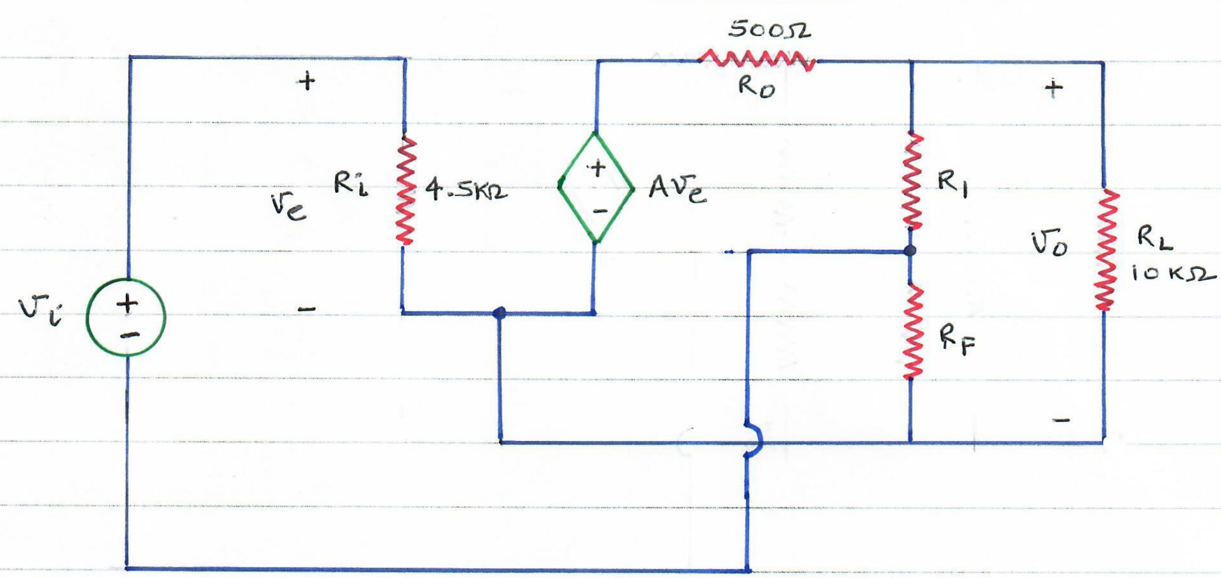
Solutions to Mid Exam-2 Paper IEC103

Q1) Feedback is applied to a voltage amplifier whose open loop parameters are $R_i = 4.5\,K\Omega$, $R_o = 500\,\Omega$; low frequency gain $A = -450$ V/V, and bandwidth $BW = f_H = 10\,KHz$. The load resistance is $R_L = 10\,K\Omega$. What is the type of feedback topology? Determine the values of the feedback network so that the bandwidth with feedback is $f_{Hf} = 1\,MHz$ and loading effect of the feedback network is minimal. For the designed feedback network. What will be R_{if} and R_{of}? Draw the closed loop circuit diagram with component values.

Sol. The circuit diagram is as shown below.



$A = -450$ V/V

The topology is series-shunt feedback. Since voltage is feedback and voltage is added at the input side.

$$\beta = \frac{R_F}{R_1 + R_F}$$

$$A_f = \frac{A}{1 + A\beta}$$

$$R_{if} = (1 + A\beta) R_i$$

$$R_{of} = \frac{R_o}{(1 + A\beta)}$$

$$f_{Hf} = (1 + A\beta) f_H$$

$f_H = 10KHz$; $R_i = 4.5K\Omega$; $R_o = 500\Omega$; $R_L = 10K\Omega$, $f_{Hf} = 1MHz$

