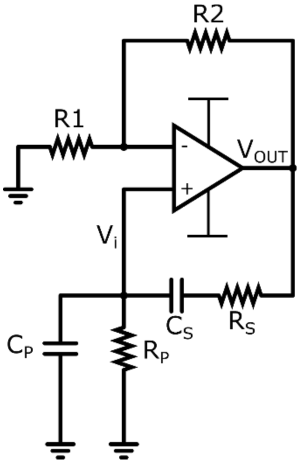
Assignment 5 solutions

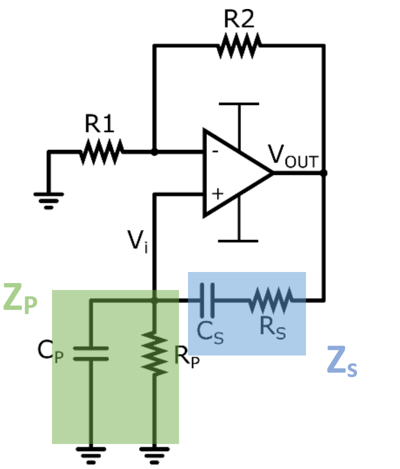
EE204: Analog Circuits

Dept of Electrical Engineering, IITB
Autumn Semester 2023

Q1.Design a Wein-Bridge Oscillator as shown with the following requirements:



Frequency of Oscillation ω0 should be 19/(1+x)kHz, where x is the last digit of your roll number.
Choose Rs/Rp=1+x and Cp/Cs =1+x, where x is the last digit of your roll number.
Rs,Rp,R1,R2 > 1kohm , Cp,Cs>100pF.
A. Determine the following to design the oscillator, assuming the opamp is ideal
A.1. β(s) - Transfer function of the feedback path as a function of Rs, Rp, Cp and Cs (2m)



$$Z_p = \frac{R_P}{R_p S C_p + 1} \quad (0.5m)$$

$$Z_s = \frac{R_S C_S S + 1}{S C_S} \quad (0.5m)$$

$$\beta(s) = \frac{Z_P}{Z_P+Z_S} = \frac{1}{\frac{C_P}{C_S}+\frac{R_S}{R_P}+1+\left(\frac{1}{R_P C_S S}+R_S C_P S\right)}$$ (1m)

A.2. Values of circuit elements - Rs, Rp, Cp and Cs (2m)

From the barkhausen criterion , the loop gain should be 1, since the Opamp is ideal and in negative feedback its gain A_v is real so $\beta(s) * A_v = 1 \Rightarrow \angle\beta(s) = 0$

$$\beta(s) = \frac{1}{\frac{C_P}{C_S}+\frac{R_S}{R_P}+1+\left(\frac{1}{R_P C_S S}+R_S C_P S\right)}$$

$\frac{C_P}{C_S} + \frac{R_S}{R_P} + 1$ is real part and $\left(\frac{1}{R_P C_S S} + R_S C_P S\right)$ imaginary part, for $\angle\beta(s) = 0$ the imaginary part should become 0

So by evaluating the imaginary part to zero and substituting $S = j\omega_0$ we get

$$\frac{1}{R_P C_S S} + R_S C_P S = 0$$

$$\frac{1}{R_P C_S j\omega_0} = -R_S C_P j\omega_0$$

$$\frac{1}{R_P C_S R_S C_P} = -j\omega_{0*} j\omega_0$$

$$\frac{1}{R_P C_S R_S C_P} = \omega_0^2$$

Given Rs/Rp=1+x and Cp/Cs =1+x

$$so\ , \qquad \frac{1}{R_P C_S(1+x)} = \omega_0 = \frac{2\pi}{1+x} * 19 * 10^3$$ (1m)

$$\frac{1}{R_P C_S} = 2\pi * 19 * 10^3 \cong 120 * 10^3$$

Given Rs,Rp,R1,R2 > 1kohm , Cp,Cs>100pF.

From the above constraints choose a value of R_p and C_S then $R_s = R_p(1+x)$, $C_p = C_s(1+x)$

(0.25m for each)

A.3. Using values from A.2, find β(jω0) - feedback Transfer Function at ω0 (1m)

$$\beta(s) = \frac{1}{\frac{C_P}{C_S}+\frac{R_S}{R_P}+1} = \frac{1}{1+x+1+x+1} = \frac{1}{3+2*x}$$ (1m)

A.4. Using values from A.2, find the ratio R2/R1 for sustained oscillations (2m)

