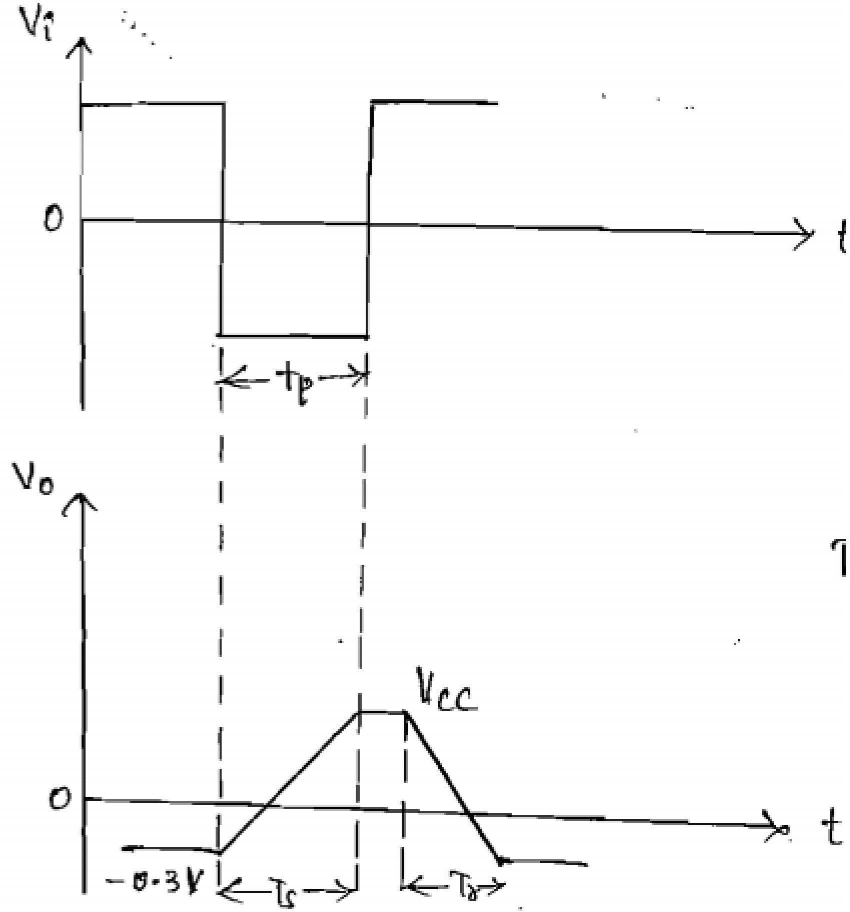
v_{B1}
V_{BE} (sat)≈0
T_g
(b)
0
t
t = 0
i_{C1}
(c)
$\approx \frac{V_{CC}}{R}$
I_{CBO}≈0
$\frac{h_{FE}V_{CC}}{R_b}$
0
t
v_o
(d)
V_{CE} (sat) −
V_{BE2}≈0
V_{CC}
0
t
T_s
T_g
T_r
T