$$f_{Hf} \times A_f = f_H \times A$$

$$10^6 \times A_f = 10 \times 10^3 \times 450$$

$$\Rightarrow A_f = \frac{450}{100} = 4.5\ V/V$$

A_f is also $\dfrac{A}{1+A\beta}$

$$\therefore\ 4.5 = \frac{450}{1+450\beta}$$

$$\Rightarrow 1+450\beta = 100$$

$$\Rightarrow 450\beta = 99$$

$$\Rightarrow \beta = \frac{99}{450} = 0.22$$

$$\beta = \frac{R_F}{R_1+R_F}$$

$$\Rightarrow \frac{R_1+R_F}{R_F} = \frac{1}{0.22}$$

$$\Rightarrow \frac{R_1}{R_F} = \frac{1}{0.22} - 1 = 3.5455$$

For minimal loading by feedback network $R_1 + R_F \geq 10 R_L$

$$(1+A\beta) = 1 + 450 \times 0.22 = 100$$

Let us choose $R_F = 50K\Omega$

$$\Rightarrow R_1 = 3.5455 \times 50K\Omega$$

$$= 177.27K\Omega$$

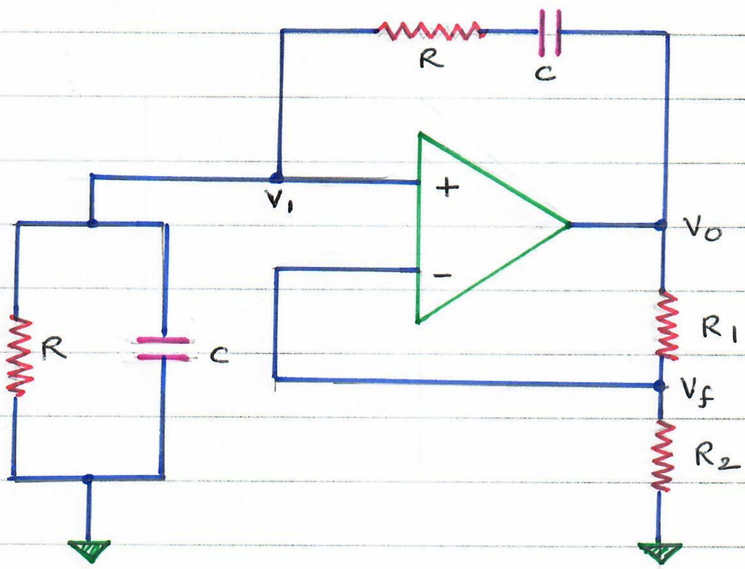
$$R_{if} = (1+A\beta)R_i = (1+450\times 0.22)R_i = 100 \times 4.5K\Omega = 450K\Omega$$

$$R_{of} = \frac{R_o}{1+A\beta} = \frac{500}{100} = 5\Omega$$

Q2 Draw the circuit diagram of an op-amp based Wein bridge oscillator and derive the expression for the frequency of oscillation and condition on gain of the amplifier for sustained oscillations.

Draw the complete circuit diagram with component values for generating a sinusoidal frequency of 10 KHZ. Assume the op-amp to be ideal.

Sol. The circuit diagram of a Wein bridge oscillator is as shown below.



Gain of the amplifier $= 1 + \frac{R_2}{R_1} = A$

$V_o = A V_1$

Also $V_1 = \frac{Z_1(s)}{Z_1(s) + Z_2(s)} V_o$

where $Z_1(s) = \frac{R \times 1/CS}{R + 1/CS} = \frac{R}{1 + RCS}$

and $Z_2(s) = R + \frac{1}{CS} = \frac{1 + RCS}{CS}$

$$V_1(s) = \frac{\frac{R}{1+RCs}}{\frac{R}{1+RCs} + \frac{1+RCs}{Cs}} = \frac{R}{(1+RCs)} \times \frac{Cs(1+RCs)}{RCs + (1+RCs)^2}$$

