EE313 - ELECTRONICS II

HOMEWORK 1 REPORT

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Part 1 – Wien Bridge

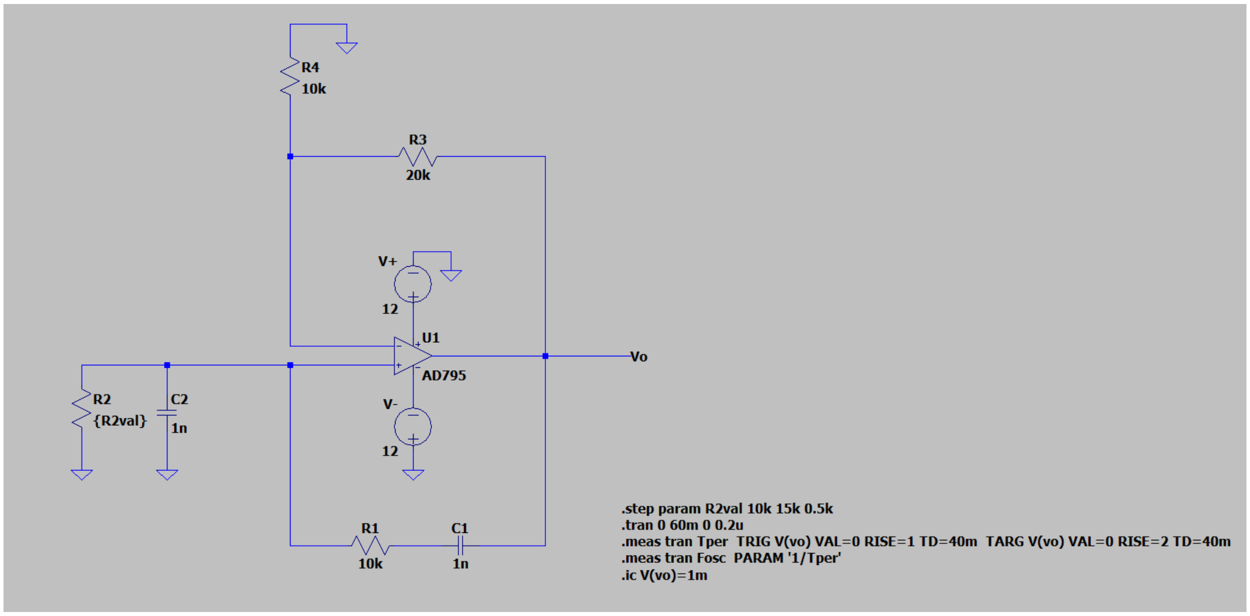


Figure 1: Wien Bridge Oscillator

The schematic in Figure 1 was driven in LTspice by using the information given in the question and values found in the calculations. The SPICE directives used in the simulation and their purpose can be explained as:

- **.step param R2val 10k 15k 0.5k:** Tells LTspice to run the simulation multiple times for the values of the parameter named 'R2val' between 10kΩ and 15kΩ in increments of 0.5kΩ. This range is specified to better compare the measured and calculated values of the oscillation frequency, as oscillations occur at all values within the selected range.
- **.tran 0 60m 0 0.2u:** Time domain analysis command with a 60 ms simulation time and a maximum time step of 0.2 µs to provide multiple points per cycle for a clean waveform.
- **.meas tran Tper TRIG V(vo) VAL=0 RISE=1 TD=40m TARG V(vo) VAL=0 RISE=2 TD=40m:** Measurement command that measures the time difference between two events to obtain the oscillation period T from the waveform. The TRIG event is the first rising edge of the V(vo) measurement at the 0V detection point after a 40 ms time delay, while the TARG event is the second rising edge under the same conditions as TRIG. It provides steady-state measurement with time delay.
- **.meas tran Fosc PARAM '1/Tper':** Measurement command that calculates the oscillation frequency from the previously measured oscillation period.

- **.ic V(vo)=1m:** Initial condition command that sets the V(vo) value to 1mV at t=0. By adding the initial voltage, it provides a disturbance to ensure that the oscillation starts reliably at each step.

After the output simulations from SPICE, the “SPICE Error Log” was opened for the results, and a table containing the oscillation frequency for each step appeared here. The collected data was also visualized with a MATLAB code that plots the calculated and measured frequency values in the same place and calculates the percentage error for each resistance value. The table seen in the “SPICE Error Log” is shown in Figure 2.