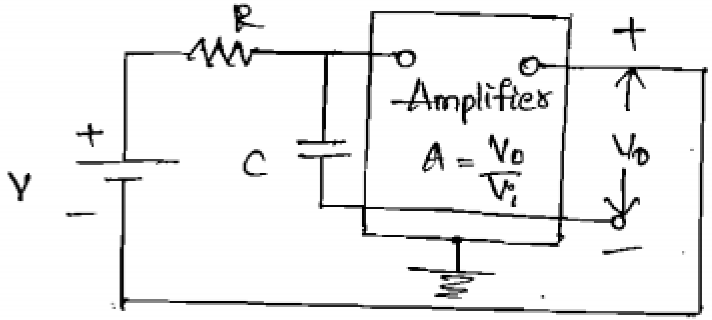
from the circuit

$I = i_1$, since Q_1 = OFF and $I_c = 0$

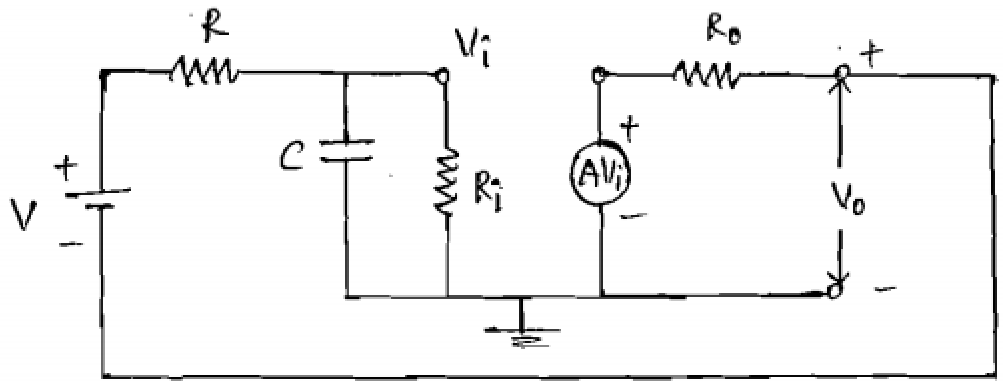
But $i_1 = i_2 + i_3$

Where i_3 = Base Current of Q_2.





Fig(a).



fig(b)

$$\text{Sweep error } (e_s) = \frac{V_s}{V_o(\text{at } t=\infty)}$$

At $t=\infty$, C acts as open-circuit. The circuit of fig (b) at $t=\infty$ is shown in fig (c).

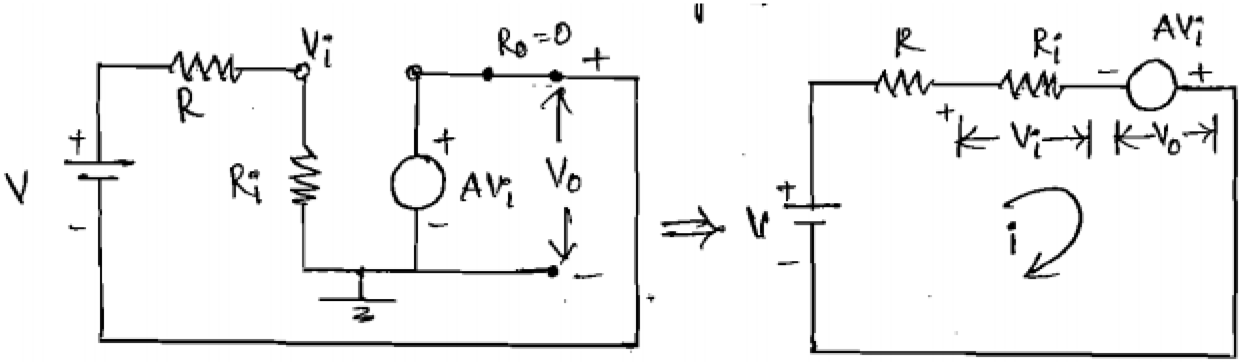


fig (c).

$$V_o = AV_i = A(iR_i) \longrightarrow ①$$

Since $V_i = iR_i$

Apply KVL

$$V - iR - iR_i + V_o = 0$$

$$V - i(R+R_i) + V_o = 0$$

$$i = \frac{V+V_o}{R+R_i} \longrightarrow ②$$

$$V_o = A(iR_i) = AR_i\left[\frac{V+V_o}{R+R_i}\right]$$

$$V_o(R+R_i) = A(V+V_o)R_i$$

$$V_oR + V_oR_i = AVR_i + AV_oR_i$$

$$V_o[R+R_i - AR_i] = AVR_i$$

$$V_o[R+R_i[1-A]] = AVR_i$$

$$V_o = \frac{AVR_i}{R+R_i(1-A)} \longrightarrow (3)$$

$$e_s = \frac{V_s}{V_0\,(\text{at } t = \infty)} = \frac{V_s}{\dfrac{AVR_i}{R + R_i(1-A)}}$$

