Voltage time base generator

Time base generator is an electronic circuit which generates o/p voltage waveform (or) current waveform that can linearly vary with time.

Applications :-

(i) Television
(ii) Radar displays
(iii) Precise time measurements
(iv) In CRO
(v) In Time modulation.

* Main Application for Time base generator is CRO.

Sweep ~~circuit~~ time :-

Sweep time is defined as the time taken by the waveform to reach maximum value (V_2) from initial value.

Return time :-

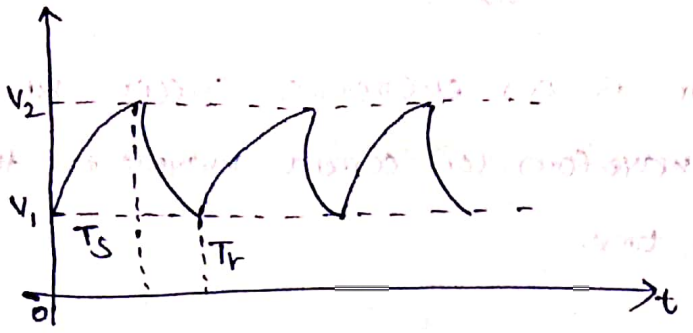
It is defined as the time taken by the waveform to return its initial value from maximum value.

Sweep circuit :-

To move the signal horizontally we apply the extra voltage using time base generators is called sweep circuit.

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General features of time base generator :-



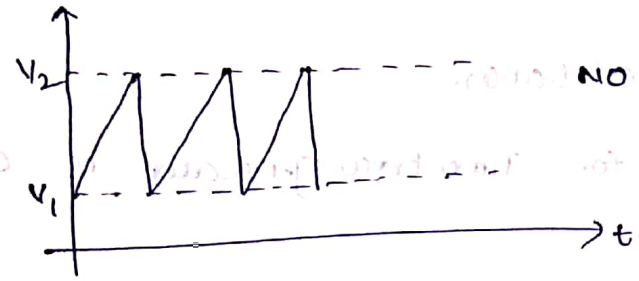
where

T_S = Sweep time

T_r = Return time or Restoration time or Flyback time

$T_S >> T_r$

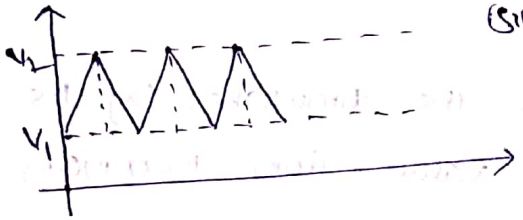
→ If $T_r = 0$, then the response is



No returning time

Response is "sawtooth".

→ $T_S >> T_r$



Similar to triangular

Drawback :- It cannot give perfect linear waveform (exactly non linear).

→ The o/p of Time base generator is not exactly linear, If the o/p of time base generator is linear, if the signal is transmitted through the coupling Network, the o/p of coupling Network is deviates from the linearity. to measure deviation b/w o/p response and linear i/p signal we go through the 3 types of errors

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1. Slope error or Sweep speed error (e_s)
2. displacement error (e_d)
3. Transmission error (e_t)

Slope error or Sweep speed error :- It is defined as the difference b/w initial slope & final slope expressed as a fraction of initial slope.

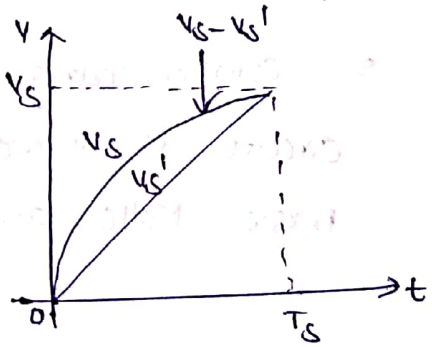
$$e_s = \frac{\text{Initial slope} - \text{Final slope}}{\text{Initial slope}}$$

$$\text{Initial slope} = \left.\frac{dv_o}{dt}\right|_{t=0} \qquad \text{final slope} = \left.\frac{dv_o}{dt}\right|_{t=T_s}$$

$$e_s = \frac{\left.\frac{dv_o}{dt}\right|_{t=0} - \left.\frac{dv_o}{dt}\right|_{t=T_s}}{\left.\frac{dv_o}{dt}\right|_{t=0}}$$

displacement error :- It is defined as the ratio of maximum deviation of the actual sweep from the linear sweep to the amplitude of the actual sweep voltage.

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

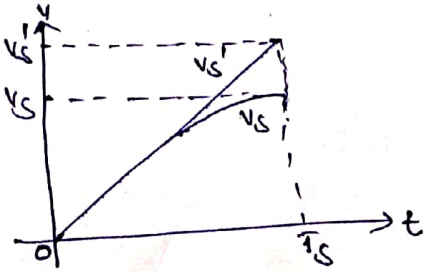


where V_s - Actual sweep

V_s' - linear sweep

Transmission error :- It is defined as the difference b/w the i/p & o/p expressed as the fraction of the i/p

$$e_t = \frac{V_s' - V_s}{V_s'}$$



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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 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.

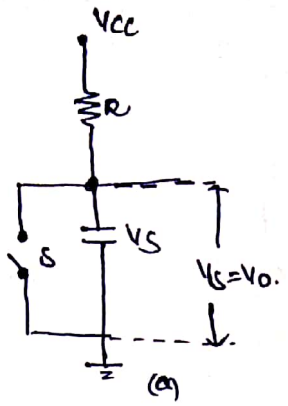
3. **Miller circuit** :- In this method an operational integrator is used to convert an input step voltage into a ramp waveform.

4. **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.

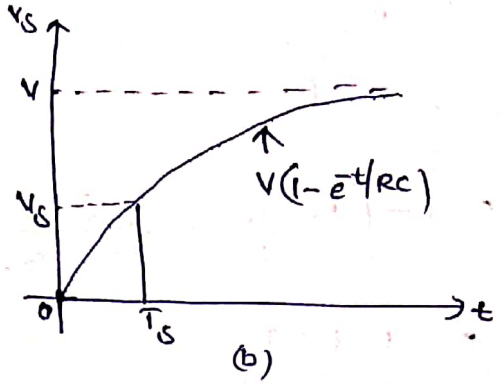
5. **Compensating Networks** :- In this method a compensating circuit is introduced to improve the linearity of the basic Miller and Bootstrap time-base generators.

