4.5.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. 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.

4.5.1.GENERAL FEATURES OF A TIME-BASE SIGNAL

- Figure 4.5.1(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. 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 shown in Figure 5.1(b) is generated. The waveforms of the type shown in Figures 5.1 (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.

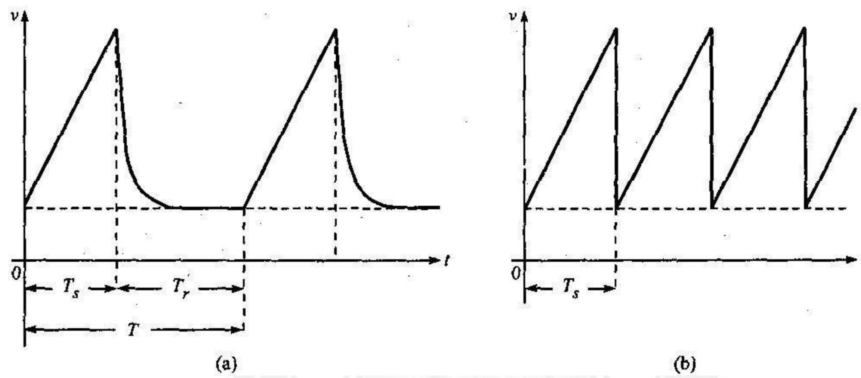


Figure 4.5.1 (a) General sweep voltage and (b) saw-tooth voltage waveforms. (Source: Microelectronics byJ. Millman and A. Grabel, Page-291)

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,

The slope 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 be constant. This deviation from linearity is defined as

$$\text{Slope or sweep-speed error, } e_s = \frac{\text{difference in slope at beginning and end of sweep}}{\text{initial value of slope}}$$

$$= \frac{\left.\frac{dv_0}{dt}\right|_{t=0} - \left.\frac{dv_0}{dt}\right|_{t=T_s}}{\left.\frac{dv_0}{dt}\right|_{t=0}}$$

The displacement error, e_d

Another important criterion of linearity is the maximum difference between the actual sweepvoltage and the linear sweep which passes through the beginning and end points of the actual sweep.

The displacement error e_d is defined as

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

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

As shown in Figure 5.2(a), v_s is the actual sweep and v'_s is the linear sweep.

The transmission **error, e_t**

When a ramp signal is transmitted through a high-pass circuit, the output falls away from the inputas shown in Figure 5.2(b).

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

where as shown in Figure 5.2(b),

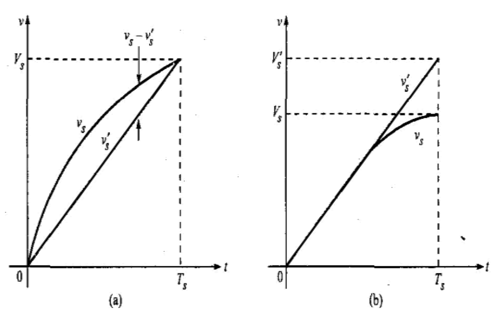


Figure 4.5.2 (a) Sweep for displacement error and (b) sweep for transmission error.

V'_S is the input and V_S is the output at the end of the sweep,

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

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

$$e_s = 2e_t = 8e_d$$

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

4.5.2.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. 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

Figure 5.3(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

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

After an interval of time T_X when the sweep amplitude attains the value V_S, the switch again closes. The resultant sweep waveform is shown in Figure 5.3(b).

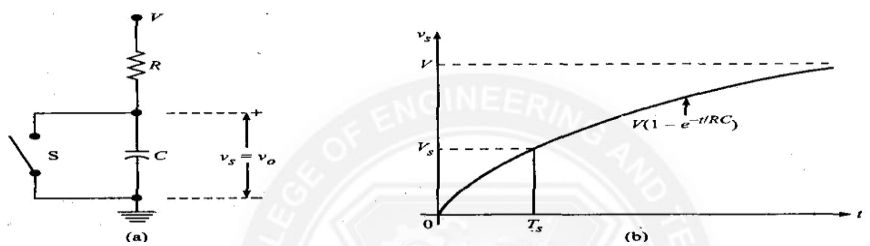


Figure 4.5.3 (a) Charging a capacitor through a resistor from a fixed voltage and (b) the resultant exponential waveform across the capacitor.