$$= \frac{V_s\left[R + R_i(1-A)\right]}{AVR_i} = \frac{V_s}{AV}\left[\frac{R + R_i(1-A)}{R_i}\right]$$

$$\boxed{e_s = \frac{V_s}{AV}\left[\frac{R}{R_i} + (1-A)\right]}$$

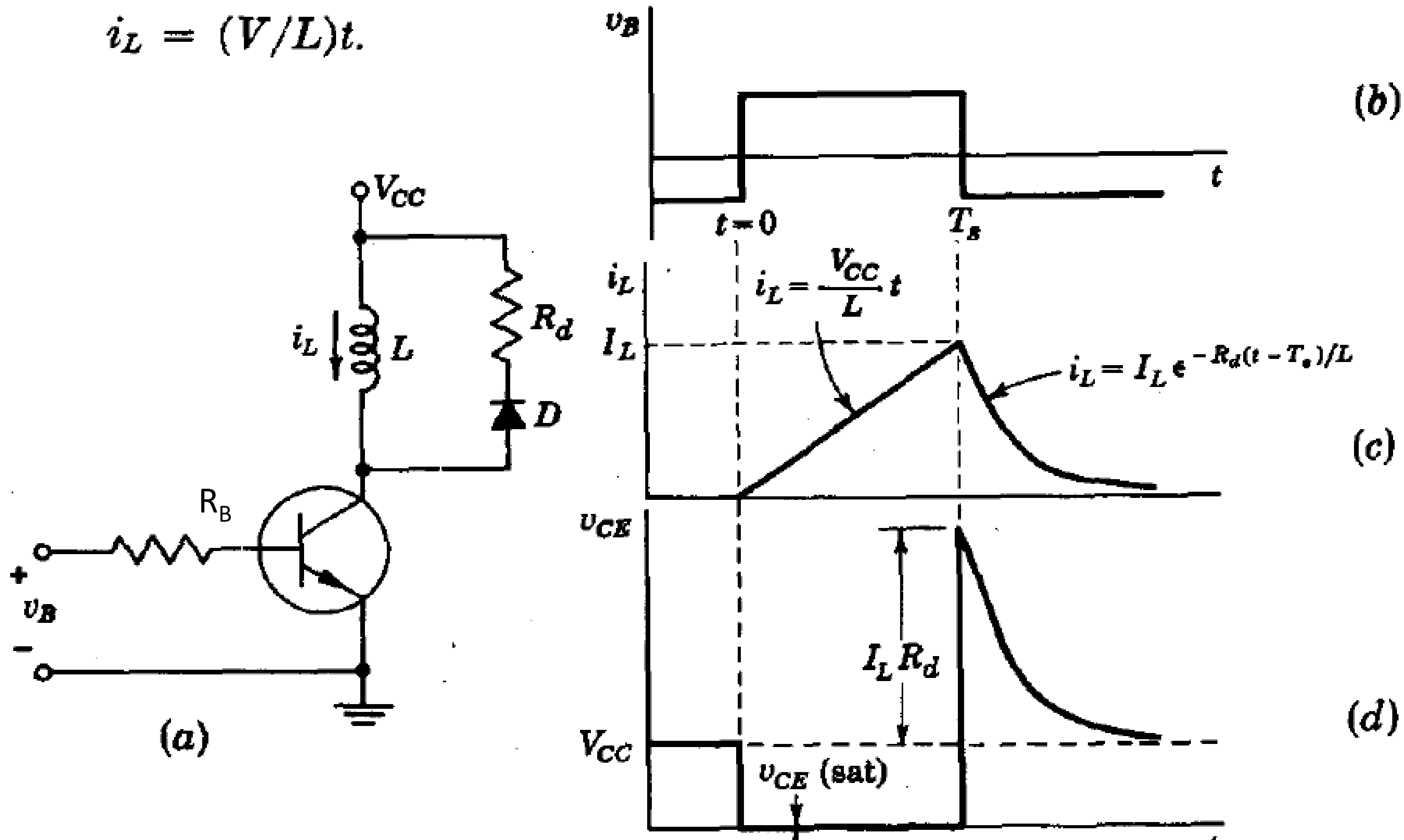
$$\boxed{e_s = \frac{V_s}{V}\left[\frac{R}{R_i}\right]}$$