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Exponential charging :-



(a)



(b)

(a) charging a capacitor through a resistor from a fixed voltage

(b) the resultant exponential waveform across the capacitor.

using slope error :-

$$e_s = \frac{\left.\frac{dv_o}{dt}\right|_{t=0} - \left.\frac{dv_o}{dt}\right|_{t=T_s}}{\left.\frac{dv_o}{dt}\right|_{t=0}}$$

the voltage across capacitor at any instant of time is given by

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

Differentiating

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

$$= -Ve^{-t/RC} \times \frac{-1}{RC}$$

$$= \frac{V}{RC}e^{-t/RC}$$

Put $t=0$, we get

$$\frac{dv_o(t)}{dt} = \frac{V}{RC}$$

$$\left.\frac{dv_o(t)}{dt}\right|_{t=T_s} = \frac{V}{RC}e^{-T_s/RC}$$

$$e_s = \frac{\frac{V}{RC} - \frac{V}{RC}e^{-T_s/RC}}{\frac{V}{RC}}$$

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$$\frac{V}{RC}\left(\frac{1-e^{-T_S/RC}}{\frac{V}{RC}}\right) \qquad \left[e^x = 1-x+\frac{x^2}{2!}-\frac{x^3}{3!}+\cdots\right]$$

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

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

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

$$\boxed{e_S = \frac{T_S}{RC}}$$

Transmission error :-

$$e_t = \frac{\text{I/P} - \text{O/P}}{\text{I/P}} = \frac{V_S' - V_S}{V_S'}$$

$$V_0(t) = V\left(1-e^{-t/RC}\right) \quad \text{at } t = T_S \quad V_0(t) = V_S$$

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

$$= V\left(1-\left(1-\frac{T_S}{RC}+\left(\frac{T_S}{RC}\right)^2\cdot\frac{1}{2!}-\cdots\right)\right)$$

Eliminating higher order terms

$$V\left(1+\frac{T_S}{RC}-\left(\frac{T_S}{RC}\right)^2\cdot\frac{1}{2!}\right)$$

$$V_S = \frac{VT_S}{RC} - \frac{V}{2}\left(\frac{T_S}{RC}\right)^2 \Rightarrow V_S = \frac{VT_S}{RC} - \frac{V}{2}\left(\frac{T_S}{RC}\right)^2$$

the initial slope

$$\left.\frac{dV_0(t)}{dt}\right|_{t=0} = \frac{V}{RC}t$$

If the initial slope is maintained at $t = T_S$,

$$V_S' = T_S \propto \frac{V}{RC}$$

$$e_t = \frac{V_S' - V_S}{V_S'} = \frac{\frac{V}{RC}T_S - \left(\frac{VT_S}{RC} - \left(\frac{VT_S}{2RC}\right)^2\right)}{\frac{V}{RC}T_S}$$

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

$$\frac{V T_S}{RC}$$

$$\frac{T_S}{2RC} \cdot e_S = \frac{e_S}{2}$$

$$\boxed{e_t = \frac{e_S}{2}}$$

Displacement error (e_d) :-

At $t = \frac{T_S}{2}$, $v_S' = \frac{V_S}{2}$

Voltage across capacitor at any instant of time

$v_0(t) = V(1 - e^{-t/RC})$

$v_0(t) = v_S$

Actual sweep v_S is given by

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

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

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

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

$$v_S = V\left[\frac{T_S}{2RC} - \left(\frac{T_S}{RC}\right)^2 \frac{1}{8}\right]$$

at $t = T_S$, $v_0 = v_S$

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

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

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

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∴ displacement error e_d is given by

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

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

$$= \frac{\frac{V}{2}\left[\frac{T_s^2}{2(RC)^2} - \frac{T_s^2}{4(RC)^2}\right]}{V\left(\frac{T_s}{RC}\right)} \quad \text{L.C.M.}$$

$$= \frac{\frac{V}{2} \cdot \frac{T_s^2}{2(RC)^2}}{}$$

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

$$= \frac{1}{8}\left(\frac{T_s}{RC}\right) = \frac{e_s}{8}$$

$$\boxed{e_d = \frac{e_s}{8}}$$

$$\boxed{e_d = \frac{e_s}{8} = \frac{e_t}{4} \quad \text{or} \quad e_s = 2e_t = 8e_d.}$$

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Sweep Circuit using UJT :-

→ Below fig shows the exponential sweep circuit in which the UJT serves the purpose of the switch.

→ Any current controlled Negative-resistance device may be used to discharge the sweep capacitor.

→ The supply voltage V_{BB} and the charging resistor R must be selected such that the load line intersects the input characteristic in the Negative resistance region.

→ Assume that UJT is OFF, the capacitor C charges from V_{BB} through R. When it is charged to the peak value 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 expression for sweep time T_s can be obtained as follows.