$$\Rightarrow V_1(s) = \frac{RCs}{(1+RCs)^2 + RCs} \; V_o(s)$$

$$\Rightarrow V_1(s) = \frac{RCs}{(1+RCs)^2 + RCs} \times AV_1(s)$$

$$\Rightarrow (1+RCs)^2 + RCs = ARCs$$

$$\Rightarrow R^2C^2s^2 + 2RCs + 1 + RCs = ARCs$$

$$\Rightarrow R^2C^2s^2 + 3RCs + 1 = ARCs$$

$$\Rightarrow R^2C^2s^2 + (3-A)RCs + 1 = 0$$

$S = j\omega$

$$\therefore \quad R^2C^2(j\omega)^2 + (3-A)RC \times j\omega + 1 = 0$$

$$\Rightarrow -R^2C^2\omega^2 + (3-A)RC\omega j + 1 = 0$$

$$\Rightarrow 1 - R^2C^2\omega^2 = 0 \quad \text{and} \quad (3-A)RC\omega = 0$$

$$\Rightarrow \omega = \frac{1}{RC} \qquad\qquad A = 3$$

$$A = 1 + \frac{R_2}{R_1}$$

$$\omega = 2\pi f = 2\pi \times 10 \times 10^3 \text{ rad/sec}$$

$$= 62.83 \times 10^3 \text{ rad/s}$$

$$\frac{1}{RC} = 62.83 \times 10^3$$

Let us choose $R = 1K\Omega$ $\Rightarrow C = \frac{1}{62.83 \times 10^3 \times 10^3}$

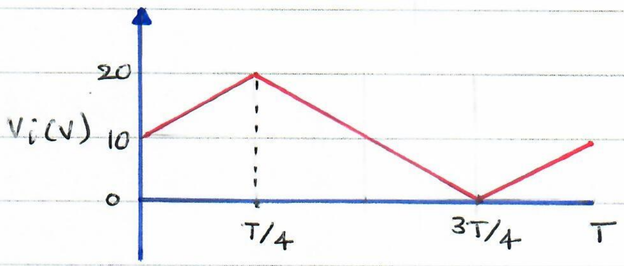
$$= 0.016 \mu F$$

$A = 1 + \frac{R_2}{R_1} = 3$; Let us choose $R_1 = 1K\Omega$

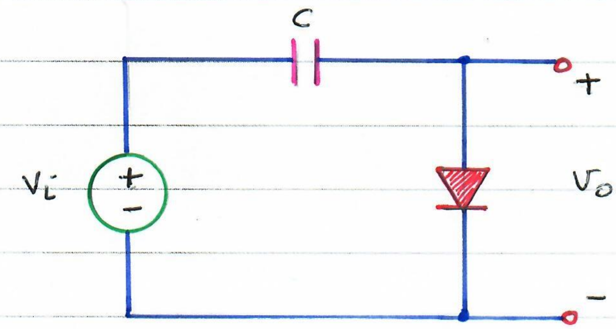
$$\Rightarrow R_2 = 2K\Omega$$

$\therefore$ The component values are $R = 1K\Omega$; $C = 0.016\mu F$; $R_1 = 1K\Omega$; $R_2 = 2K\Omega$

Q3



a)



b)

Fig. Q3

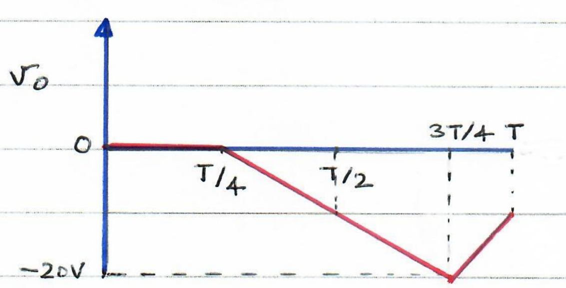
The voltage waveform of Fig. Q3 a) is applied as input to the circuit shown in Fig. Q3 b). Sketch the output voltage waveform upto T and mark the voltage levels. What will be the average value of V_o over the time period 0 to T ? Find the PIV of the diode. Assume the diode to be ideal.

Sol. During the time interval $0 \le t \le T/4$ the diode conducts, so $V_o = 0$ and the capacitor voltage V_c charges upto 20V. During the interval $T/4 \le t \le 3T/4$ $V_i < 20V$, and the diode is reverse biased and does not conduct.

from $t > T/4$

Applying KVL $V_o = V_i - V_c$

The output waveform is as shown below.



