3EJ4 LAB FOUR

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Questions for Part 1:

Q1.

(1). Based on the simulation data obtained in Step 1.2, the low-frequency voltage gains in dB are: Ad1 = 7.38, Ad2 = 70.05, and Ad3 = 0.

(2). Based on the simulation data obtained in Step 1.2, the overall voltage gain for the differential-mode signal is Ad = 77.43 dB or Ad = 7437.8 which is the real magnitude.

(3). The non-inverting input of the operational amplifier is V2, since at low-frequency the simulated phase of the output voltage Vo is in phase with the phase offset of V2.

(4). The upper 3-dB frequency fH of the operational amplifier is approximately 6.338 kHz, and this value was determined the frequency when the phase drops by 45 degrees from its initial value.

Q2. The differential-mode gain Ad1 in Q1, 7.38 dB, is around one-tenth of the differential-mode gain Ad in Lab 3, 69.95 dB. The difference is due to feedback received by the emitters of the PNPs in the current mirror, which affects the differential amplifier's collector current at the output. A drop in voltage gain is most likely due to an increase in emitter currents.

Q3. The input resistance Rin = 81.757 kΩ and the output resistance Ro = 461 Ω are calculated using the simulated results obtained in Steps 1.2 and 1.3. This corresponds to the expected resistances for an operational amplifier, which are high input and low output.

Q4.

(1). Figure 4.1(a) and (b) shows the plots for the output voltage Vo vs. the time features at 1 KHz for the simulated and observed results from Steps 1.6 and 1.13.

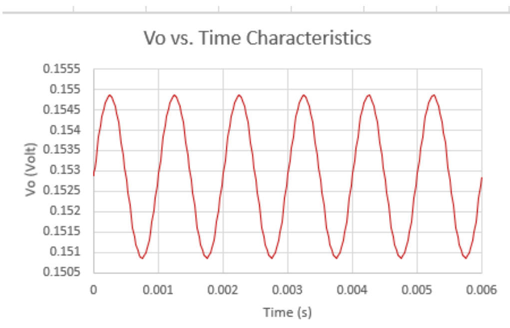

Figure 4.1(a)

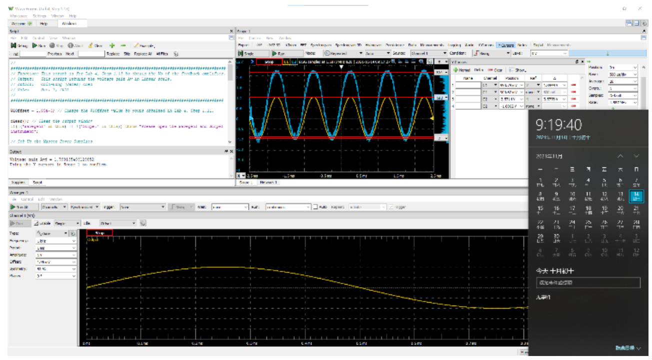

Figure 4.1(b)

(2). The computed findings have a peak to peak voltage of 40 mV, whereas the measured data have a peak to peak value of roughly 4 V. The simulated findings' AC amplitude, Vp, and DC voltages, Vdc, are 20 mV and 155 mV, respectively, but the real results' Vp and Vdc are 2 V and -15 mV. The differences in Vpp and Vp voltages can be explained by the different input AC voltages at V1. Because the measured peak to peak voltage and AC voltage are 1000 times greater than the simulated peak to peak voltage and AC voltage, the measured peak to peak voltage and AC voltage are 1000 times greater than the simulated peak to peak voltage and AC voltage. Aside than that, both sets of data have the same frequency/period and behave similarly.

Q5.

(1). Figure 5.1 exhibit plots of the simulated and observed findings for the voltage gain magnitude and phase vs. frequency characteristics from Steps 1.7 and 1.13.