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for $0 < t < T_S$

$$V_S = V_{BB} - (V_{BB} - V_v)\, e^{-t/RC}$$

$t = T_S \quad V_o = V_S = V_p$

$$V_p = V_{BB} - (V_{BB} - V_v)\, e^{-T_S/RC}$$

$$(V_{BB} - V_v)\, e^{-T_S/RC} = V_{BB} - V_p$$

$$e^{T_S/RC} = \frac{V_{BB} - V_p}{V_{BB} - V_v} \Rightarrow e^{T_S/RC} = \frac{V_{BB} - V_v}{V_{BB} - V_p}$$

$$T_S = RC \ln \frac{V_{BB} - V_v}{V_{BB} - V_p}$$

Frequency of oscillation $f = \frac{1}{T}$

$T = T_S + T_r$ is the period

$$f = \frac{1}{T_S + T_r} = \frac{1}{T_S}$$ neglecting T_r $T_r << T_S$ or $T_S >> T_r$

$$f = \frac{1}{RC \ln \left(\frac{V_{BB} - V_v}{V_{BB} - V_p} \right)}$$

$$= \frac{1}{RC \ln \left(\frac{V_{BB}}{V_{BB} - V_p} \right)} \qquad V_v << V_{BB}$$

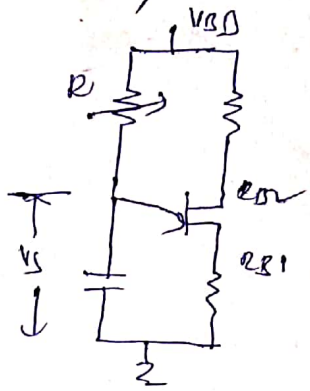
$$= \frac{1}{RC \ln \left(\frac{1}{1 - \frac{V_p}{V_{BB}}} \right)}$$

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Q: Calculate the component values of a UJT switch Generator requires to generate a o/p frequency of 10KHz with sweep amplitude of 10V. the UJT available has $\eta = 0.75$, $V_V = 1.2V$ $R_{BB} = 6K\Omega$, $I_V = 3mA$ $I_P = 10\mu A$ Power supply is 18V.

Sol: Given that $V_V = 1.2V$ $I_V = 3mA$

$I_P = 10\mu A$; $V_S = 10V$, $V_{BB} = 18V$



$V_S = V_P - V_V$

$V_P = V_S + V_V$

$= 10 + 1.2$

$V_P = 11.2V$

$\eta = \frac{V_P}{V_{BB}}$

$V_P = \eta V_{BB}$

$V_P = 13.5$

$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{18 - 11.2}{10 \times 10^{-6}} = 0.6M\Omega$

$0.45M\Omega$

$= \frac{4.5}{10 \times 10^{-6}} =$

$R_{min} = \frac{V_{BB} - V_V}{I_V} = \frac{18 - 1.2}{3 \times 10^{-3}} = 5.6K\Omega$

$\therefore$ R lies between R_{max} & R_{min}

we assume $R = 100K\Omega$

we ~~assume~~ know that $T_S >> T_r$

$T = T_S + T_r$

$f = \frac{1}{T} \Rightarrow T = \frac{1}{f} = \frac{1}{10K} = 0.0001$

$= 0.1ms$

$T = 100\mu s$

$T = T_S + T_r$

$T_S = T - T_r$

$T_S = 99\mu s$

$$T_S = RC \ln\left(\frac{V_{SS} - V_V}{V_{SS} - V_P}\right)$$

$$T_S = RC \ln\left(\frac{18 - 1.2}{18 - 11.2}\right)$$

$$99 = 100KC \ln\left(\frac{18 - 1.2}{18 - 11.2}\right)$$

$$C = 1.1\,nf$$

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Miller & Bootstrap Time-base Generators – Basic principles

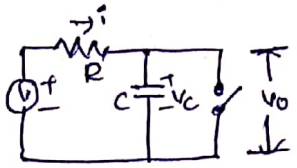
→ the linearity of time-base waveform may be improved by using circuits involving feed back.

→ To improve the linearity of time-base generators

→ exponential charging at initial time it is linearity.

$V = iR + V_C$ or $-V + iR + V_C = 0$

$i = \frac{V - V_C}{R}$ $i = \frac{V - V_C}{R}$

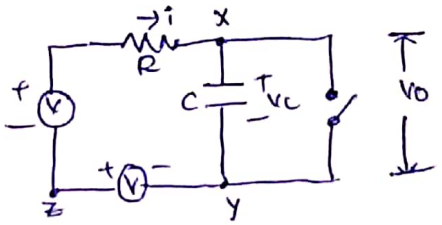


there the current flow is not constant

→ To overcome the drawback we redraw the ckt by adding Auxilary voltage or Auxilary variable generator V.

→ By adding Auxilary voltage the current is constant

* → whose generated voltage V is always equal to and opposite to the voltage across capacitor.

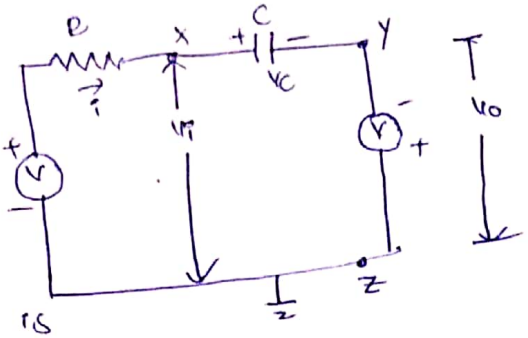


ie $-V + iR + V_C - V = 0$ (∵ where generated voltage is equal to & opposite to voltage across capacitor V_C)

$\therefore -V + iR + V_C - V_C = 0$

$\boxed{i = V/R}$

→ By using X, Y, Z variables modify the ckt. It acts as miller's circuit & Bootstrap generator.



* If Z is grounded.

Input terminals are XZ

O/p terminals YZ

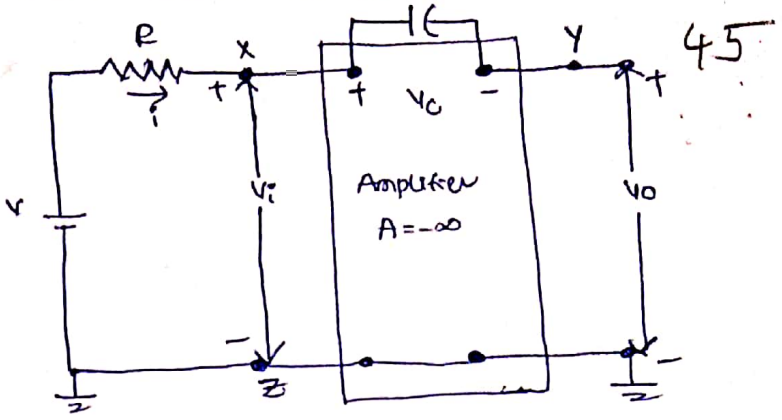
* the voltage between X and Z is equal to zero. $i = \frac{V_c - V_C}{} = 0$. ∵ $\left(\text{gain} = \frac{V_o}{V_i} = \frac{V_o}{0} = \infty\right)$

* Now for the amplifier, the input is zero volts and the O/p is finite Negative value. This can be achieved by using an operational integrator with a gain of infinity. (Op-Amp has a infinite gain)

* this is refered as Miller integrator ckt or Miller sweep.