(Source: Microelectronics by J. Millman and A. Grabel, Page-293)

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, 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 5.3(a),

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

Rate of change of output or slope is

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

$$\therefore \quad \text{Slope error, } e_s = \frac{\left.\frac{dv_o}{dt}\right|_{t=0} - \left.\frac{dv_o}{dt}\right|_{t=T_s}}{\left.\frac{dv_o}{dt}\right|_{t=0}} = \frac{\frac{V}{RC} - \frac{Ve^{-T_s/RC}}{RC}}{\frac{V}{RC}}$$

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

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

For small T_S, neglecting the second and higher order terms

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

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

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

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

Neglecting the second and higher order terms

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

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

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

The transmission error, e,

From Figure 5.2(b),

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

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

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

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

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

If the initial slope is maintained at $t = T_s$, $v_s = V_s' = T_s \times \dfrac{V}{RC}$

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

The displacement error, e_d

From Figure 5.2(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 $t = \frac{T_s}{2}$, $v_s' = \frac{V_s}{2}$ The actual sweep vs is given by

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

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

$$v_s = V(1 - e^{-T_s/2RC})$$

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

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

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

$\therefore \quad V_s = V(1 - e^{-T_s/RC})$

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

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

The displacement error ed is given by

$$e_d = \frac{(v_s - v_s')_{\max}}{V_s} = \frac{V\left[\frac{T_s}{2RC} - \frac{1}{8}\frac{T_s^2}{(RC)^2}\right] - \frac{V}{2}\left[\frac{T_s}{RC} - \frac{T_s^2}{2(RC)^2}\right]}{V\left[\frac{T_s}{RC} - \left(\frac{T_s}{RC}\right)^2 \frac{1}{2}\right]}$$

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

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

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

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

If a capacitor C is charged by a constant current /, then the voltage across C is ft/C. Hence the rate of change of voltage with time is given by

Sweep speed = I/C

4.5.3.UNIJUNCTION TRANSISTOR

- 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 5.4(a). There are two bases: base B| and base **B2,** base BOriginally this device was named as double base diode but now it is commercially known as UJT. The circuit of the UJT is shown in Figure 5.4(bemitter, and it is basically a variable resistance, its value being dependent upon the emitter current

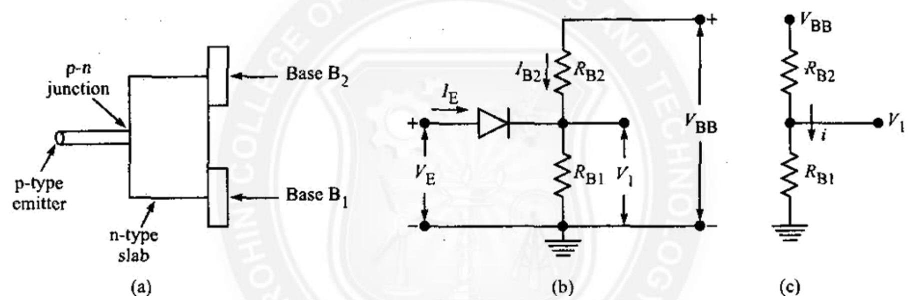


Figure 4.5.4 (a) Construction of UJT, (b) equivalent circuit of UJT, and (c) circuit when $i_E = 0$.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-295)

If IE = 0, due to the applied voltage V_{BB}, a current i results as shown in Figure 5.4(c).

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

$$V_1 = iR_{B1} = \frac{V_{BB}}{R_{B1} + R_{B2}} R_{B1} = \frac{R_{B1}}{R_{B1} + R_{B2}} V_{BB}$$

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

$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}} \quad \text{when } i_E = 0.$$

$$V_1 = \eta V_{BB}$$

From the equivalent circuit, it is evident that the diode cannot conduct unless the emitter voltage

$$V_E = V_\gamma + V_1$$

where V_γ 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.

$$V_P = V_\gamma + V_1$$

$$V_P = V_\gamma + \eta V_{BB} \text{ since } V_1 = \eta V_{BB}$$

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 5.5(a). The input characteristics of UJT (plot of VE versus I_E) are shown in Figure 5.5(b). The main application of UJT is in switching circuits wherein rapid discharge of capacitors is very essential. UJT sweep circuit is called a relaxation oscillator.