Measurement: fosc

step	(1/tper)
1	15109.2
2	14616.3
3	14231.4
4	13861.2
5	13508.1
6	13172.2
7	12853.2
8	12550.2
9	12262.3
10	11988.5
11	11728

Figure 2: “SPICE Error Log” Section

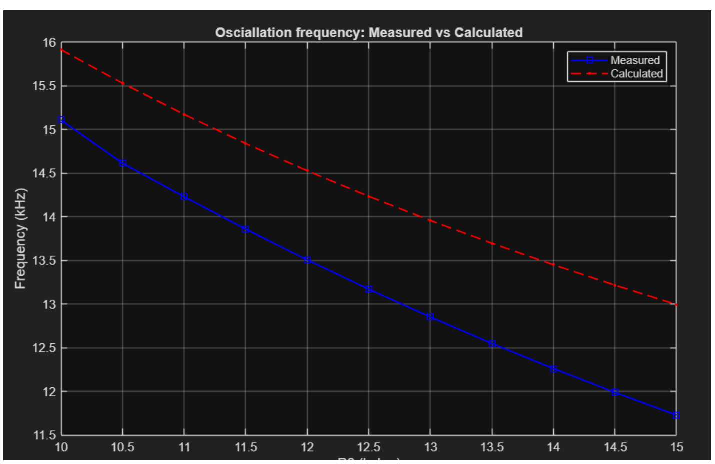


Figure 3: The comparison between measured and calculated frequency values

When we look at the table generated by Matlab (Figure 3) and calculate the error, we see that the error rates are between 5% and 10%. This error is due to the fact that while the calculation using the formula is performed under ideal conditions, the components used in the simulation are non-ideal.

Additionally, instead of using the range specified with .stem, I manually assigned resistance values of 10k, 12k, 15k and 17k ohms for R2 separately and presented the resulting oscillation graphs in Figures 4, 5, 6 and 7.