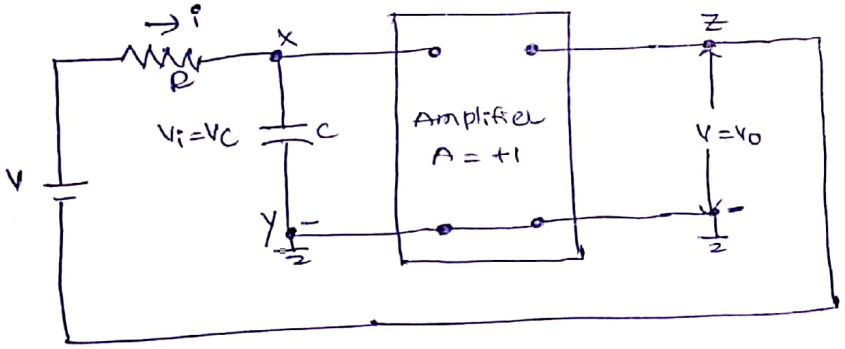
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* ~~If Y is grounded & o/p is taken at Z~~ C



45

* If Y is grounded, and o/p is taken at Z.
* A linear sweep will appear between Z and ground and will increase in positive direction.
* Let us now replace fictitious generator (Ramp voltage variable generator) by an amplifier with input terminals XY & o/p terminals ZY.
* We have assumed that generated voltage V_{ramp} at any instant is equal to the voltage across the capacitor V_c.
* V_o must be equal to V_i, and amplifier voltage gain must be equal to unity., this is referred as Bootstrap sweep circuit.



Bootstrap sweep circuit.

Expression for slope error in Boot-strap sweep generator

Slope error $e_s = T_s/RC$

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

at $t = T_s$

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

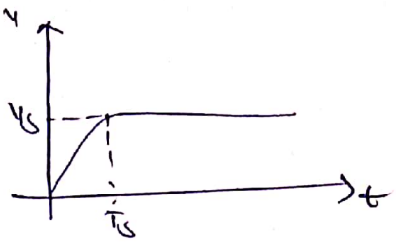
$= V\left[1 - \left(1 - \frac{T_s}{RC} + \left(\frac{T_s}{RC}\right)^2 \frac{1}{2!} - \cdots\right)\right]$

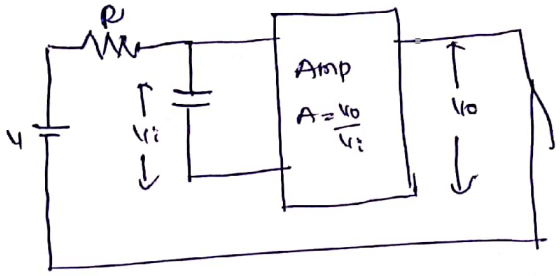
Neglect higher order terms

$v_s = V\left(\frac{T_s}{RC}\right)$

$\frac{v_s}{V} = \frac{T_s}{RC} \Rightarrow \boxed{e_s = \frac{v_s}{V}}$

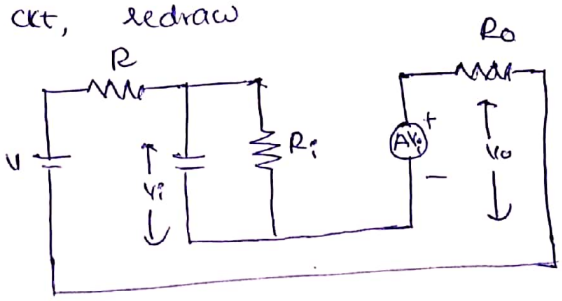
$e_s = \frac{v_s}{V \text{ at } (t=\infty)}$

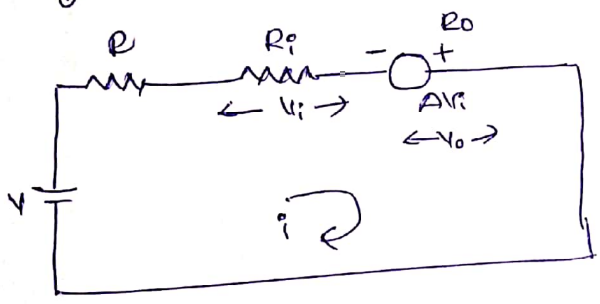




Replace amplifier with equivalent h parameters

at $t = \infty$, the capacitor open ckt, redraw the equivalent ckt





Apply KVL in the loop

$V = iR + iR_i - v_o = 0$

$V + v_o = i(R + R_i)$

$i = \frac{V + v_o}{R + R_i}$

$\therefore v_o = Av_i$

$v_i = iR_i$

$\boxed{v_i = \left(\frac{V + v_o}{R + R_i}\right) R_i}$

$\therefore v_o = Av_i$

$v_o = A\left(\frac{V + v_o}{R + R_i}\right) R_i$

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

$v_o R + v_o R_i = AVR_i + Av_o R_i$

$v_o(R + R_i - AR_i) = AVR_i$

$v_o(R + R_i(1 - A)) = A_V R_i$

$v_o = \frac{A_V R_i}{R + R_i(1 - A)}$

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$$e_{ss} = \frac{V_s}{V} \text{ at } t=\infty.$$

$$= \frac{V_s}{\frac{A_v R_i}{R + R_i(1-A)}}$$

$$= \frac{V_s\,(R + R_i(1-A))}{A_v R_i}$$

$$= \frac{V_s}{A_v}\left(\frac{R}{R_i} + \frac{R_i(1-A)}{R_i}\right)$$

$$\boxed{e_{ss} = \frac{V_s}{A_v}\left(\frac{R}{R_i} + 1 - A\right)}$$

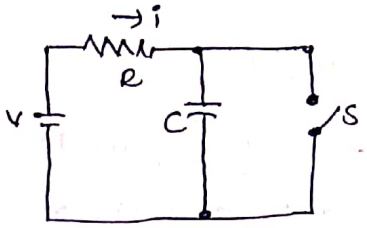
$$\therefore \quad e_t = \frac{\frac{V_s}{A_v}\left(\frac{R}{R_i} + (1-A)\right)}{4}$$

$$e_d = \frac{\frac{V_s}{A_v}\left(\frac{R}{R_i} + (1-A)\right)}{8}$$

Miller and Bootstrap Time-Base Generators - Basic principles 48

→ The linearity of the time-base waveforms may be improved by using circuits involving feedback.