SWEEP CIRCUIT USING UJT

Many devices are available to serve as the switch S. Figure 5.6(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 V_P, the UJT turns ON and the

The capacitor voltage appears as shown in Figure 5.6(b). The expression for the sweep time T_S can be obtained as follows.

4.5.4.MILLER AND BOOTSTRAP TIME-BASE GENERATORS—BASIC PRINCIPLES

- The linearity of the time-base waveforms may be improved by using circuits involving feedback. Figure 5.10(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 / = VIR 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 5.10(b). Two methods of simulating the fictitious generator are discussed below.

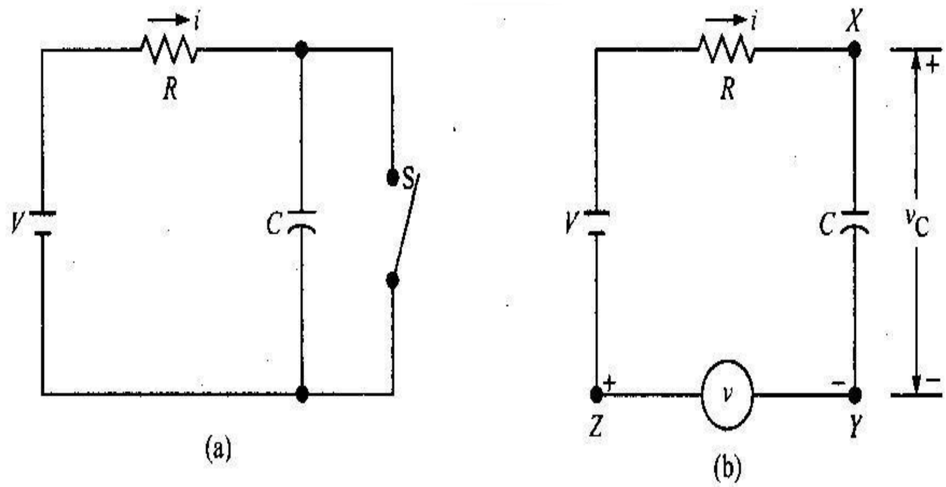


Figure 4.5.5 (a) The current decreases exponentially with time and (b) the current remains constant.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-297)

- In the circuit of Figure (b) suppose the point Z is grounded as in Figure 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 (b).
- Since we have assumed that the generated voltage is always equal and opposite to the voltage across the capacitor,

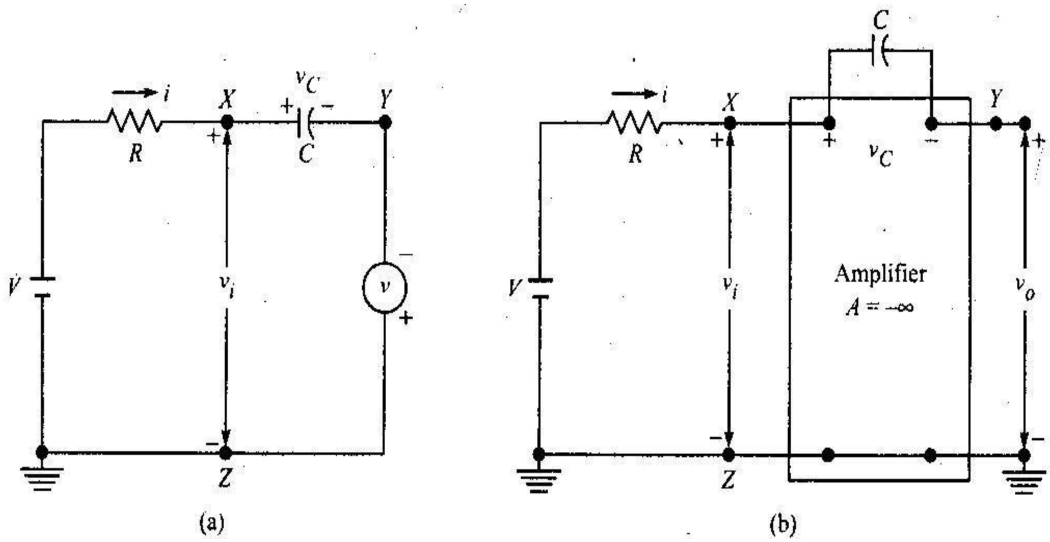
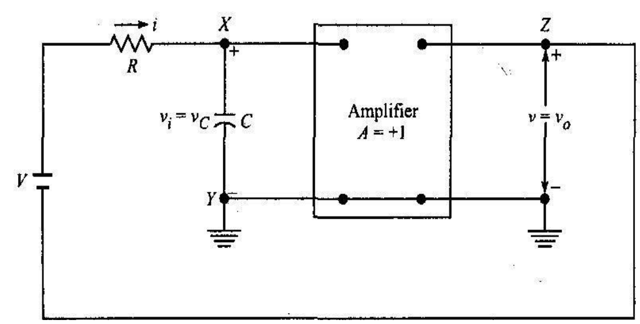


