Chapter 12
Voltage Sweep Generators

1. For the UJT relaxation oscillator shown in Fig. 12p.1, $R_{BB} = 4 \, \text{k}\Omega$, $R_1 = 0.1 \, \text{k}\Omega$, $\eta = 0.6$, $V_V = 3 \, \text{V}$, $I_V = 10 \, \text{mA}$, $I_P = 0.01 \, \text{mA}$. (i) Calculate $R_{B1}$ and $R_{B2}$ under quiescent condition (i.e., $I_E = 0$). (ii) Calculate the peak voltage, $V_P$. (iii) Calculate the permissible value of $R$. (iv) Calculate the frequency assuming that the retrace time is negligible. Also calculate $f$ using the value of $\eta$. (v) Calculate the frequency, also considering the retrace time. Assume $R_{B1} = 0.1 \, \text{k}\Omega$ during retrace time. (vi) Calculate the voltage levels of $V_{B1}$. (vii) Plot the waveforms of the output voltage and $V_{B1}$.

Solution:

Given $R_{BB} = 4 \, \text{k}\Omega, \eta = 0.6$.

(i) $\eta = \frac{R_{B1}}{R_{B1} + R_{B2}} = \frac{R_{B1}}{R_{BB}}$

$0.6 = \frac{R_{B1}}{4 \, \text{k}\Omega}$

$R_{B1} = 0.6 \times 4 \, \text{k}\Omega = 2.4 \, \text{k}\Omega$

We have $R_{BB} = R_{B1} + R_{B2}$

$\therefore R_{B2} = R_{BB} - R_{B1} = 4 \, \text{k}\Omega - 2.4 \, \text{k}\Omega = 1.6 \, \text{k}\Omega$

(ii) The circuit that enables the calculation of $V_P$ is shown in Fig. 1.1.
Fig. 1.1 Circuit to calculate $V_P$

From Fig. 1.1,

$$V_P = 0.7V + V_{BB} \times \frac{(R_{B1} + R_1)}{R_{BB} + R_1} = 0.7 + 20 \times \frac{(2.4 + 0.1)}{(4 + 0.1)} = 12.89 \text{ V.}$$

(iii) $R_{\text{min}} = \frac{(V_{BB} - V_Y)}{I_Y} = \frac{(20 - 3)}{10 \times 10^{-3}} = 1.7 \text{ kΩ}$

$$R_{\text{max}} = \frac{(V_{BB} - V_P)}{I_P} = \frac{(20 - 12.89)}{0.01 \times 10^{-3}} = 711 \text{ kΩ}$$

$R_{\text{min}} < R < R_{\text{max}}$

Choose $R = 100 \text{ kΩ}$.

(iv) $T_s = RC \ln \left( \frac{(V_{BB} - V_Y)}{(V_{BB} - V_P)} \right) = 100 \times 10^3 \times 100 \times 10^{-9} \times \ln \left( \frac{(20 - 3)}{(20 - 12.89)} \right) = 8.7 \text{ ms.}$

$$f = \frac{1}{8.7 \times 10^{-3}} = 114.9 \text{ Hz.}$$

$T_s$ using the value of $\eta$ is given as:

$$T_s = RC \ln \left( \frac{1}{1 - \eta} \right) = 100 \times 10^3 \times 100 \times 10^{-9} \ln \left( \frac{1}{1 - 0.6} \right) = 9.1 \text{ ms.}$$

$$f = \frac{1}{9.1 \times 10^{-3}} = 109.8 \text{ Hz.}$$

(v) $T_r = (R_{B1} + R_1)C \times \ln \left( \frac{V_P}{V_Y} \right) = (0.1 + 0.1)10^3 \times 100 \times 10^{-9} \times \ln \left( \frac{12.89}{3} \right) = 29.1 \text{ μs.}$

$$T = T_s + T_r = 9.1 + 0.0291 = 9.129 \text{ ms.}$$

$$f = \frac{1}{9.129 \times 10^{-3}} = 109.54 \text{ Hz.}$$

(vi) $V_{B1}$ during charging of $C$ is given as:

$$V_{B1} = V_{BB} \times \frac{R_1}{(R_1 + R_{BB})} = \frac{20 \times 0.1}{0.1 + 4} = 0.487 \text{ V.}$$

$V_{B1}$ during discharge of $C$ is given by:

$$V_{B1} = (V_P - V_F) \times \frac{0.1}{0.1 + 0.1} = \frac{(12.89 - 0.7)}{2} = 6.09 \text{ V.}$$

$V_F$ is the diode voltage when ON, Fig. 1.1.