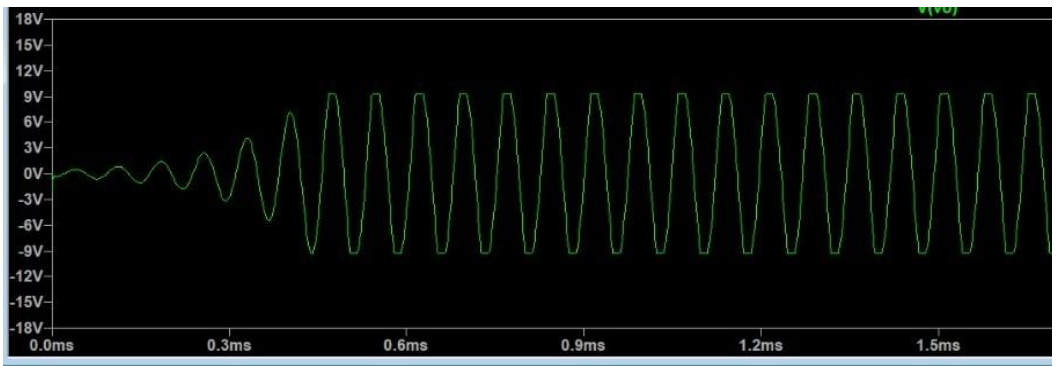


Figure 4: R2=12k ohm

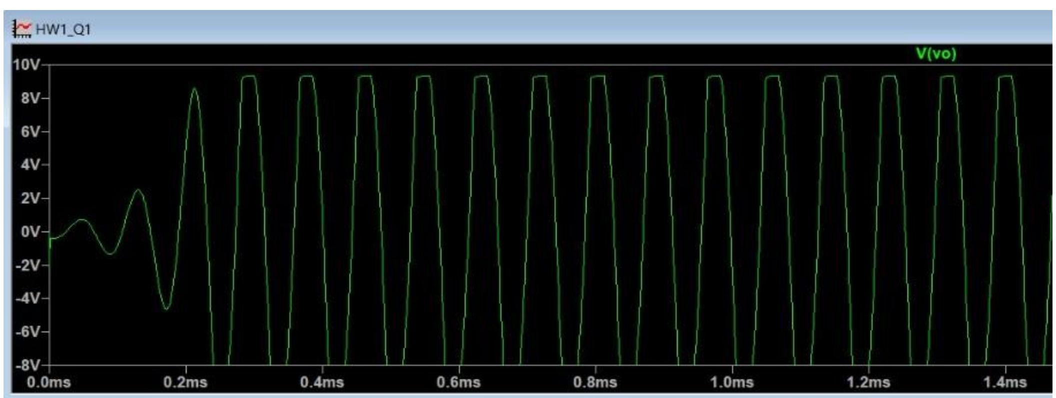


Figure 5: R2=15k ohm

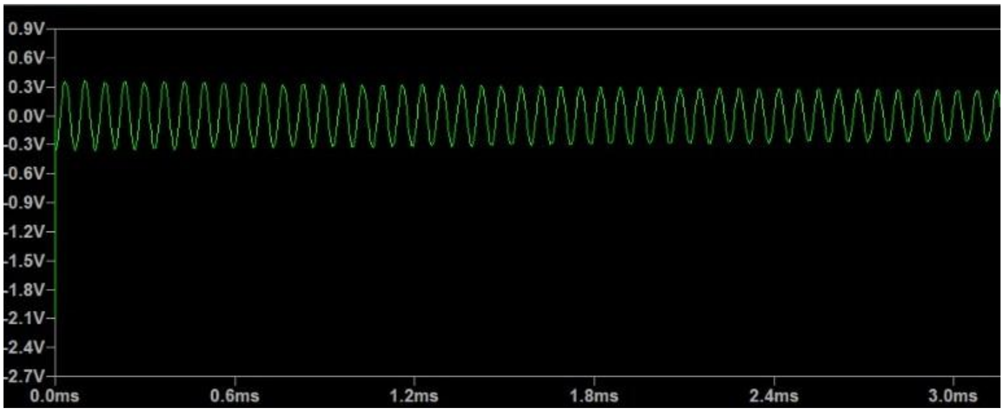


Figure 6: R2=10k ohm

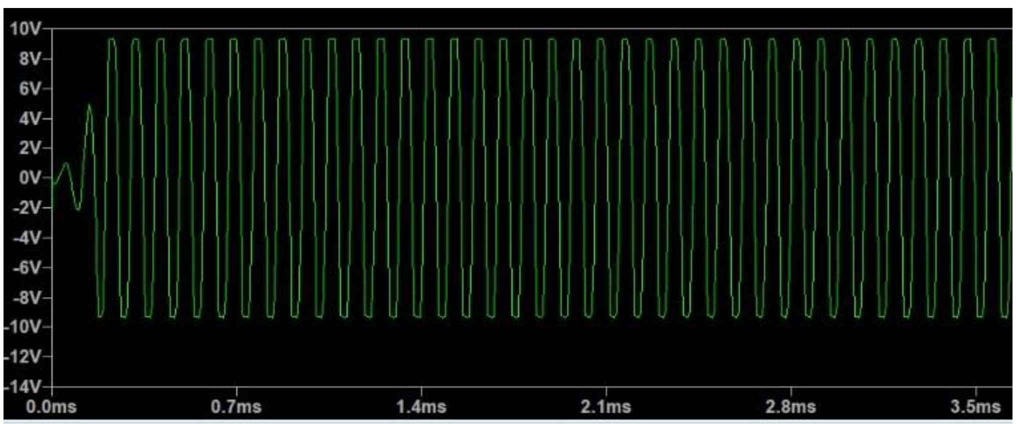
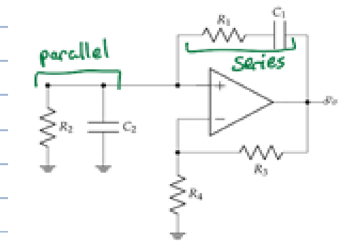


Figure 7: R2=17k ohm

A simulation was not drawn for R2 with a value below 10k because oscillation does not fully occur at those values.