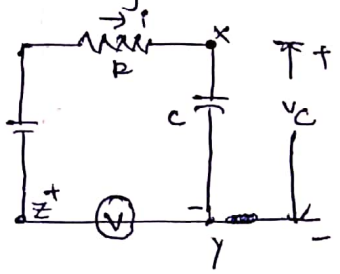
→ Fig. shows the basic exponential sweep circuit in which S opens to form the sweep.



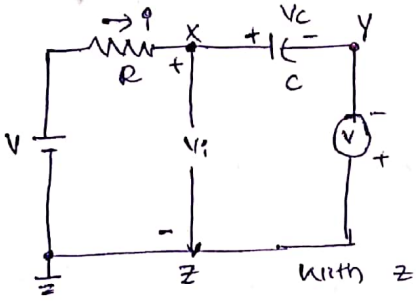
→ A linear sweep cannot be obtained from this circuit because as the capacitor charges, the charging current decreases and hence the rate at which the capacitor charges, i.e. slope of the o/p waveform decreases.

→ A perfectly linear o/p can be obtained if the initial charging current $i = V/R$ is maintained constant.

→ This can be done by introducing auxiliary variable generator v whose generated voltage v is always equal to and opposite to the voltage across the capacitor. as shown in fig



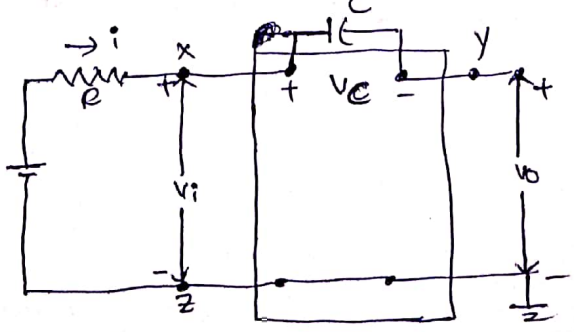
→ In this figure, suppose the point z is grounded



with z grounded

→ A linear sweep will appear between the point y and ground will increase in the negative direction.

→ Let us now replace the fictous (imagmary) generator by an amplifier with o/p terminals yz and i/p terminals xz as shown in fig.



Miller integrator circuit

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→ since we have assumed that the generated voltage is always equal and opposite to the voltage across capacitor,

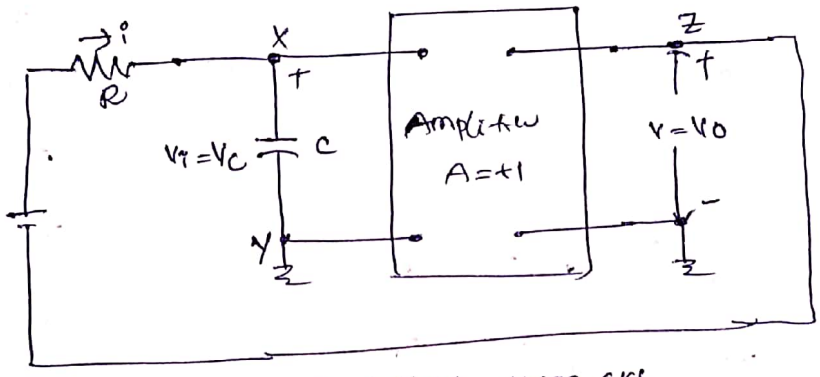
→ the voltage between x and z is equal to zero.

→ Now for the amplifier, the input is zero volts and the o/p is finite negative value.

→ this can be achieved by using an operational integrator with a gain of infinity. This is referred to as the miller integrator circuit or the miller sweep

→ suppose that the point y is grounded and the o/p is taken at z. A linear sweep will appear b/w z and ground will increase in positive direction.

→ Let us now replace the ficticious generator by an amplifier with i/p terminals xy and o/p terminals zy as shown in fig.

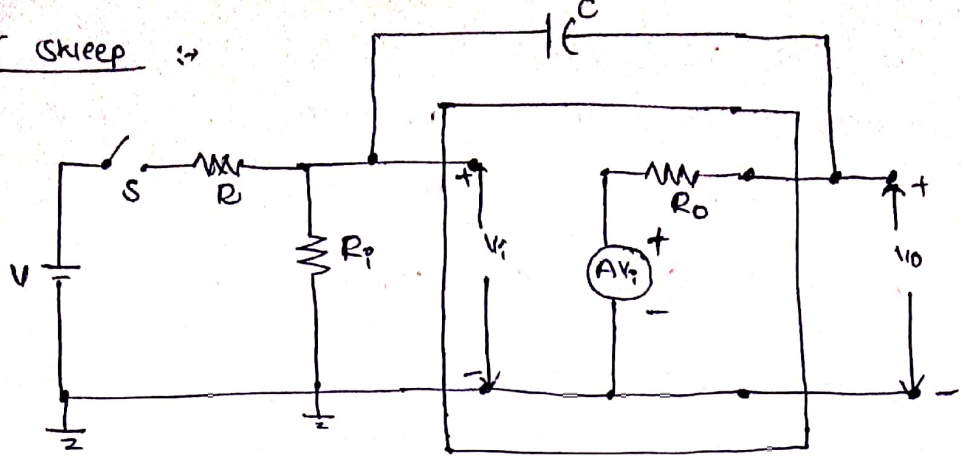


Bootstrap sweep ckt

→ since we have assumed that the generated voltage v at any instant is equal to the voltage across the capacitor V_C then V_O must be equal to V_i, and the amplifier voltage gain must be equal to unity. this circuit is refered to as bootstrap sweep circuit