(vii) Waveforms of the output and $V_{B1}$ are shown in Fig. 1.2.
2. For the UJT relaxation oscillator is shown in Fig. 12p.2. Find (i) the sweep amplitude; (ii) the slope and displacement errors; and (iii) the duration of the sweep. Given that $V_V = 3\, \text{V}$, $\eta = 0.6$.

Solution:
The waveform of the sweep generator is shown in Fig. 2.1.

$V_{BB} = 20\, \text{V}$, $V_{YY} = 50\, \text{V}$, $R = 100\, \text{k}\Omega$, $C = 0.1\, \mu\text{F}$
We know that \( V_p = \eta V_{bb} + V_F = 0.6 \times 20 + 0.7 = 12.7 \) V

We have \( V_v = 3 \) V

(i) Amplitude of the sweep \( V_s = V_p - V_v = 12.7 - 3 = 9.7 \) V.

(ii) Sweep speed error, \( e_s = \frac{V_s}{V} = \frac{V_s}{V_{yy} - V_v} = \frac{9.7}{50 - 3} = 0.206 = 20.6\% \)

Displacement error, \( e_d = \frac{1}{8} e_s = \frac{1}{8} \times 20.6\% = 2.57\% \)

(iii) Sweep time, \( T_s = RC \log \left[ \frac{V_{yy} - V_v}{V_{yy} - V_p} \right] \)

\[
T_s = 100 \times 10^3 \times 0.1 \times 10^{-6} \times \log \left[ \frac{50 - 3}{50 - 12.7} \right]
\]

\( T_s = 2.31 \) ms

3. (a) Design a UJT sweep circuit shown in Fig.12p.3(b) to generate a sweep of 15 V amplitude and 3 ms duration, given that \( \eta = 0.6 \). If the sweep error is 10 per cent and \( T_r = 1 \) per cent of \( T_s \), calculate \( V_{bb}, V_{yy}, R, R_1, R_2 \) and \( C \). If the sweep duration is 300 \( \mu s \), calculate the new value of \( C \). The V–I characteristic of UJT is as shown in Fig. 12p.3(a)

**Solution:**

From the characteristics, we have \( V_p = 3 \) V, \( I_v = 1 \times 10^{-3} \) A, \( I_p = 0.3 \times 10^{-3} \) A

Given \( V_s = 15 \) V and \( e_s = 0.1 \)

\( \therefore V_p = V_s + V_v = 15 + 3 = 18 \) V.

Peak-to-peak excursion of the output swing = \( Y_{yy} - V_v \).

\[
e_s = \frac{V_s}{V} = \frac{V_s}{V_{yy} - V_v}
\]

\[
0.1 = \frac{15}{V_{yy} - 3}
\]

\( \therefore V_{yy} = 153 \) V.
Given \( \eta = 0.6 \). We have \( V_p = \eta V_{BB} + V_F \).

\[
V_{BB} = \frac{V_p - V_F}{\eta} = \frac{18 - 0.6}{0.6} = 29 \text{ V}.
\]

To calculate \( R \) and \( C \)

\[
T_s = RC \log \frac{V_{yy} - V_F}{V_{yy} - V_p} = RC \log \frac{153 - 3}{153 - 18} = 0.105 RC
\]

\[
R_{\text{max}} = \frac{V_{BB} - V_p}{I_p} = \frac{29 - 18}{0.3 \times 10^{-3}} = 36.66 \text{ k}\Omega
\]

\[
R_{\text{min}} = \frac{V_{BB} - V_F}{I_F} = \frac{29 - 3}{1 \times 10^{-3}} = 26 \text{ k}\Omega
\]

\( R \) should lie between 26 k\( \Omega \) and 36 k\( \Omega \). Choose \( R = 33 \text{ k}\Omega \)

\[
RC = 28.57 \times 10^{-3}
\]

\[
C = \frac{28.57 \times 10^{-3}}{33 \times 10^3} = 0.865 \mu\text{F}
\]

Given \( T_r = 1 \) per cent of \( T_s \)

\[
T_r = 0.01 \times 3 \times 10^{-3}
\]

\[
C = \frac{T_r}{R C} = \frac{0.01 \times 3 \times 10^{-3}}{0.865 \times 10^{-6}} = 34.68 \approx 35 \text{ \Omega}
\]

\( R_2 \) is higher than \( R_1 \) and must be of the order of several hundred ohms. Let

\( R_2 = 10 \times R_1 = 350 \text{ \Omega} \). If \( T_r \) is to be 300 \( \mu \text{s} \) \( C \) should be \( \frac{1}{10} \) of the earlier value. By reducing the value of \( C \), the charging current will be reduced, but by reducing the value of \( R \) the charging current is increased, which is undesirable. So the reduction of \( C \) is advisable.

\[
C_{\text{new}} = \frac{0.865 \mu\text{F}}{10} = 86.5 \text{ nF}
\]