Average value of V_o over time interval 0 to T is

$$V_{avg} = \frac{1}{T}\int_0^T V_o(t)\,dt$$

$$= \frac{1}{T}\left[\int_0^{T/4} 0\,dt + \int_{T/4}^{3T/4}\left(-\frac{40t}{T}+10\right)dt + \int_{3T/4}^{T}\left(\frac{40}{T}t-50\right)dt\right]$$

$$= \frac{1}{T}\left[-\frac{40t^2}{2T}+10t\Big|_{T/4}^{3T/4} + \frac{40t^2}{2T}-50t\Big|_{3T/4}^{T}\right]$$

$$= \frac{1}{T}\left[-\frac{20t^2}{T}+10t\Big|_{T/4}^{3T/4} + \frac{20t^2}{T}-50t\Big|_{3T/4}^{T}\right]$$

$$= \frac{1}{T}\left[-\frac{45T}{4}+\frac{30T}{4}+\frac{5T}{4}-\frac{10T}{4}+20T-50T-\frac{45T}{4}+\frac{150T}{4}\right]$$

$$= -\frac{45}{4}+\frac{30}{4}+\frac{5}{4}-\frac{10}{4}+20-50-\frac{45}{4}+\frac{150}{4}$$

$$= \frac{1}{4}(-45+30+5-10+80-200-45+150)$$

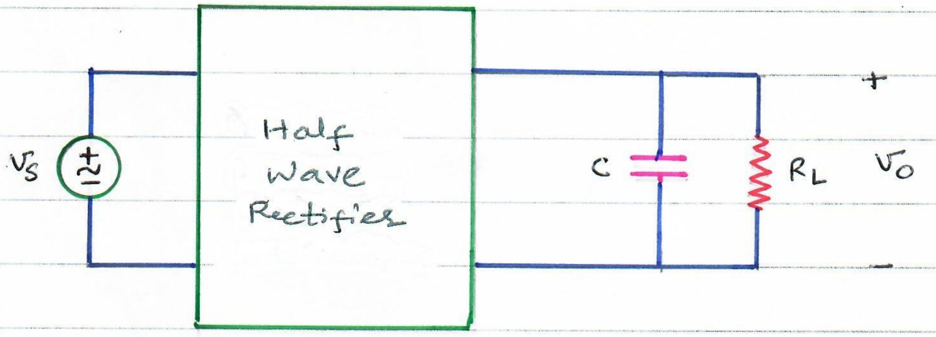
$$= \frac{-35}{4} = -8.75$$

The maximum reverse voltage across the diode is $-20V$.

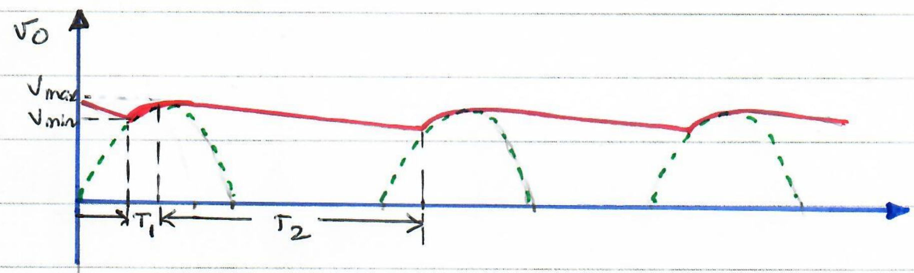
so PIV of diode is 20V

Q4 Derive the expression for the ripple factor of the output voltage of a half wave rectifier with capacitor filter and load.

Sol. The circuit diagram is as shown below.



The o/p waveform will be as shown below.

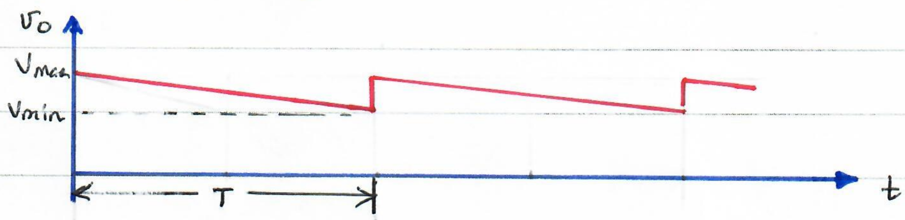


The charging time T_1 will be much smaller than the discharge time T_2

$T_1 << T_2$ Also, $R_L C >> T$

Time period $= T = T_1 + T_2 \simeq T_2$

The above can be approximated as saw tooth wave form shown below as $T_1 << T_2$



$T = \frac{1}{f}$, where f is the supply frequency.