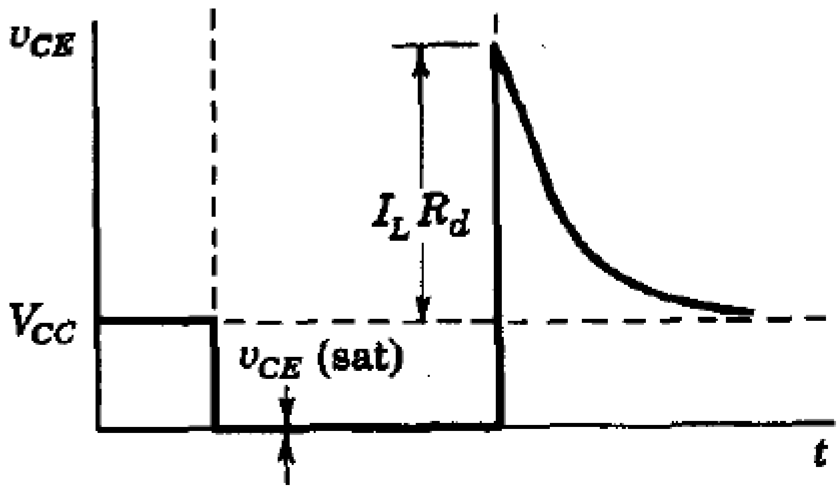
Bootstrap Sweep Circuit	Miller Sweep Circuit
(1). The circuit employs positive feedback.	(1) The circuit employs negative feedback.
(2). The circuit generates positive going ramp.	(2). The circuit generates negative going ramp.
(3). The circuit employs an emitter follower whose gain is nearly unity	(3). The circuit requires an amplifier whose gain is very very large.
(4). The amplifier must have high input resistance.	(4). Amplifier with high input resistance is not very essential.

Current time base generator

- Consider an inductor L having zero initial current.

$$i_L = (V/L)t.$$





(*d*)

Transistor OFF, $V_{CE}=V_{CC}$

Transistor ON, $V_{CE}=V_{CEsat}$

Again transistor ON → current reverses its direction and $V_{CE}=V_{CC}+I_LR_d$→ Breakdown

L in not ideal, consists of small resistance R_L. R_{CS} is transistor sat resistance

$$i_L = \frac{V_{CC}}{R_L + R_{CS}} \left(1 - \epsilon^{-(R_L+R_{CS})t/L}\right) \approx \frac{V_{CC}}{L} t \left[1 - \frac{1}{2} \frac{(R_L + R_{CS})t}{L}\right]$$

Slope or Sweep speed eror e_s = $\frac{\textit{difference in slope at the beginning and end of sweep}}{\textit{initial value of slope}}$

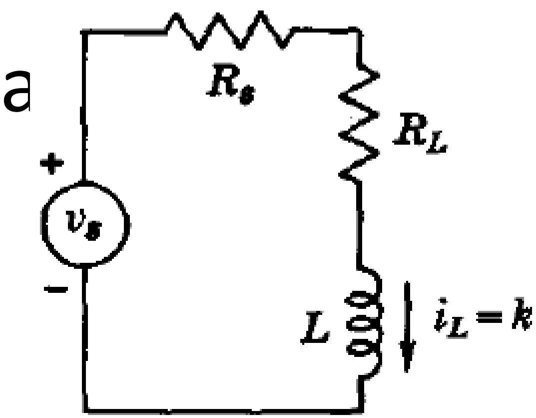
$$= \frac{\left(\frac{dI_0}{dt}\right)_{t=0} - \left(\frac{dI_0}{dt}\right)_{t=T_s}}{\left(\frac{dI_0}{dt}\right)_{t=0}}$$

$$e_s = \frac{I_L}{i_{L(t\to\alpha)}} = \frac{I_L}{V_{CC}/(R_L + R_{CS})} = \frac{(R_L + R_{CS}) I_L}{V_{CC}}$$