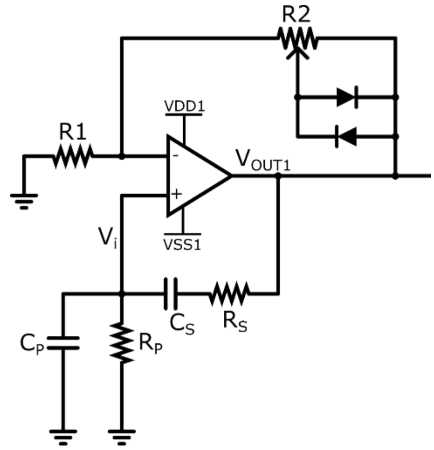
$$A_v = 1 + \frac{\mathrm{R2}}{\mathrm{R1}}$$ (0.5m)

$$\beta(j\omega_0) * A_v = 1$$ (0.5m)

$$\beta(j\omega_0) * \left(\frac{\text{R2}}{\text{R1}} + 1\right) = 1$$

$$\frac{R2}{R1} = 2x + 2 \qquad \text{(1m)}$$

B. The following amplitude control is implemented with all other circuit elements being the same as before, except R2 is now a potentiometer and two diodes are added across R2 as shown



B.1. Choose R2/R1 so that it is greater than the ratio obtained in A.4 . Determine the values of R2, R1. (1m)

Given Rs,Rp,R1,R2 > 1kohm

$$\frac{R2}{R1} > 2x + 2$$

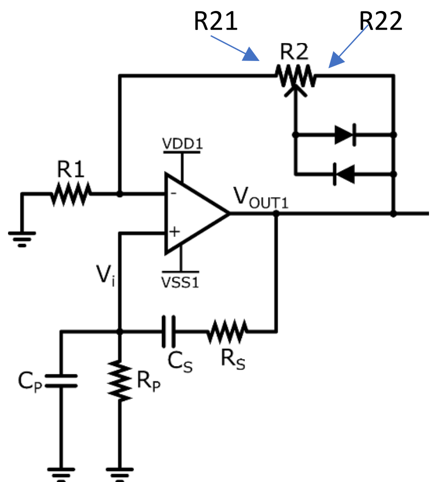
Then choose a value of R1 and evaluate the constraint on R2 [R2> R1(2+2x)]and choose its value

(1m)

B.2. Find the setting on the R2 Potentiometer so that the output sine wave has an amplitude of 6V.

Given Vdd1=-Vss1=15V,

Diode current ID=Is*(exp(V/VT)) where VT=25mV, Is=100nA, and V is the drop across the diode. (2m)



Lets assume that potentiometer is in setting R21 , R22 as shown in the figure

From the positive feedback, Vi = Vout/(3+2x)

R1 also sees the voltage of Vi across it due to virtual short

Now a current of Vi/R1 flows through negative feedback loop

Let 3+2x=k

$I_{feedback}$= Vi/R1= Vout/(3+2x)/R1=Vout/(kR1)

Then voltage drop across diode V = Vout – (R21+R1)($I_{feedback}$)

$$\mathrm{V} = \mathrm{V_{out}} - \frac{(R21+R1)V_{out}}{k*R1}$$
$$V = V_{out} - \left(\frac{R21}{kR1} + \frac{1}{k}\right)V_{out}$$
$$V = V_{out}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)$$

Let R2/R1=q , q>$2x+2$

Since the circuit is symmetrical we analyse it for maximum case
at Voutmax We can now find the current through Forward biased diode and Current through R22 neglecting I through reverse biased diode.

So $I_{feedback} = I_{R22}+I_D$

Voltage across diode= voltage across R22=V= $V_{outmax}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)$

$$I_{R22} = \frac{V}{R22}$$
$$I_D = I_s \exp\left(\frac{V}{V_t}\right)$$
$$\mathrm{I_{R22}} + \mathrm{I_D} = \frac{V_{outmax}}{\mathrm{k*R1}}$$

$$\frac{V}{R22} + I_s \exp\left(\frac{V}{V_t}\right) = \frac{V_{outmax}}{\mathrm{k*R1}}$$
$$\frac{V_{outmax}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)}{R22} + I_s \exp\left(\frac{V_{outmax}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)}{V_t}\right) = \frac{V_{outmax}}{\mathrm{k*R1}}$$
$$\frac{V_{outmax}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)}{qR1 - R21} + I_s \exp\left(\frac{V_{outmax}\left(1 - \frac{R21}{kR1} - \frac{1}{k}\right)}{V_t}\right) = \frac{V_{outmax}}{\mathrm{k*R1}}$$

(1.5m)

The only parameter un known in the above non linear equation in R21 , substitute rest of the values.

RHS turns out to be a constant, then sweep the R21 parameter in the range to achieve the equality.

Also a good place to start the sweep is r21=R1*(2x+2)

Value of R22,R21 - (0.5m)

Here is a desmos link plotting these curves , substitute the values of your rollnumber , R1 , q that you have assumed to evaluate R21 and R22

https://www.desmos.com/calculator/kwrbk42cdw