$$V_{min} = V_{max}\, e^{-T/R_L C}$$

$$= V_{max}\left(1 - \frac{T}{R_L C} + \frac{T^2}{2R_L^2 C^2} - \cdots\right)$$

$$\simeq V_{max}\left(1 - \frac{T}{R_L C}\right) \qquad \because R_L C >> T$$

$$\text{Ripple factor} = \frac{\text{RMS value of ripple voltage}}{\text{DC value of the o/p voltage}} =$$

$$V_{dc} = \frac{V_{max} + V_{min}}{2} = \frac{1}{2}\left[V_{max} + V_{max}\left(1 - \frac{T}{R_L C}\right)\right]$$

$$= V_{max}\left(1 - \frac{T}{2R_L C}\right)$$

Peap to peak ripple voltage $= V_{max} - V_{min} = V_{p-pr}$

$$= V_{max} - V_{max}\left(1 - \frac{T}{R_L C}\right) = \frac{V_{max} T}{R_L C}$$

$$\text{RMS value of ripple voltage} = \frac{V_{p-pr}}{2\sqrt{3}} = \frac{V_{max} T}{2\sqrt{3} R_L C}$$

$$r = \frac{\dfrac{V_{max} T}{2\sqrt{3} R_L C}}{V_{max}\left(1 - \dfrac{T}{R_L C}\right)} = \frac{T}{2\sqrt{3} R_L C\left(1 - \dfrac{T}{R_L C}\right)}$$

$$= \frac{T}{2\sqrt{3}(R_L C - T)}$$

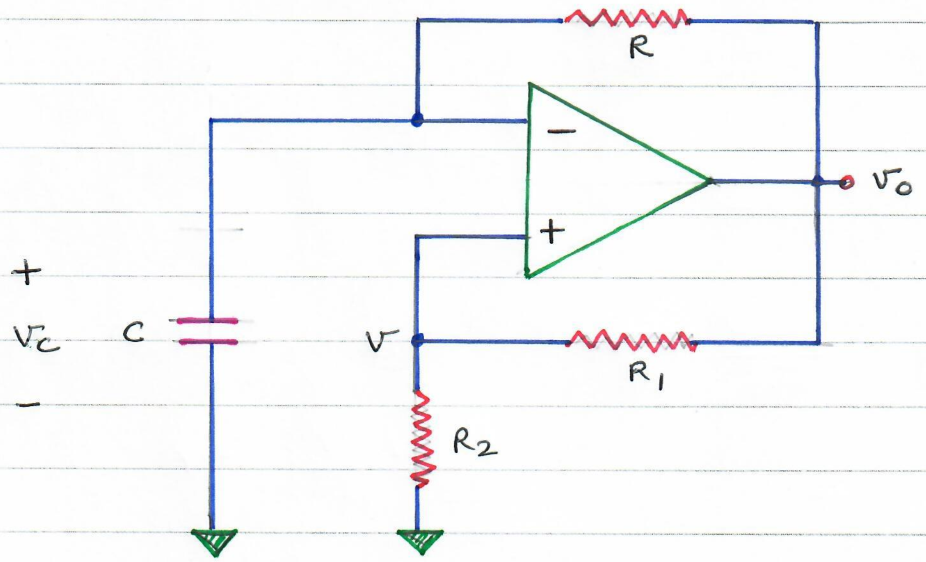
$$\simeq \frac{T}{2\sqrt{3} R_L C} \qquad \because R_L C >> T$$

$$\therefore \boxed{r = \frac{1}{2\sqrt{3} f R_L C}} \qquad \text{where } T = \frac{1}{f}$$

Q5) Draw the circuit diagram of a square wave generator using Schmitt trigger and derive the expression for the frequency of oscillations.

Draw the circuit diagram with all the values of components to generate a square wave of frequency 1KHz

Sol. The circuit diagram of a square wave generator using Schmitt trigger is as shown below.