4. For the Miller’s sweep shown in Fig.12p.5, \( V_{CC} = 24 \text{ V}, R_{C2} = 2 \text{ k}\Omega, R_{C1} = 10 \text{ k}\Omega \) and \( C = 1 \mu\text{F} \). The amplitude of the sweep is 18 V. (a) Calculate the sweep duration \( T_s \); (b) the retrace time \( T_r \); (c) frequency of the sweep generator and (d) the slope error. The transistor has the following parameters: \( h_{fe} = 100, h_{ie} = 1 \text{ k}\Omega, h_{oe} = \frac{1}{20 \text{ k}\Omega} \) and \( h_{re} = 2.5 \times 10^{-4} \).
Solution:

(a) 

\[ V_s = \frac{V_{cc}}{R_{c1}C} \times T_s \]

\[ T_s = \frac{V_s}{V_{cc}} \times R_{c1}C = \frac{18}{24} \times 10^3 \times 1 \times 10^{-6} = 7.5 \text{ ms.} \]

(b) Retrace time \( T_r = \frac{V_s}{V_{cc}} \times R_{c2}C = \frac{18}{24} \times 2 \times 10^3 \times 1 \times 10^{-6} = 1.5 \text{ ms.} \)

(c) \( T = T_s + T_r = 7.5 + 1.5 = 9 \text{ ms.} \)

\[ f = \frac{1000}{9} = 111.11 \text{ Hz}. \]

(d) \( A_1 = \frac{-h_{fe}}{1 + h_{re}R_{c2}} = \frac{-100}{1 + \frac{2}{20}} = -90.90 \)

\[ R_i = h_{le} + h_{re}A_1R_{c2} = 1 + (2.5 \times 10^{-4})(-90.90)(2) = (1 - 0.045) = 0.955 \text{ k}\Omega \]

\[ A = A_1 \frac{R_{c2}}{R_i} = -90.90 \times \frac{2}{0.955} = -190.36 \]

\[ e_s(Miller) = \frac{V_s}{V_{cc}} \times \frac{1}{|A|} \times \frac{1 + R_{c1}}{R_i} = \frac{18}{24} \times \frac{1}{190.66} \times \frac{10}{0.955} = 0.045 \]

\[ e_s = 4.5 \text{ per cent.} \]

6. The transistor used in the bootstrap circuit shown in Fig.12p.6 has the following \( h \)-parameter values. \( h_{re} = 2.5 \times 10^{-4}, h_{le} = 1.1 \text{ k}\Omega, h_{fe} = 60, 1/h_{re} = 40 \text{ k}\Omega. \) Assume \( V_{BE(sat)} = V_{CE(sat)} = 0. \) If the applied input gating voltage is a symmetrical square wave of the frequency 9.5 kHz, determine the time-base amplitude, retrace time and recovery time.
Solution:

$V_s = V_{CC} = 12 \text{ V}$

At the end of the input pulse, $Q_1$ once again goes into saturation.

$$i_{B1} = \frac{V_{CC}}{R_b} = \frac{12}{30 \times 10^3} = 0.4 \text{ mA}$$

$$i_{C1} = h_{fe} i_{B1} = 60 \times 0.4 = 24 \text{ mA}$$

The retrace time $T_r$ is

$$T_r = \frac{V_s}{h_{fe} i_{B1}} C_1 = \frac{12}{60} \times 0.06 \times 10^{-6} = 31.4 \mu\text{s}$$

$$T = \frac{1}{f} = \frac{1}{9.5 \times 10^3} = 0.105 \text{ ms}$$

Recovery time $T_1 = \frac{V_{CC}}{V_{EE}} \times \frac{R_E}{R_1} \times T = \frac{12}{12} \times 4 \times 0.105 \times 10^{-3} = 35.08 \mu\text{s}$.

7. Find (a) the sweep amplitude and (b) the slope error for the bootstrap sweep generator shown in Fig.12p.7, when a 2-kHz symmetrical square wave is applied as an input to it. Plot to scale the input and output waveforms. The typical $h$-parameter values of transistor are, $h_{fe} = 90$, $1/h_{oe} = 35 \text{ k}\Omega$, $h_{fe} = 1 \text{ k}\Omega$ and $h_{re} = 1$. Assume all forward-biased junction voltages are zero.
Solution:

Time period of input waveform $T = \frac{1}{f} = \frac{1}{2 \times 10^3} = 0.5 \text{ ms.}$

The input is a symmetrical square wave, so the gate width $T_g = \frac{T}{2} = 0.25 \text{ ms.}$

Maximum value of ramp voltage or sweep amplitude is equal to

$$V_s = \frac{V_{cc}T_g}{R_1C_1} = \frac{12 \times 0.25 \times 10^{-3}}{10 \times 10^3 \times 0.3 \times 10^{-6}} = 10 \text{ V}$$