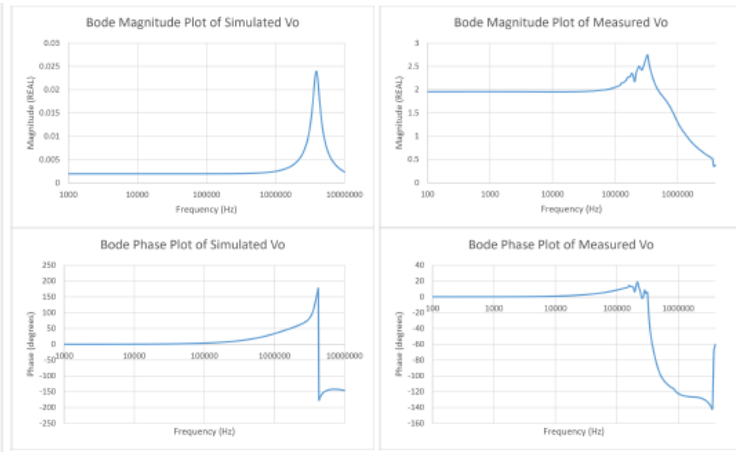

Figure 5.1

(2). In order to operate this amplifier, its highest operating frequency to provide a constant gain as design is about 100 kHz according to the measurement.

Q6.

A series-shunt feedback configuration is used in the circuit. The input is connected in series to the directional amplifier, whilst the output provides feedback to the differential amplifier, resulting in a shunt connection.

Q7.

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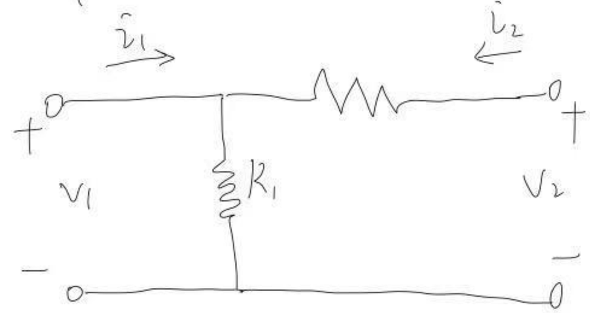
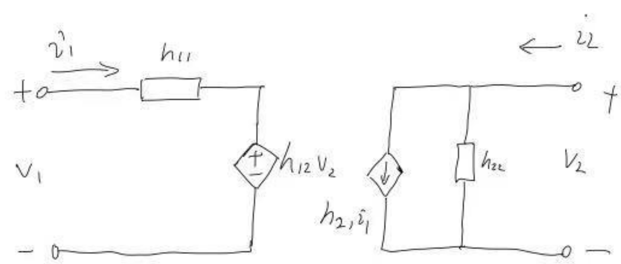
Q7. β network:



use h-parameters



$$\begin{cases} V_1 = h_{11} i_1 + h_{12} V_2 \\ i_2 = h_{21} i_1 + h_{22} V_2 \end{cases}$$

$$R_{11} = h_{11} = \frac{v_1}{i_1}\Big|_{V_2=0} = R_1 // R_2 = 100k // 100k = 50k\Omega$$

$$R_{22} = \frac{1}{h_{22}} = \frac{V_2}{i_2}\Big|_{i_1=0} = R_1 + R_2 = 100k + 100k = 200k\Omega$$

$$\beta = h_{12} = \frac{v_1}{v_2}\Big|_{i_1=0} = \frac{R_1}{R_1+R_2} = \frac{100k}{100k+100k} = 0.5$$

Q8.

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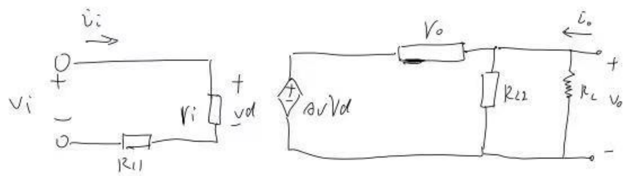
Q8. Disconnect the β network from A network



$$r_i' = r_i + R_{11} = 81757.3\,\Omega + 50k\Omega = 131.76k\Omega$$

$$r_o' = R_L \,//\, R_{22} \,//\, r_o = 240k\Omega \,//\, 200k\Omega \,//\, 461\,\Omega = 459\,\Omega$$

$$A_v' = \frac{V_o}{V_i} = A_v \cdot \frac{r_i}{r_i + R_{11}} \cdot \frac{R_{22}//R_L}{r_o + R_{22}//R_L} = 7437.8 \times \frac{81.757}{131.76} \cdot \frac{200k\,//\,240k}{200k//240k + 461\,\Omega} = 4596\,V/V$$