The o/p of the op-amp will be either $+V_{sat}$ or $-V_{sat}$

If the output voltage is $+V_{sat}$, $v = \frac{R_2}{R_1+R_2} \times V_{sat}$

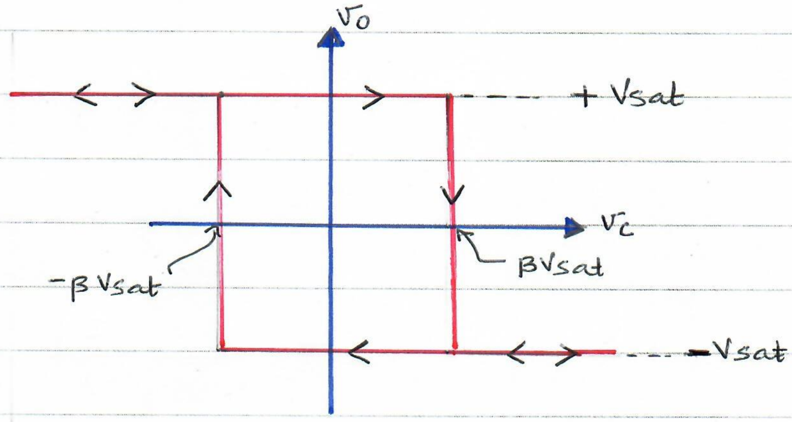
$$= \beta V_{sat} \quad \text{where } \beta = \frac{R_2}{R_1+R_2}$$

If the output voltage is $-V_{sat}$, $v = \frac{R_2}{R_1+R_2} \times -V_{sat}$

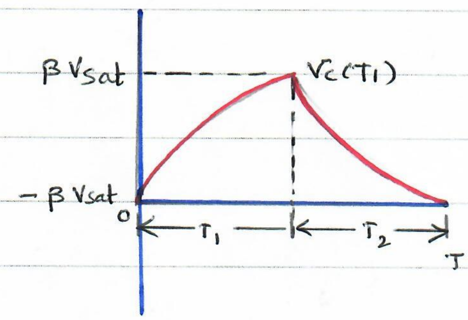
$$= -\beta V_{sat}$$

When the capacitor voltage v_c is more than v, then $v_o = -V_{sat}$ and when the capacitor voltage v_c is less than v_o, then $v_o = +V_{sat}$.

v_o V/s v_c characteristics are as shown below.



charging and discharging of capacitor



$$v_c(T_1) = \beta V_{sat}$$

$$v_c(T_1+T_2) = -\beta V_{sat}$$

During charging of capacitor, $v_c(t) = v_c(0) + (V_{sat} - v_c(0))(1 - e^{-t/RC})$

$$\Rightarrow v_c(t) = -\beta V_{sat} + (V_{sat} - (-\beta V_{sat}))(1 - e^{-t/RC})$$

$$\Rightarrow v_c(t) = -\beta V_{sat} + (1+\beta)(1 - e^{-t/RC})$$

$$\Rightarrow v_c(T_1) = \beta V_{sat} = -\beta V_{sat} + V_{sat}(1+\beta)(1 - e^{-T_1/RC})$$

$$\Rightarrow 2\beta V_{sat} = (1+\beta) V_{sat} (1 - e^{-T_1/RC})$$

$$\Rightarrow 1 - e^{-T_1/RC} = \frac{2\beta}{1+\beta}$$

$$\Rightarrow e^{-T_1/RC} = \frac{1-\beta}{1+\beta}$$

$$\Rightarrow -\frac{T_1}{RC} = \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow \frac{T_1}{RC} = \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$\Rightarrow T_1 = RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

If $R_1 = R_2$, $\beta = 0.5$ $\quad \therefore T_1 = RC\ln\left(\frac{1.5}{0.5}\right) = RC\ln(3)$

During discharging

$$V_c(t) = V_c(T_1) + (-V_{sat} - V_c(T_1))(1 - e^{-(t-T_1)/RC})$$

$$= \beta V_{sat} + (-V_{sat} - \beta V_{sat})(1 - e^{-(t-T_1)/RC})$$

$$V_c(T) = V_c(T_1+T_2) = -\beta V_{sat} = \beta V_{sat} - V_{sat}(1+\beta)(1-e^{-T_2/RC})$$

$$\Rightarrow \quad -2\beta V_{sat} = -(1+\beta)V_{sat}(1-e^{-T_2/RC})$$

$$\Rightarrow \quad 1 - e^{-T_2/RC} = \frac{2\beta}{1+\beta}$$

$$\Rightarrow \quad e^{-T_2/RC} = \frac{1-\beta}{1+\beta}$$

$$\Rightarrow \quad -\frac{T_2}{RC} = \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow \quad \frac{T_2}{RC} = \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$\text{or } T_2 = RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