For an emitter follower, the current gain is

$$A_I = \frac{h_{fe} + 1}{1 + h_{ie}R_E} = \frac{90 + 1}{1 + \frac{5 \times 10^3}{35 \times 10^3}} = 79.68$$

Input impedance $= R_i = h_{ie} + A_I R_E$

$$R_i = 1 \times 10^3 + 79.68 \times 5 \times 10^3 = 399.4 \text{ k}\Omega$$

We have $(1 - A) = \frac{h_{ie}}{R_i} = \frac{1}{399.4} = 0.0025$

Sweep error $e_s = \frac{V_s}{V_{cc}} \left( \frac{R_i}{R} + (1 - A) \right) = \frac{10}{12} \left[ \frac{10}{399.4} + 0.0025 \right] = 0.0029$

Sweep error $= 0.29 \text{ per cent.}$

7. The transistor bootstrap has the following parameters: $V_{cc} = 20 \text{ V}$, $V_{ee} = -20 \text{ V}$, $R_B = 15 \text{ k}\Omega$, $R_1 = 5 \text{ k}\Omega$, $R_E = 2.5 \text{ k}\Omega$, $C_1 = 0.001 \mu\text{F}$, $C_3 = 0.25 \mu\text{F}$. The input gate has amplitude of 1 V and a width of 50 $\mu\text{s}$. The transistor parameters are $h_{fe} = 60$, $h_{ie} = 2 \text{ k}\Omega$, $1/h_{oe} = 10 \text{ k}\Omega$, $h_{re} = 10^{-4}$ and the forward-biased junction voltages are negligible. The diode is ideal. (i) Evaluate (a) the sweep speed and the maximum amplitude of the sweep; (b) the retrace time; (c) the peak voltage change across $C_3$ and the recovery time and (d) the slope error. (ii) Plot the gate voltage, collector current $i_{c1}$, and the output voltage $v_o$. 
Solution:

(i) Referring to circuit in Fig.12p.8

(a) Sweep speed = \( \frac{I_1}{C_1} = \frac{V_{CC}}{R_1C_1} = \frac{20}{5 \times 10^3 \times 0.001 \times 10^{-6}} = 4 \times 10^6 \text{ V/s} \)

\[ V_{s/(\text{max})} = V_{CC} = 20 \text{ V} = \text{sweep speed} \times T_s \]

\[ \text{i.e.} \quad 20 = (4 \times 10^6)T_s \]

\[ \therefore \quad \text{Sweep time}, \quad T_s = \frac{20}{4 \times 10^6} = 5 \mu s. \]

(b) At the end of the input pulse, \( Q_1 \) once again goes into saturation.

\[ i_{B1} = \frac{V_{CC}}{R_B} = \frac{20}{15 \times 10^3} = 1.33 \text{ mA} \]

\[ i_{C1} = h_{fe} i_{B1} = 60 \times 1.33 \text{ mA} = 79.8 \text{ mA} \]

The retrace time \( T_r \) is

\[ T_r = \frac{V_s}{V_{CC}} C_1 = \frac{20}{15 \times 10^3} = 0.26 \mu s \]

\[ T = T_g + T_r = (50 + 0.26) = 50.26 \mu s. \]

Recovery time \( T_i = \frac{V_{CC} R_E}{V_{EE} R_i} \times T = \frac{15}{10} \times \frac{5}{10} 	imes 63.18 \times 10^{-6} = 47.385 \mu s \)

(c) To find the slope error:

The current gain of the emitter follower is given by:

\[ A_f = \frac{1 + h_{fe}}{1 + h_{oe} R_E} = \frac{1 + 60}{1 + \frac{1}{10} \times 2.5} = \frac{61}{1.25} = 48.8 \]
Input impedance of the emitter follower is given by

\[ R_i = h_{ie} + A_I R_E \]

\[ 1 - A = \frac{h_{ie}}{R_i} \]

\( A \) is the voltage gain of the emitter follower.

\[ R_i = h_{ie} + A_I R_E = 2 \text{k}\Omega + 48.8 \times 2.5 \text{k}\Omega = 124 \text{k}\Omega \]

\[ 1 - A = \frac{h_{ie}}{R_i} = \frac{2}{124} = 0.016 \]

(d) The slope error, \( e_s = \left[ 1 - A + \frac{R_i}{R_i} \right] \frac{V_s}{V_{cc}} \]

\[ e_s = \left[ 0.016 + \frac{5}{124} \right] \frac{20}{20} = 0.056 \]

\( e_s = 5.6 \text{ per cent.} \)

(ii) Using the above calculations, the waveforms can be sketched as shown in Fig. 8.1.

Fig. 8.1 Waveforms