Calculations

Wien- Bridge



$$T(j\omega_0) = A(j\omega_0)\,\beta(j\omega_0) = -1.$$

$$Z_S = R_1 + \frac{1}{j\omega_0 C_1} = \frac{j\omega_0 C_1 R_1 + 1}{j\omega_0 C_1} = \frac{sC_1R_1+1}{sC_1}$$

$$Z_p = \left(R_2 // \frac{1}{j\omega_0 C_2}\right) = \frac{R_2/j\omega_0 C_2}{R_2 + \frac{1}{j\omega_0 C_2}} = \frac{R_2}{j\omega_0 C_2 R_2 + 1} = \frac{R_2}{sR_2C_2+1}$$

$$\beta(j\omega_0) = \frac{V^+(j\omega_0)}{V_o(j\omega_0)} = \frac{Z_p}{Z_s+Z_p} = \frac{\frac{R_2}{j\omega R_2 C_2 + 1}}{\underset{(j\omega_0 R_2 C_2 + 1)}{\frac{j\omega R_1 C_1 + 1}{j\omega_0 C_1}} + \underset{(j\omega C_1)}{\frac{R_2}{j\omega_0 R_2 C_2 + 1}}} = \frac{(j\omega R_2 C_2 + 1)(j\omega_0 C_1)\cdot\frac{R_2}{j\omega R_2 C_2 + 1}}{(j\omega)^2 R_1 R_2 C_1 C_2 + j\omega_0 R_1 C_1 + j\omega_0 R_2 C_2 + 1 + j\omega_0 R_2 C_1}$$

$$= \frac{j\omega_0 R_2 C_1}{(1 - R_1R_2C_1C_2\,\omega_0^2) + (R_1C_1 + R_2C_1 + R_2C_2)\,j\omega_0}$$

⇒ For oscillation $\angle T(s) = \angle A(s)\beta(s) = 360° \times N$ → The gain is $A = \frac{V_o}{V^+} = 1 + \frac{R_3}{R_4}$

A has to be real and positive number so, $\angle A(s) = 0°$. For the total phase, we need $\beta(j\omega_0)$ to be real and positive so that it contributes $0°$ phase.

$$1 - R_1R_2C_1C_2\,\omega_0^2 = 0 \Rightarrow \omega_0^2 = \frac{1}{R_1R_2C_1C_2} \Rightarrow \omega_0 = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$ so, $\boxed{f_0 = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$

$f_0 = 16\times10^3\ Hz$, $C_1 = C_2 = 10^{-9}\ F$ $\Rightarrow f_0 = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \frac{1}{2\pi C\sqrt{R_1R_2}} \Rightarrow \sqrt{R_1R_2} = \frac{10^9}{2\pi\times16\times10^3} \cong 9.95\ k\Omega$

→ We assume $R_1 = R_2 = R \Rightarrow \sqrt{R_1R_2} = \sqrt{R^2} = R \cong 9.95\ k\Omega$

→ So, $R_1 = R_2 = 10k\Omega$, $f_0 = 15.9\ kHz$

⇒ $|A(j\omega_0)\beta(j\omega_0)| = 1$, $\angle A(j\omega_0)\beta(j\omega_0) = 360° \times N$ ⟶ $A(j\omega_0)\beta(j\omega_0) = 1 \Rightarrow A(j\omega_0) = \frac{1}{\beta(j\omega_0)}$

$$\beta(j\omega_0) = \frac{R_2C_1\cdot j\omega_0}{(1-R_1R_2C_1C_2\omega_0^2) + (R_1C_1+R_2C_1+R_1C_2)j\omega_0} = \frac{R_2C_1}{R_1C_1+R_2C_1+R_2C_2}$$

$$A = \frac{1}{\beta} = \frac{R_1C_1+R_2C_1+R_1C_2}{R_2C_1} = \frac{R_1C_1}{R_2C_1} + \frac{R_2C_1}{R_2C_1} + \frac{R_1C_2}{R_2C_1} \Rightarrow \boxed{A_{req} = \frac{R_1}{R_2} + 1 + \frac{C_2}{C_1}}$$

oscillation criterion

for $R_1 = R_2 = R$, $C_1 = C_2 = C$ — $A = 1+1+1 = 3$

⇒ Non-inverting amplifiers, $A = 1 + \frac{R_3}{R_4} \Rightarrow 1 + \frac{R_3}{R_4} = 3 \rightarrow \frac{R_3}{R_4} = 2 \Rightarrow R_3 = 2R_4 \xrightarrow{R_4 = 10k\Omega} \boxed{R_3 = 20k\Omega}$

Figure 8: Calculations

Part 2 – Schmitt Trigger Oscillator

The oscillation of the Schmitt trigger oscillator was analyzed by examining the relationship between the node voltages vn and vp and the threshold voltages $\pm VT$. Due to the positive feedback, the voltage at the non-inverting input is determined by the resistor divider formed by R2 and R3, which sets the switching thresholds of the circuit. The capacitor voltage vn oscillates between these threshold levels, and by equating the peak values of vn to $\pm VT$, the threshold voltage and the corresponding resistor value R3 were determined.