if $R_1 = R_2$, $\quad T_2 = RC\ln\left(\frac{1.5}{0.5}\right) = RC\ln(3)$

$$T = T_1 + T_2 = 2RC\ln(3) = 2.2RC$$

Required frequency $= 1\,KHz \Rightarrow T = 1\,msec$

Let us take $R_1 = R_2 = 1K\Omega$; and $R = 1K\Omega$

$$\therefore 10^{-3} = 2.2 \times 10^{3} \times C$$

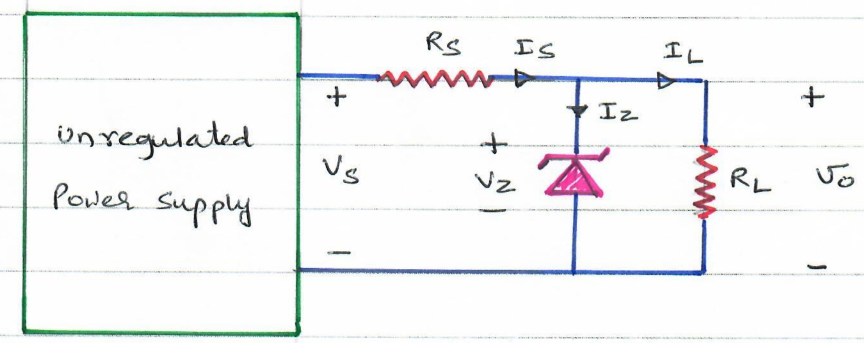
$$\Rightarrow C = \frac{10^{-3}}{2.2\times 10^{3}} = \frac{1}{2.2} \times 10^{-6}\,F = 0.45\,\mu F$$

Final design values : $R_1 = R_2 = R = 1K\Omega$

$$C = 0.45\,\mu F$$

Q6) The parameters of a zener diode in a shunt regulator circuit are $V_Z = 5V$; $I_Z(\text{Knee}) = 1\,mA$, and $P_Z(max) = 750\,mW$. The input voltage V_S to the regulator varies from 18 to 12V. Design the value of R_S and power rating of the resistor R_S so that the voltage across the load is maintained at 5V from no load to full load current of 100 mA.
Draw the circuit diagram with component values.

Sol.



$V_S(max) = 18V$; $V_S(min) = 12V$

$P_Z(max) = V_Z I_Z(max)$

$$\Rightarrow I_Z(max) = \frac{P_Z(max)}{V_Z} = \frac{750\times10^{-3}}{5} = 150\,mA$$

$I_Z(\text{Knee}) = 1\,mA$

$I_L(min) = 0\,A$; $I_L(max) = 100\,mA$

$I_Z = I_S - I_L$

Maximum value of current through zener diode $= I_S(max) - I_L(min)$ should be less than $I_Z(max)$

$$\Rightarrow I_S(max) - I_L(min) < I_Z(max)$$

$$\Rightarrow \frac{V_S(max) - V_Z}{R_S(min)} - I_L(min) < I_Z(max)$$

$$\Rightarrow \frac{18-5}{R_S(min)} - 0 < 150\times10^{-3}$$

$$\Rightarrow \quad R_S(min) > \frac{13}{150\times10^{-3}} = 86.667\ \Omega$$

Minimum value of current through zener diode = $I_S(min) - I_L(max)$ should be greater than $I_Z(knee)$

$$\Rightarrow \quad I_S(min) - I_L(max) > I_Z(knee)$$

$$\Rightarrow \quad \frac{V_S(min) - V_Z}{R_S(max)} - I_L(max) > I_Z(knee)$$

$$\Rightarrow \quad \frac{12-5}{R_S(max)} - 100\times10^{-3} > 10^{-3}$$

$$\Rightarrow \quad \frac{7}{R_S(max)} > 101\times10^{-3}$$

$$\Rightarrow \quad R_S(max) < \frac{7}{101}\times1000 = 69.3\Omega$$

This gives two conditions $R_S(min) > 86.667\Omega$ and

$R_S(max) < 69.3\ \Omega$

$\therefore$ We cannot design R_S to meet the specificatione

Either the ripple content of V_S should be decreased by increasing the value of capacitor voltage or load current should be decreased.