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Miller sweep :-

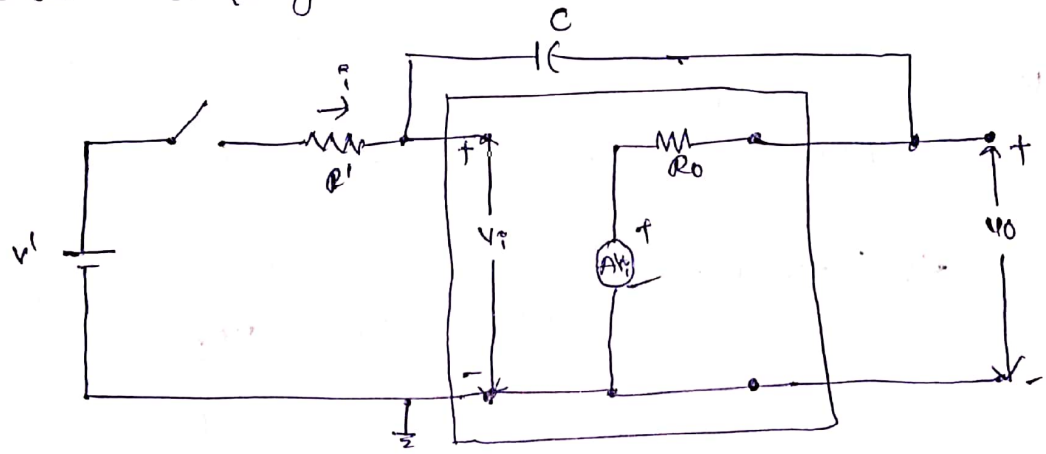


→ Miller integrating circuit is redrawn as in above fig.

→ A switch S at the closing of which the sweep starts is included.

→ Basic amplifier has been replaced at input side by its input resistance and on the o/p side by its thevenins equivalent.

→ R_o is the o/p resistance of the amplifier and A its open circuit voltage gain.



the above fig is obtained by replacing V, R and R_i on the i/p side by a voltage source V' in series with a resistance R' where

$$V' = V \frac{R_i}{R_i + R} = \frac{V R_i}{R_i \left(1 + \frac{R}{R_i}\right)} = \frac{V}{1 + \frac{R}{R_i}}$$

and $$R' = R \| R_i = \frac{R R_i}{R + R_i}$$

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Neglecting the o/p resistance in the circuit of the switch is closed at $t=0$ and if the initial voltage across the capacitor is zero, $V_0(t=0^+)=0$ because at $t=0^-$, $V_i=0$ and since the voltage across the capacitor cannot change instantaneously.

At $t=0^+$, $V_i - AV_i = 0$ or $V_f = AV_i = V_0 = 0$.

this indicates that the sweep starts from zero

At $t=\infty$, the capacitor acts as an open circuit for dc. so no current flows and therefore

$$V_i = V' \quad \text{and} \quad V_0 = AV'$$

this indicates that the o/p is exponential and the sweep is negative-going since A is a negative number

~~Sets~~ slope error $= \frac{V_s}{V'}$

V_s = sweep amplitude

V' = peak to peak value of the o/p.

$$e_s(\text{miller}) = \frac{V_s}{|A|V'} = \frac{V_s}{|A|} \cdot \frac{R_i + R}{VR_i}$$

$$= \frac{V_s}{V'} \cdot \frac{1+\frac{R}{R_i}}{|A|}$$

the duration from linearity is $\frac{1+\frac{R}{R_i}}{|A|}$ times that of an RC circuit charging directly from a source V_i.

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If R_0 is taken into an account, the final value is altered by v_0 remains as before $Av' = -|A|v'$. 50

The initial value however is slightly different

To find v_0 at $t = 0^+$, writing KVL around the mesh in fig (b), assuming zero voltage across the capacitor, we have

$$V' - R'i - R_0 i - Av_i = 0$$

$$v_i = V' - R'i$$

$$v_i(t=0^+) = \Delta v_i = v_0(t=0^+) = \Delta v_0$$

$$= \frac{\left(\frac{R_0}{R'}\right)V'}{1 - A + \frac{R_0}{R'}}$$

$$v_i(t=0^+) \simeq \frac{R_0 V'}{R'|A|}$$

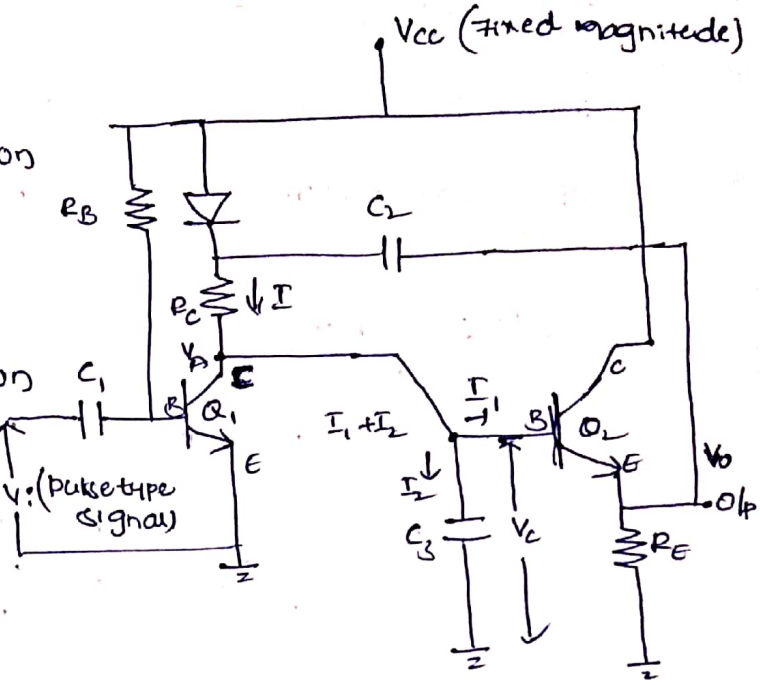
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Transistor Bootstrap Time-Base generator :-