Figure 4.5.6 (a) Figure (b) with Z grounded and (b) Miller integrator circuit.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-301)

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. Suppose that the point Y in Figure (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 Since we have assumed that the generated voltage v at any instant is equal to the voltage across the capacitor vc, then v0 must be equal to v,-, and the amplifier voltage gain must be equal to unity. The circuit of Figure is referred to as the Bootstrap sweep circuit.



(Source: Microelectronics byJ. Millman and A. Grabel, Page-303)

Miller sweep

- The Miller integrating circuit of Figure 5.11(b) is redrawn in Figure 5.13(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_0 is the output resistance of the amplifier and A its open circuit voltage gain. Figure (b) is obtained by replacing V, R and tf, on the input side by a voltage source V in series with a resistance R' where

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

- Neglecting the output resistance in the circuit of Figure (b), if the switch is closed at t = 0 and if the initial voltage across the capacitor is zero, then v_0 (f = 0^+) = 0,

At $t = 0^+$, $\quad v_i - Av_i = 0 \quad$ or $\quad v_i = Av_i = v_o = 0$

  - This indicates that the sweep starts from zero.

    - At t = ∞, the capacitor acts as an open-circuit for dc. So no current flows

$$v_i = V' \quad \text{and} \quad v_o = AV'$$

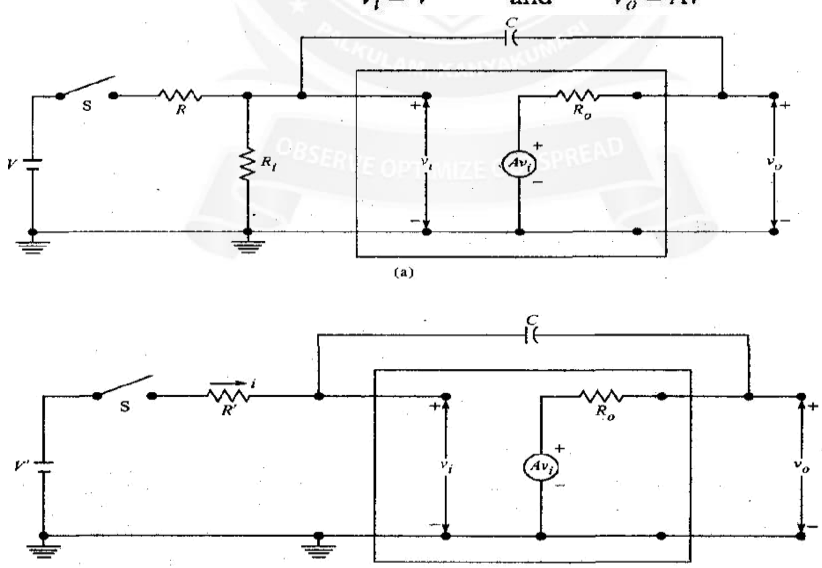


Figure 5.13 (a) A Miller integrator with switch S, input resistance R_f and Thevenin's equivalent on the output side and (b) Figure 5.13(a) with input replaced by Thevenin's equivalent.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-305)

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

$$\text{Slope error, } e_s = \frac{V_s}{V}$$

$$e_s(\text{miller}) = \frac{V_s}{|A|V'} = \frac{V_s}{|A|} \cdot \frac{R_i + R}{VR_i} = \frac{V_s}{V} \cdot \frac{1 + \frac{R}{R_i}}{|A|}$$

where V_S is the sweep amplitude and V is the peak-to-peak value of the output.