$$\therefore r_{if}' = r_i'(1 + A_v'\beta) = 131.76k\,(1 + 4596 \times 0.5) = 303\ M\Omega$$

$$r_{of}' = r_o' / (1 + A_v'\beta) = 459 / (1 + 4596 \times 0.5) = 0.2\,\Omega$$

$$A_{vf}' = \frac{A_v'}{1 + A_v'\beta} = \frac{4596}{1 + 4596 \times 0.5} \approx \frac{1}{0.5} = 2V/V$$

$$\therefore R_i = r_{if}' - R_s = 303M - 0 = 303\,M\Omega$$

$$R_o = \frac{1}{\frac{1}{r_{of}'} - \frac{1}{R_L}} = \frac{1}{\frac{1}{0.2} - \frac{1}{240k}} = 0.2\,\Omega$$

$\therefore$ In conclusion, $A_{vf}' = 2V/V$, $R_i = 303\,M\Omega$, $R_o = 0.2\,\Omega$.

Questions for Part 2:

Q9.

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Q9. $\because C = C_1 = C_2$ and $R = R_3 = R_4$

$$V_o = V_+\left(1+\frac{1}{sCR}\right) + R V_+\left[\frac{1}{R} + sC\left(1+\frac{1}{sCR}\right)\right]$$

$$= V_+\left(1+\frac{1}{sCR}\right) + V_+(2+sCR)$$

$$= V_+\left(3+\frac{1}{sCR}+sCR\right)$$

$$\Rightarrow \frac{V_+}{V_o} = \frac{s/CR}{s^2+s\left(\frac{3}{CR}\right)+\left(\frac{1}{CR}\right)^2} \qquad \therefore L(s) = \left(1+\frac{R_2}{R_1}\right)\frac{s/CR}{s^2+s\frac{3}{CR}+\left(\frac{1}{CR}\right)^2}$$

$\therefore$ The zero loop phase frequency ω_0 is $\omega_0 = \frac{1}{CR}$. At the zero loop phase frequency, $|L(j\omega)| = \frac{1}{3}\left(1+\frac{R_2}{R_1}\right)$, therefore for oscillation we require $\frac{1}{3}\left(1+\frac{R_2}{R_1}\right) \geq 1$ which occurs when

$\frac{R_2}{R_1} \geq 2$.

Q10.

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Q10. The characteristic equation of the system is $1-L(s) = 1-\left(1+\frac{R_2}{R_1}\right)\frac{s/CR}{s^2+s\frac{3}{CR}+\left(\frac{1}{CR}\right)^2} = 0$. To find the pole Q, we can convert $L(s)$ into the frequency domain, can find that $L(j\omega) = \frac{j\omega\left[\frac{1+R_2/R_1}{CR}\right]}{\left[\left(\frac{1}{CR}\right)^2-\omega^2\right]+j\frac{3\omega}{CR}}$

From the equation, we see that the value of $R_2/R_1 = 2$ will give us $j\frac{3\omega}{RC}$ in both the numerator and denominator, leaving us with $-\omega^2-\left(\frac{1}{CR}\right)^2$ or a pole Q at $\left(\frac{1}{CR}\right)^2$ due to the Barkhausen Criterion.

Q11.

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Q11. The settling times for $R_2 = 220\,k\Omega$, $240\,k\Omega$ and $280\,k\Omega$ are approximately 2.51ms, 1.4ms and 0.63ms. The settling time decreases as the value of R_2 increases. This behaviour is due to the loop gain $L(s)$ (from Q9) increasing as the value of R_2 increases, decreasing the amount of time the oscillator circuit requires to reach saturation |5V|

Q12.

(1).