→ Two transistors Q_1 & Q_2

Q_1 → common emitter configuration (i.e Emitter ground · collector O/P)

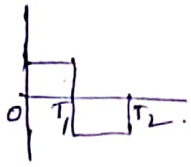
Q_2 → common collector configuration (i.e Emitter ground)



In CC having high impedence gain is unity ie $\frac{V_o}{V_i} = 1$

i.e $V_o = V_i$

Working principle :-



When the i/p (Pulse signal) is applied to Base 1, the transistor Q_1 is ON (ie NPN transistor), the current flows through Diode (Assume D-ON) and the current flows through transistor & it goes to the ground through Emitter. ie i=0

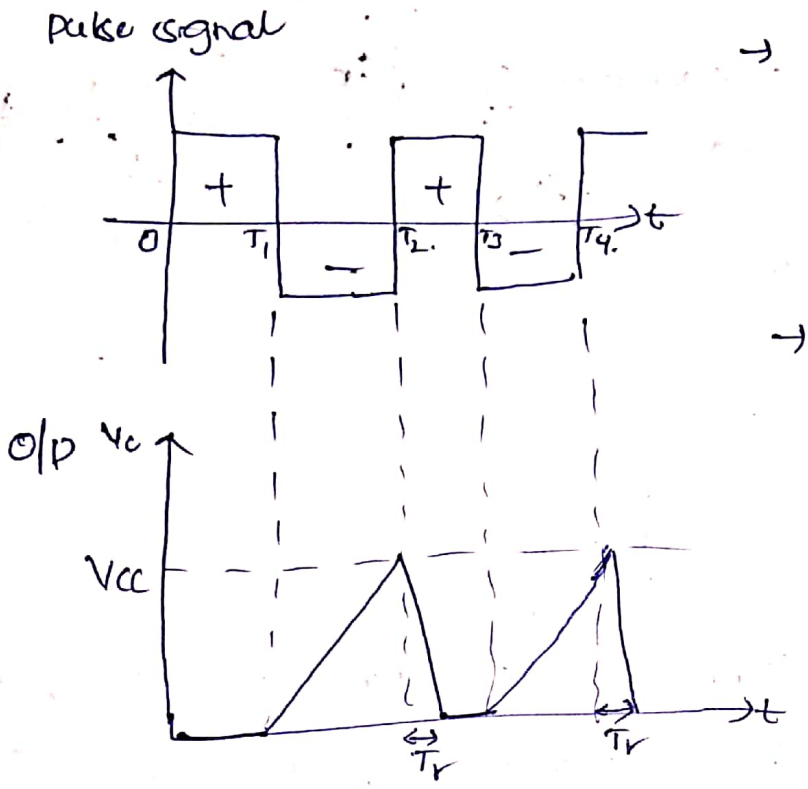


Generally $V_c = \frac{1}{C}\int i \cdot dt$ if $i = 0$

$V_c = 0$

Therefore NO current flow thrugh C_3. Overall o/p taken at Vc. If Vc is 0, the Vc is the i/p to the transistor Q_2, the O/P of Q_2 is fed back to the i/p.

From $T_1 \rightarrow T_2$ Negative half cycle, the transistor Q_1 is OFF. NO current flow through the transistor Q_1 the current by passes through C_3. [current entering into the capacitor means charging].



→ During 0 to T_1 T_1 = ON
= 0V.

V_0 = 0V then D = ON
$V_p = V_{CC}$

→ During T_1 & T_2 T_1 = OFF &
$V_0 = V_A$ this
is feedback to diode
D = ON &
$V_D = V_{CC} + V_A$

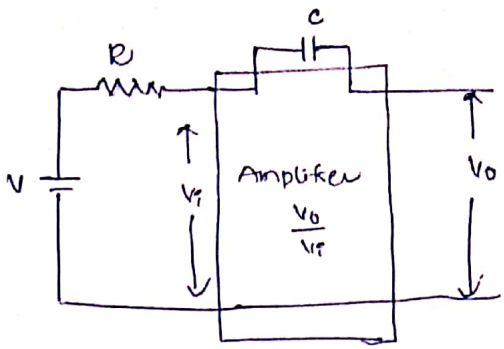
$$I = \frac{V_{CC} + V_A - V_A}{R_C}$$

$$= \frac{V_{CC}}{R_C}$$

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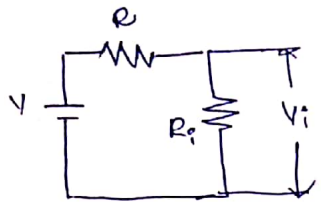
Slope error for Miller Sweep Generator :-

$$e_S = \frac{V_S}{V(\text{at } t=\infty)}$$

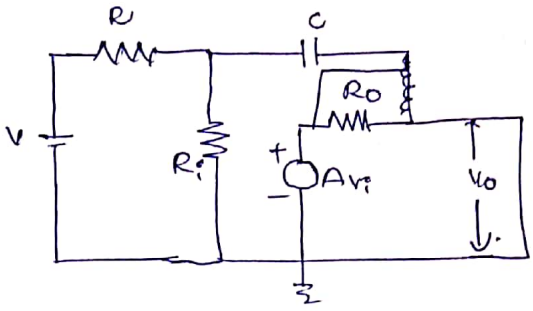


at $t=\infty$ the capacitor is open circuit

$\therefore V_o = AV_i \rightarrow (1)$ R_o is negligible



Equivalent circuit from RE model



Voltage divider rule $V_i = \frac{VR_i}{R+R_i} \rightarrow (2)$

From (1) $V_o = AV_i$

Substitute eq (2) in (1)