The oscillation period was obtained by modeling the capacitor voltage using the first-order RC charging and discharging equation. For each half-cycle, the output voltage was assumed to be constant while the capacitor voltage transitioned between $-VT$ and $+VT$. By substituting the initial and final voltage conditions into the exponential expression, the period was written in terms of the time constant τ=R1C1. Using the wanted oscillation frequency and the given capacitor value, the resistance R1 was then calculated.

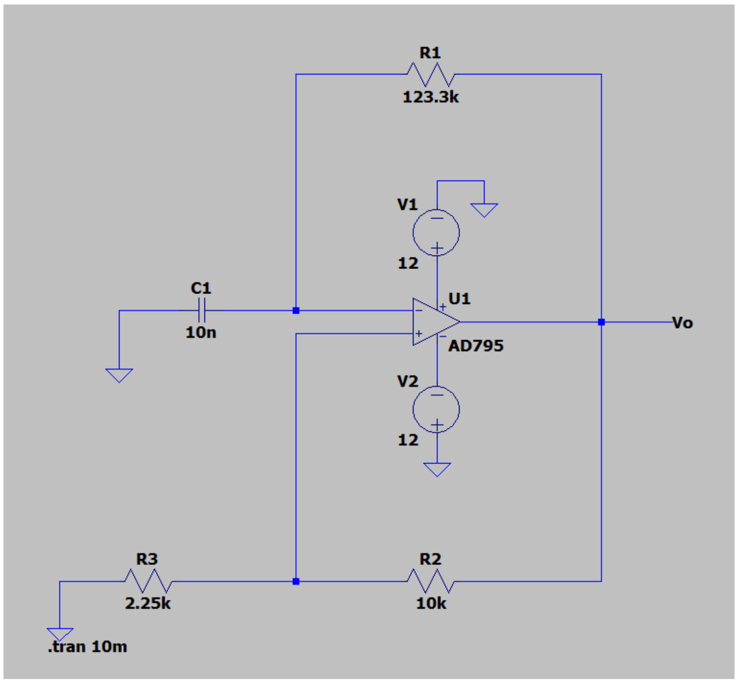


Figure 9: Schmitt Trigger Oscillator

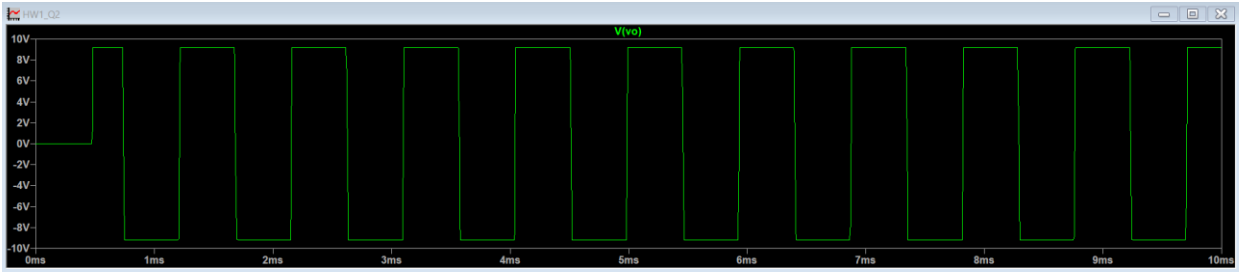


Figure 10: Simulation plot of Vo

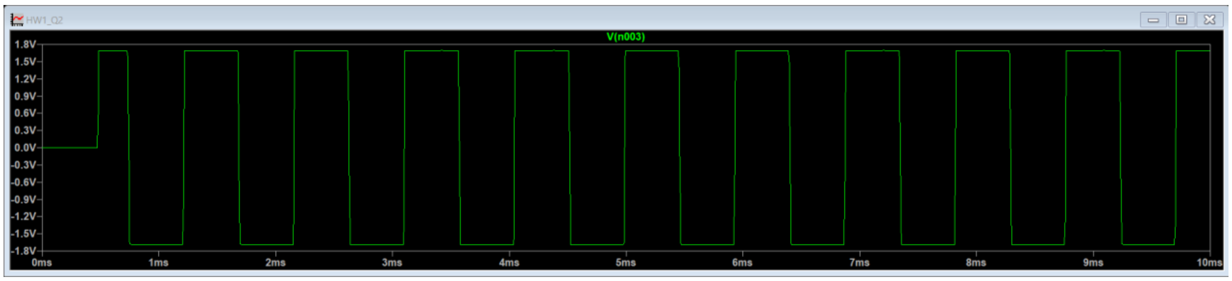


Figure 11: Simulation plot of Vp

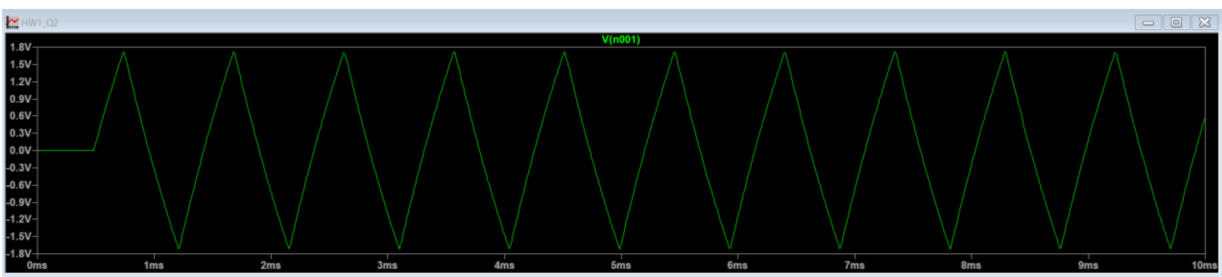
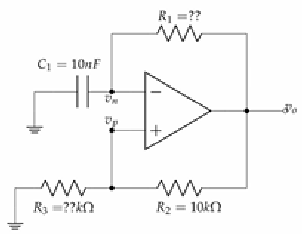


Figure 12: Simulation plot of Vn

Calculations:



→ Positive feedback through resistors R_2 and R_3 which creates two thresholds at the non-inverting input v_p.

→ RC charging and discharging of capacitor C_1 through resistor R_1, which determines the oscillation period.