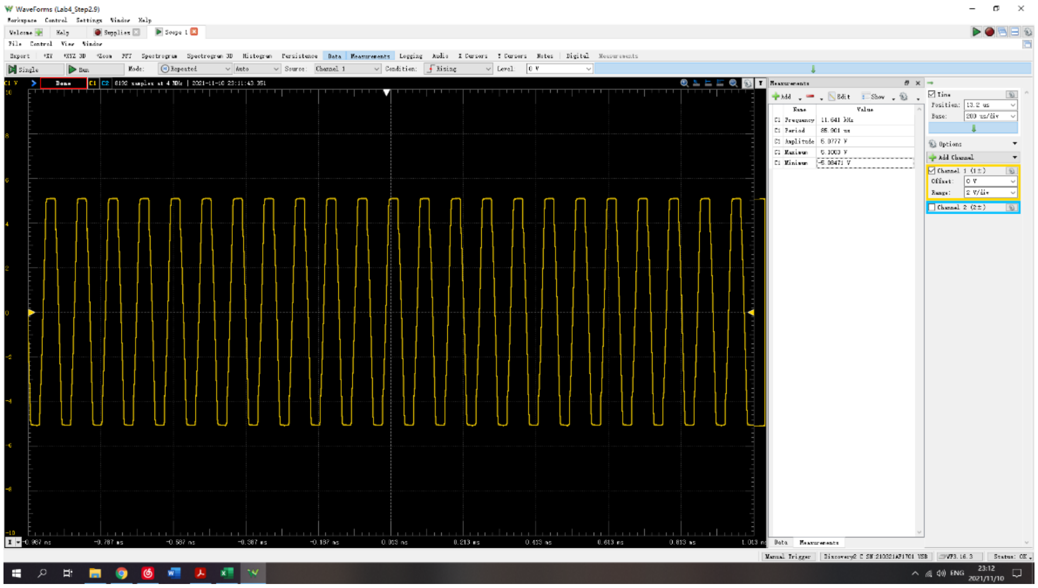

Fig 12.1(Screenshot for 2.9)(measured data)

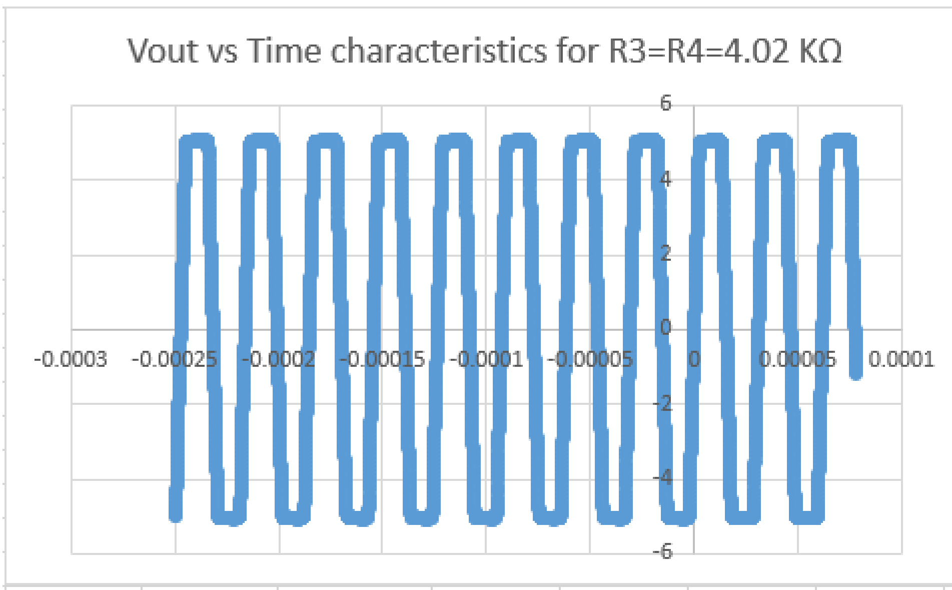

Fig 12.2(Screenshot for 2.10)(measured data)