- The deviation from linearity is times that of an RC circuit charging directly from a source V.

$$\frac{1 + \frac{R}{R_i}}{|A|}$$

If R_0 is taken into account, the final value attained by v_0 remains as before, AV = -\A\V. The initialvalue however is slightly different.

- To find v_0 at $t = 0^+$, writing the KVL around the mesh in Figure 5.13(b), assuming zero voltage across

the capacitor, we have

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

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

From the above equations, we find

$$v_i(t = 0^+) = \Delta v_i = v_o(t = 0^+) = \Delta v_o = \frac{\left(\frac{R_o}{R'}\right)V'}{1 - A + \frac{R_o}{R'}}$$

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

- 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', Hence, improvement in linearity because of the increase in total excursion is negligible.

The bootstrap sweep

- Figure 5.14 shows the bootstrap circuit of Figure 5.12. 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_0 is the output resistance of the amplifier.

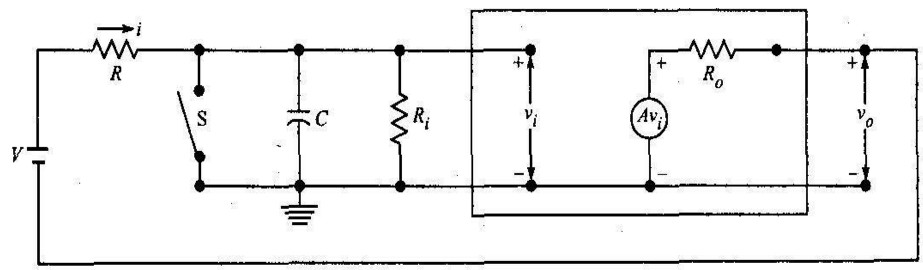


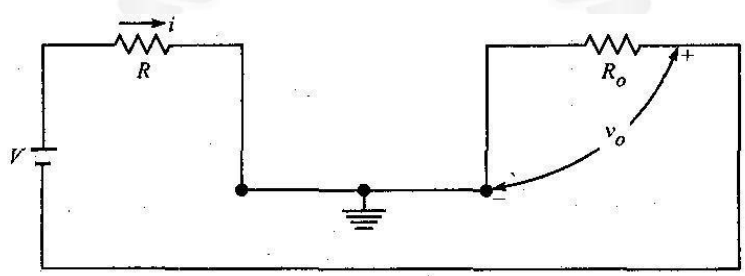
Figure 5.14 Bootstrap circuit of Figure 5.12 with switch S which opens at (= 0, input resistance R_f, and Thevenin's equivalent of the amplifier on the output side.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-307)

At t = 0~, the switch was closed and so v_t - 0, Since the voltage across the capacitor cannot change instantaneously, at t = 0* also, v(- = 0 and hence Av, = 0, and the circuit shown in Figure 5.15 results.

$$t = 0^+, \qquad v_o = -V\frac{R_o}{R + R_o}$$

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



t =

Figure 5.15

(Source: Microelectronics byJ. Millman and A. Grabel, Page-309)

At t the capacitor acts as an open-circuit and the equivalent circuit shown in Figure 5.16 results.

$$v_o(t = \infty) = AV_i - iR_o = AiR_i - iR_o = i(AR_i - R_o)$$

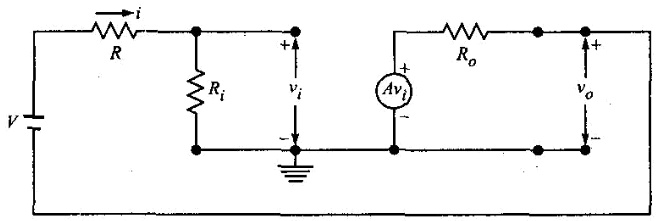


Figure 5.16 Equivalent circuit of Figure 5.14 at $t = \infty$.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-311)

Writing KVL in the circuit of Figure 5.16,

$$V - iR - iR_i + AV_i - iR_o = 0$$

i.e.

$$i = \frac{V}{R + R_o + R_i(1 - A)}$$

$\therefore$

$$v_o(t = \infty) = \frac{V(AR_i - R_o)}{R + R_o + R_i(1 - A)}$$

Since A « 1, and if R_0 is neglected, we get

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

Since R_0 v_0 at t = 0 can be neglected compared to the value of v_0 at t - <». Then the total excursion of the output is given by

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

and the slope error is

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

- This shows that the slope error is [1 - A + (R/Rj)] 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/Rj 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 impedance is less important.