$v_p = \frac{R_3}{R_2+R_3} \cdot v_o$ $\quad v_o = \mp 10V \quad v_{n,pp} = 4V = 2V_T \quad \boxed{2V = V_T}$

Schmitt trigger thresholds must be $\boxed{v_p = \pm 2V}$

Solving for R_3: $2 = \frac{R_3}{R_2+R_3} \cdot 10$, $R_2 = 10k\Omega \Rightarrow \cancel{2}^{1} = \frac{R_3}{10k\Omega + R_3} \cdot \cancel{10}^{5} \Rightarrow \frac{1}{5} = \frac{R_3}{10k + R_3}$

$10k + R_3 = 5R_3$

$\boxed{R_3 = 2.5k\Omega}$

$\tau = R_1 C_1$

$$v_n = V_{final} + (V_{initial} - V_{final}) e^{-t/\tau} = v_p + \left(-\frac{v_o}{5} - v_p\right) e^{-t/R_1C_1} = v_p - \frac{6v_p}{5} \cdot e^{-t/R_1C_1}$$

$v_n = 2 = 10 - 12 e^{-t/R_1C_1}$

$-8 = -12 e^{-t/R_1C_1}$

$\frac{t_1}{R_1C_1} = 0.4055$

$t_1 = (0.4055) R_1 C_1$

$v_n = v_L + (-2 - v_L) \cdot e^{-(t_2-t_1)/\tau}$

$-2 = -10 + (-2+10) e^{-(t_2-t_1)/\tau}$

$\cancel{8} = \cancel{8} \cdot \underbrace{e^{-(t_2-t_1)/\tau}}_{1}$

$\boxed{t_2 = t_1}$

$T = 2 \cdot (0.4055) R_1 C_1 \quad f = 1kHz \rightarrow T = 10^{-3}s$, since $C_1 = 10nF$

$10^{-3} = (0.811) R_1 (10 \times 10^{-9}) \longrightarrow \boxed{R_1 = 123304.56\Omega} \quad \boxed{\tau = R_1 C_1 = 1.23ms}$

peak values of $V_n = \pm 2V$, $V_o = \pm 10V$

Figure 13: Calculations