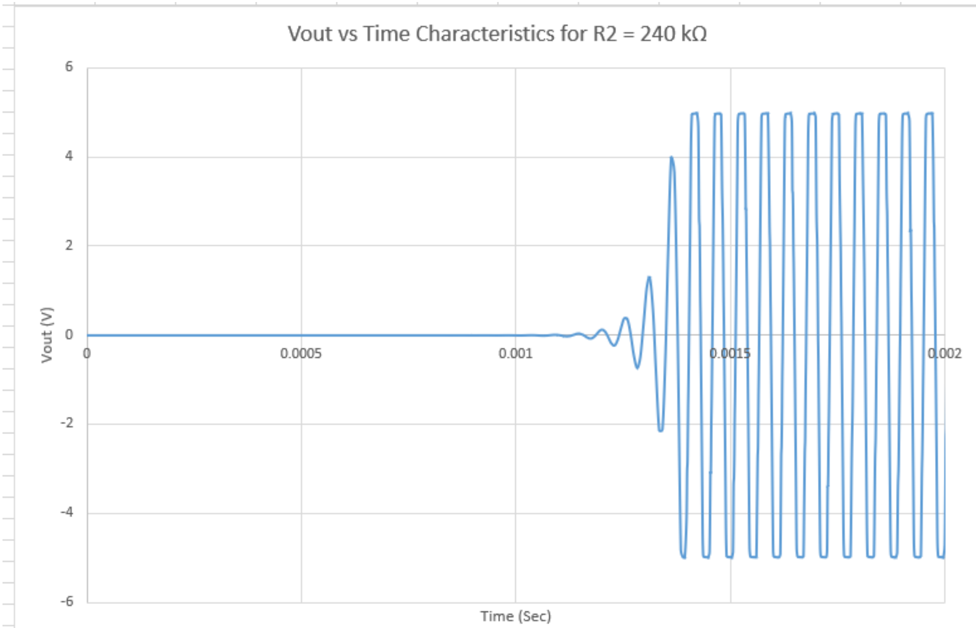

Fig 12.3(simulated data)

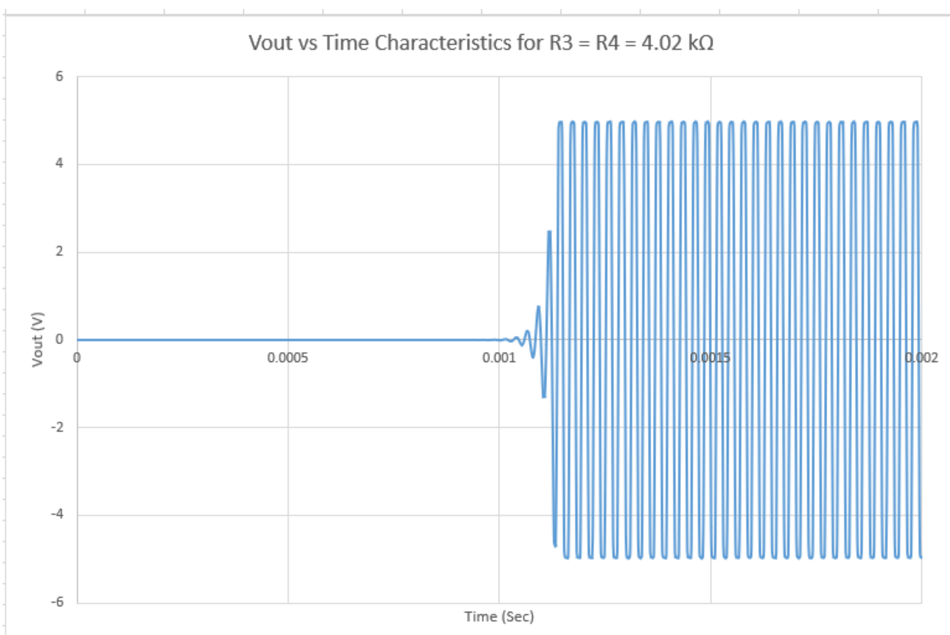

Fig 12.4(simulated data)

(2).

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Q12 (2)

The frequencies in step 2.4 (simulated) was found to be approximately 17.5 kHz, while the frequencies in step 2.9 (measured) was found to be approximately 11.641 kHz. The difference between simulated data and measured data is due to some errors in measurement.

However, for the frequencies in step 2.6 (simulated) and 2.10 (measured) were found to be to approximately 33 kHz. This matches the expected results from theory, as the frequency is inversely proportional to the values of R and C.

Thus, if I decrease the value of R to half its value, then it nearly doubles the frequency of the oscillations.