4.5.5.THE TRANSISTOR MILLER TIME-BASE GENERATOR

- Figure 5.17 shows the circuit diagram of a transistor Miller time-base generator. It consists of a three- stage amplifier. To have better linearity, it is essential that a high input impedance amplifier be used for the Miller integrator circuit. Hence the first stage of the amplifier of Figure 5.17 is an emitter follower. The second stage is a common-emitter amplifier and it provides the necessary voltage amplification. The third stage (output stage) is also an emitter follower for two reasons.
- First, because of its low output impedance R_0 it can drive a load such as the horizontal amplifier. Second, because of its high input impedance it does not load the collector circuit of the second stage and hence the gain of the second stage can be very high. The capacitor C placed between the base of Qi and the emitter of Q_3 is the timing capacitor. The sweep speed is changed from range to range by switching R and C and may be varied continuously by varying V_{BB}.

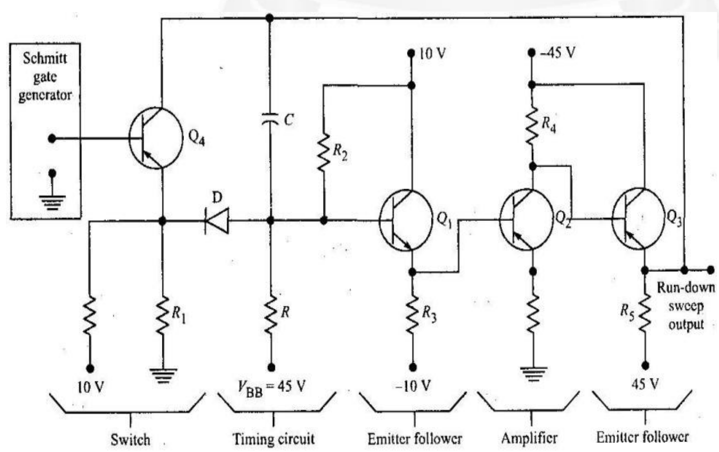


Figure 5.17 A transistorized Miller time-base generator.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-313)

- Under quiescent condition, the output of the Schmitt gate is at its lower level. So transistor Q4 is ON. The emitter current of Q4 flows through RI and hence the emitter is at a negative potential. Therefore the diode D conducts. The current through R flows through the diode D and the transistor Q4.

- When a triggering signal is applied, the output the Schmitt gate goes to its higher

$$e_s = \frac{V_s}{V}\left(1 - A + \frac{R}{R_i} + \frac{C}{C_1}\right)$$

level. So the base voltage of Q4 rises and hence the transistor Q4 goes OFF. A current flows now from 10 V source through RI. The positive voltage at the emitter of Q4 now makes the diode D reverse biased. At this time the upper terminal of C is connected to the collector of Q4 which is in cut-off. The capacitor gets charged from VBB and hence a rundown sweep output is obtained at the emitter of Q3. At the end of the sweep, the capacitor C discharges rapidly through D and Q4.

THE TRANSISTOR BOOTSTRAP TIME-BASE **GENERATOR**

- Figure 5.18 shows a transistor bootstrap time-base generator. The input to transistor Q] is the gating waveform from a monostable multivibrator (it could be a repetitive waveform like a square wave). Figure 5.19(a) shows the base voltage of Qj. Figure 5.19(b) shows the collector current waveform of Qj and Figure 5.19(c) shows the output voltage waveform at the emitter of q2.