$$V_o = \frac{AVR_i}{R+R_i}$$

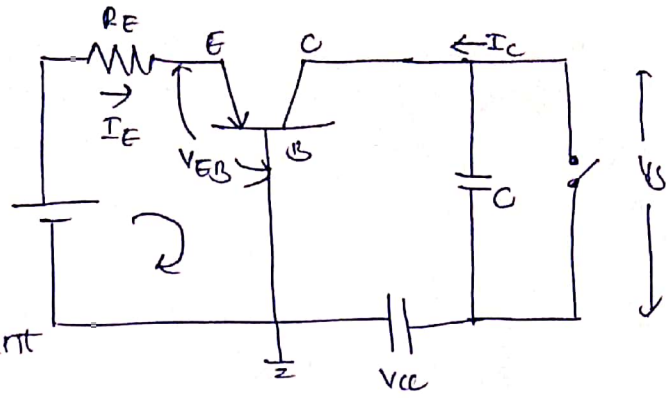
$$e_S = \frac{V_S}{\frac{AVR_i}{R+R_i}} \Rightarrow \frac{V_S(R+R_i)}{AVR_i}$$

$$\boxed{e_S = \frac{V_S}{AV}\left(\frac{R}{R_i}+1\right)}$$

Transistor constant current sweep generator :-

→ We use CB configuration

In CB configuration the VEE gain is unity.



The current is constant

$$I_C = \alpha I_E + I_{CEO}$$

(α = current gain)

$$I_C = \alpha I_E$$

The α value is approximately equal to '1' so the collector current is proportional to the emitter current.

then $I_C \uparrow$ I_E is also $\uparrow$

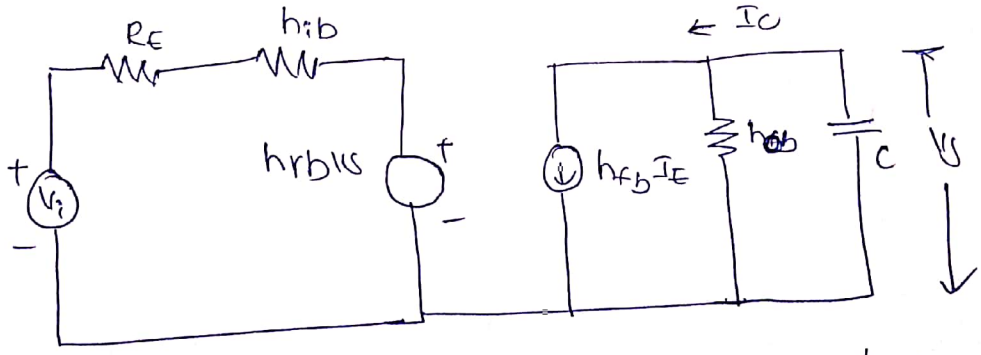
Apply KVL

$$+V_{EE} = R_E I_E + V_{EB} = 0$$

$$\boxed{I_{EB} = \frac{V_{EE} - V_{EB}}{R_E}}$$

where V_{EE} is very small voltages & also constant, I_E is also constant & I_C is also constant then there is constant current flow through the circuit

→ Draw the equivalent circuit



From exponential charging method

hob = Admittan

Slope error $e_s = \frac{T_s}{RC}$

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Apply KVL

$V_i = I_E R_E + I_E h_{ib} + h_r b V_s = 0.$ $\qquad i_c = C \frac{dv_s}{dt}$

$V_i = I_E R_E + I_E h_{ib} + h_r b V_s$

$V_i = I_C \left[R_E + h_{ib}\right] + h_r b V_s \longrightarrow (1)$

Apply KVL at O/P side

$I_C = h_{fb} I_E + h_o b V_s$

$-C \frac{dv_s}{dt} = h_{fb} I_E + h_o b V_s \longrightarrow (2)$

Let initial conditions $t=0$ $V_s=0$, solving above 2 eq's we get

$$V_s = \frac{\alpha \tau V_i}{C\left(R_E + h_{ib}\right)} \left(1 - e^{-t/\tau}\right) \longrightarrow (3)$$

where $\alpha = -h_{fb}$

$$\frac{1}{\tau} = \frac{1}{C}\left(h_{ob} + \frac{\alpha h_{rb}}{R_E + h_{ib}}\right)$$

From (3)

$$V_s = \frac{\alpha \tau V_i}{C\left(R_E + h_{ib}\right)} \left[1 - \left[1 - \left(\frac{t}{\tau}\right) + \left(\frac{t}{\tau}\right)^2 - \cdots\right]\right.$$

$$= \frac{\alpha \tau V_i}{C\left(R_E + h_{ib}\right)} \left(\frac{t}{\tau}\right)$$

$$V_s = \frac{\alpha V_i t}{C\left(R_E + h_{ib}\right)}$$

at $t = T_s$ $V_o = V_s$

$$V_s = \frac{\alpha V_i T_s}{C\left(R_E + h_{ib}\right)}$$

$$T_s = \frac{V_s C \left(R_E + h_{ib}\right)}{\alpha V_i t_s}$$

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w.r.t $e_s = \frac{I_s}{I} = \frac{V_s \, C (R_E + h_{ib})}{\alpha V_i} \times \frac{1}{C} \left(h_{ob} + \frac{\alpha h_{rb}}{R_E + h_{ib}} \right)$

$= \frac{V_s C (R_E + h_{ib}) h_{ob}}{\alpha V_i \alpha C} + \frac{V_s C (R_E + h_{ib}) \alpha h_{rb}}{\alpha V_i C (R_E + h_{ib})}$

$= \frac{V_s (R_E + h_{ib}) h_{ob}}{\alpha V_i} + \frac{V_s h_{rb} \alpha}{\alpha V_i}$

$= \frac{V_s (R_E + h_{ib}) h_{ob}}{\alpha V_i} + \frac{V_s h_{rb}}{V_i}$

$e_s = \frac{V_s}{V_i} \left[\frac{(R_E + h_{ib}) h_{ob}}{\alpha} + h_{rb} \right]$

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