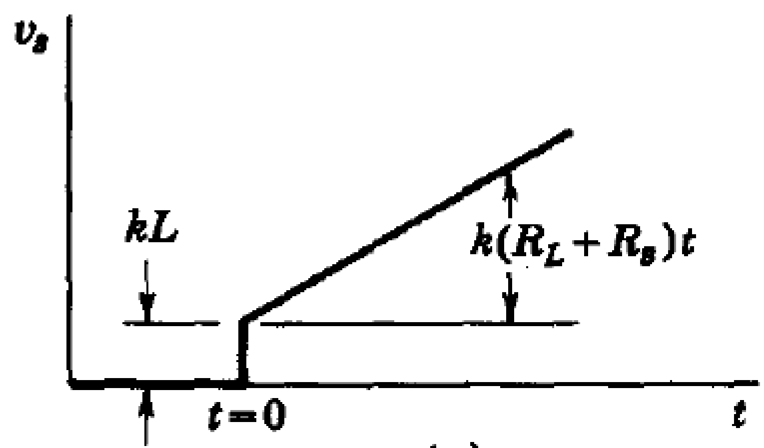
"linearity compensation coil."

LINEARITY CORRECTION

- As current in L increases
- voltage drop across series resista
- Voltage across L decreases
- Desired $i_L(t)=kt$



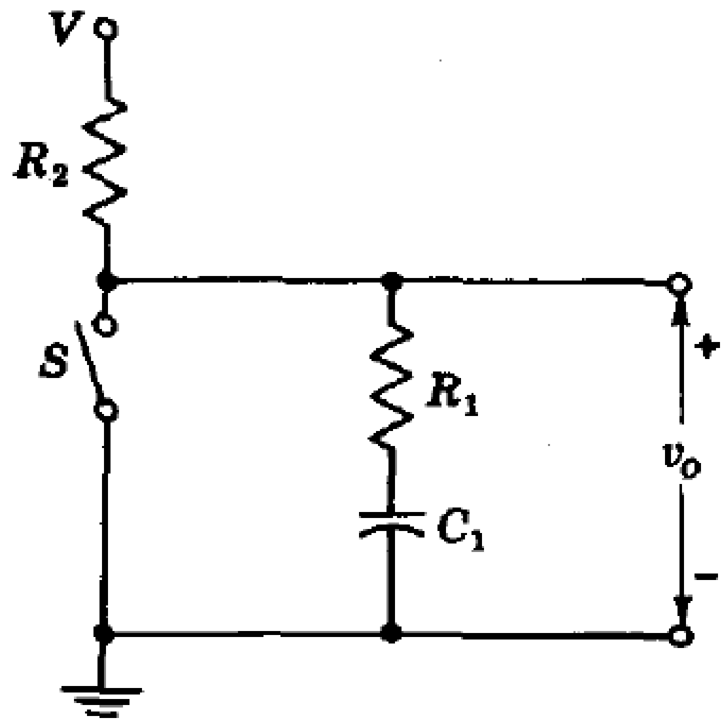
$$v_s = L\frac{di}{dt} + (R_s + R_L)i = Lk + (R_s + R_L)kt$$



trapezoidal

A circuit for generating a trapezoidal

Waveform



$$v_o = V - \frac{R_2 V}{R_1 + R_2} \epsilon^{-t/(R_1+R_2)C_1}$$

$$v_o \approx \frac{R_1 V}{R_2} + \frac{Vt}{R_2 C_1}\left(1 - \frac{t}{2R_2C_1}\right)$$

A TRANSISTOR CURRENT TIME–BASE GENERATOR