Retrace interval

- At t = Tg, when the gate terminates, the transistor Qi goes into conduction and a current r'Bi = VCC/R-Q flows into the base of Qi.
- Hence a current/ci =/IFE*BI flows into the collector of Qj. This current remains constant till the transistor goes into saturation. Since Q] is ON the capacitor C discharges through Qi.
- Because of emitter follower action, when v_C falls, v_0 also falls by the same amount and so the voltage across R remains constant at V_{CC}.

$$i_{C1} = i_R + i_A \quad \text{i.e.} \quad i_A = i_{C1} - i_R = \frac{V_{CC}}{R_B} h_{FE} - \frac{V_{CC}}{R}$$

- The constant current i_R = Vcc/R also flows through Qi. Applying KVL at the collector of Qi and neglecting /B2,
- Since the discharging current of C, i.e. IA is constant, the voltage across C and hence the output voltage falls linearly to its initial value.

If the retrace time is T_r, then the charge lost by the capacitor = $I_A T_r$

$$\frac{i_A T_r}{C} = V_s$$

where V_S is the sweep amplitude. That is,

$$T_r = \frac{CV_s}{i_A} = \frac{C\frac{V_s}{V_{CC}}}{\frac{h_{FE}}{R_B} - \frac{1}{R}}$$

- After C is discharged, the collector current is now supplied completely through R and becomes established at the value V^c/R- The retrace time can be reduced by choosing a small value of R_S. However if R_R is reduced

The recovery process

During the entire interval $T = T_g + T_r$ the capacitor C[discharges at a constant rate because the Current $i = V_{CC}/R$ through it has remained constant. So it would have lost a charge

Hence at the time T when the voltage across C and at the base of Q_2 returns to its value for t< 0, the voltage across Ci is smaller than it was at the beginning of the sweep. The diode D starts conducting at t - T, and the end of Ci, which is connected to D, returns to its initial voltage, i.e. Vcc- Therefore,. the other terminal of Ci which is connected to the emitter is at a more positive potential than it was at t = 0 and so Q_2 goes to cut-off.

- So the capacitor Ci charges through the resistor R_E with a current,

$$i_E = V_{EE}/R_E.$$

The maximum recovery time T for C can be calculated as follows.

$$\frac{V_{CC}}{R}T.$$

Charge lost by capacitor Ci in time T is

$$\frac{V_{EE}}{R_E}T_1.$$

Charge gained by capacitor Ci in minimum recovery time T

$$\frac{V_{CC}}{R}T = \frac{V_{EE}}{R_E}T_1$$

$$T_1 = \frac{V_{CC}}{V_{EE}}\frac{R_E}{R}T$$

This shows that T is independent of C and varies inversely with V_{EE}. T can be reduced by increasing V_{EE}. However this modification will increase the quiescent current in Q_2 and hence its dissipation.

4.5.6.CURRENT TIME-BASE GENERATORS

- We have mentioned earlier that a linear current time-base generator is one that provides an output current waveform a portion of which exhibits a linear variation with respect to time. This linearly varying current waveform can be generated by applying a linearly varying voltage waveform generated by a voltage time-base generator, across a resistor. Alternatively, a linearly varying current waveform can be generated by applying a constant voltage across an inductor. Linearly varying currents are required for magnetic deflection applications.

A SIMPLE CURRENT SWEEP

- Figure 5.26(a) shows a simple transistor current sweep circuit. Here the transistor is used as a switch and the inductor L in series with the transistor is bridged across the supply voltage. R_d represents the sum of the diode forward resistance and the damping resistance.

- These levels are selected such that when the input, is at the lower level the transistor is cut-off and when it is at the upper level the transistor Is in saturation. For t < 0, the input to the base is at its lower level (negative).
- So the transistor is cut-off. Hence no currents flow in the transistor and i_L = 0 and V_{CE} = Vcc- At f = 0, the gate signal goes to its upper level (positive). So the transistor conducts and goes into saturation. Hence the collector voltage falls to $v_{CE(sat)}$ and the entire supply voltage V_{CC} is applied across the inductor. So the current through the inductor

$$i_L = \frac{1}{L}\int V_{CC}\, dt = \frac{V_{CC}t}{L}$$

increases linearly with time. This continues till t = T_g, at which time the gating signal comes to its lower level and so the transistor will be cut-off. During the sweep interval T_S (i.e. from t = 0 to t = T_g), the diode D is reverse biased and hence it does not conduct. At t ~ T_S, when the transistor is cut-off and no current flows through it, since the current through the inductor cannot change instantaneously it flows through the diode and the diode conducts. Hence there will be a voltage drop of I_LR_d across the resistance R_d. So at t = T_g, the potential at the collector terminal rises abruptly to Vcc + fiftd* i-^{e}- there is a voltage spike at the collector at t = T_g. The duration of the spike depends on the inductance of Z-^but the amplitude of the spike does not. For t > T_g, the inductor current decays exponentially to zero with a time constant T- LIR_d. So the voltage at the collector also decays exponentially and settles at Vcc under steady-state conditions. The inductance L normally represents a physical yoke and its resistance R_L may not be negligible. If R_{CS} represents the collector saturation resistance of the transistor, the current increases in accordance with the equation

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

$$\approx \frac{V_{CC}}{R_L + R_{CS}}\left(1-\left\{1-\frac{(R_L+R_{CS})t}{L}+\frac{1}{2}\left(-\frac{(R_L+R_{CS})t}{L}\right)^2\right\}+\ldots\right)$$

$$= \frac{V_{CC}t}{L}\left(1-\frac{1}{2}\frac{(R_L+R_{CS})t}{L}\right)$$

- If the current increases linearly to a maximum value I_L, the slope error is given by

$$e_s = \frac{I_L}{\frac{V_{CC}}{R_L + R_{CS}}} = \frac{(R_L+R_{CS})I_L}{V_{CC}}$$

The inductor current waveform and the waveform at the collector of the transistor are shown in Figures respectively. kept small compared with the supply voltage V_{CC}.

4.5.7.A TRANSISTOR CURRENT TIME-BASE GENERATOR

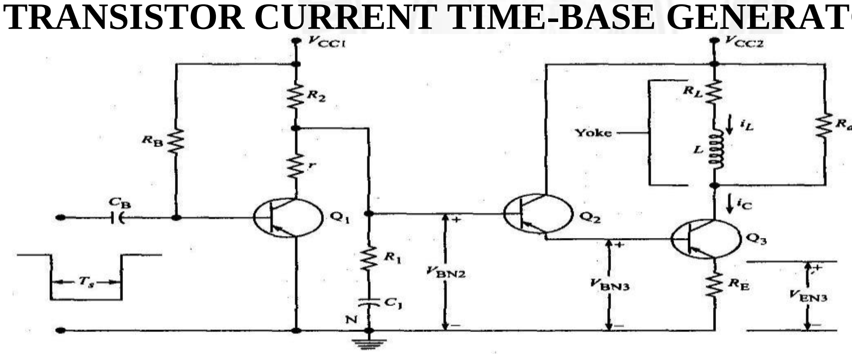


Figure 5.30 A transistor current sweep circuit.

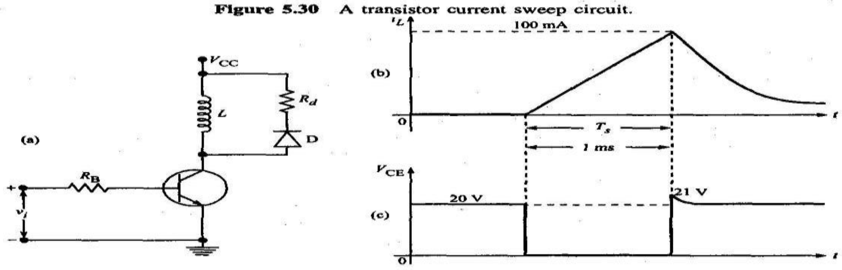


Figure 5.31 Example 5.15: (a) circuit diagram, (b) waveform of i_L, and (c) waveform of v_{CE}.

Figure 5.30 shows the circuit diagram of a transistor current time-base generator.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-323)

- Transistor Q! is a switch which serves the function of S in Figure 5.29. Transistor Qi gets enough base drive from V_{CC1} through KB hence is in saturation under quiescent conditions. At T = 0, when the gating signal isapplied it turns off Qi and a trapezoidal voltage waveform appears at the base of Q_2. Transistors Q_2 and Q_3 are connected as darlington pair to increase the input impedance so that the trapezoidal waveform source is not loaded. Such loading would cause nonlinearity in the ramp part of the trapezoid.The emitter resistor R_E introduces negative current feedback into the output stage and thereby improves the linearity with which the collector current responds to the base voltage.

- For best linearity it is necessary to make the emitter resistance as large as possible. R_E is selected so that the voltage developed across it will be comparable to the supply voltage