Lab 1 - Solutions

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Prelab questions:

1.1 a) $V_{out} \approx -Ae^{\frac{qV_{in}(t)}{\eta kT}}$, $I = I_0\left[\exp\left(\frac{qV_D}{\eta kT}\right)-1\right]$

$$\Rightarrow I_{in} = I = I_0\left[\exp\left(\frac{qV_D}{\eta kT}\right)-1\right] \approx I_0\exp\left(\frac{qV_D}{\eta kT}\right)$$

(Since heavily forward biased)

- This same current flows through R_2, so:

$$V_{out} = -I_{in}R_2 = -I_0 R_2\exp\left(\frac{qV_{in}(t)}{\eta kT}\right)$$

- Therefore it is clear to see that $A = I_0 R_2$

b) $V_{in}(t) = V_{in-DC} + V_{in-1}\cos(\omega t)$

$$\Rightarrow V_{out}(t) = -R_2 I_0\exp\left(\frac{qV_{in}(t)}{\eta kT}\right)$$

$$= -R_2 I_0\exp\left(\frac{q(V_{in-DC}+V_{in-1}\cos(\omega t))}{\eta kT}\right)$$

$$= -R_2 I_0\exp\left(\frac{qV_{in-DC}}{\eta kT}\right)\exp\left(\frac{qV_{in-1}\cos(\omega t)}{\eta kT}\right)$$

→ Useful expansion: $e^{a\cos(b)} = I_0(a) + 2\sum_{n=1}^{\infty} I_n(a)\cos(nb)$

$$\Rightarrow V_{out}(t) = -R_2 I_0\exp\left(\frac{qV_{in-DC}}{\eta kT}\right)\left[I_0\left(\frac{qV_{in-1}}{\eta kT}\right) + 2\sum_{n=1}^{\infty} I_n\left(\frac{qV_{in-1}}{\eta kT}\right)\cos(n\omega t)\right]$$

$$\Rightarrow V_{out-DC} = -R_2 I_0\exp\left(\frac{qV_{in-DC}}{\eta kT}\right)I_0\left(\frac{qV_{in-1}}{\eta kT}\right)$$

$$V_{out-n} = -2R_2 I_0\exp\left(\frac{qV_{in-DC}}{\eta kT}\right)I_n\left(\frac{qV_{in-1}}{\eta kT}\right)$$

* I_0, I_n are sol'ns to the modified Bessel func. of the 1st kind

c) $V_{in-DC} = 400\,mV$, $V_{in-1} = 100\,mV$, $\eta = 1.8$, $\frac{kT}{q} = 25.8\,mV$

Plugging in values yields:

$n=2$ case: ≈ -6.78 dB

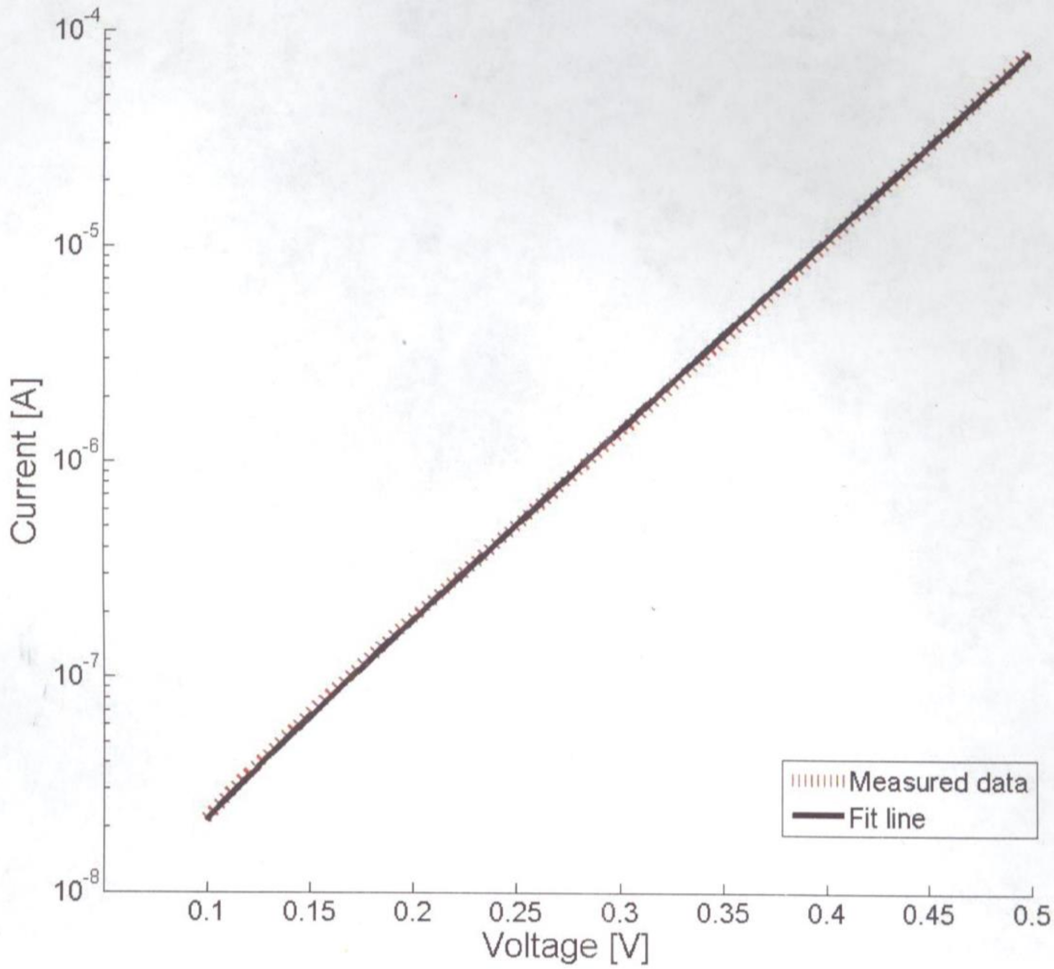
$n=3$ case: ≈ -16.58 dB

$n=4$ case: ≈ -28.39 dB

$n=5$ case: ≈ -44.87 dB

← Calculation of values straight-forward from work in part b)

Question 1.5:

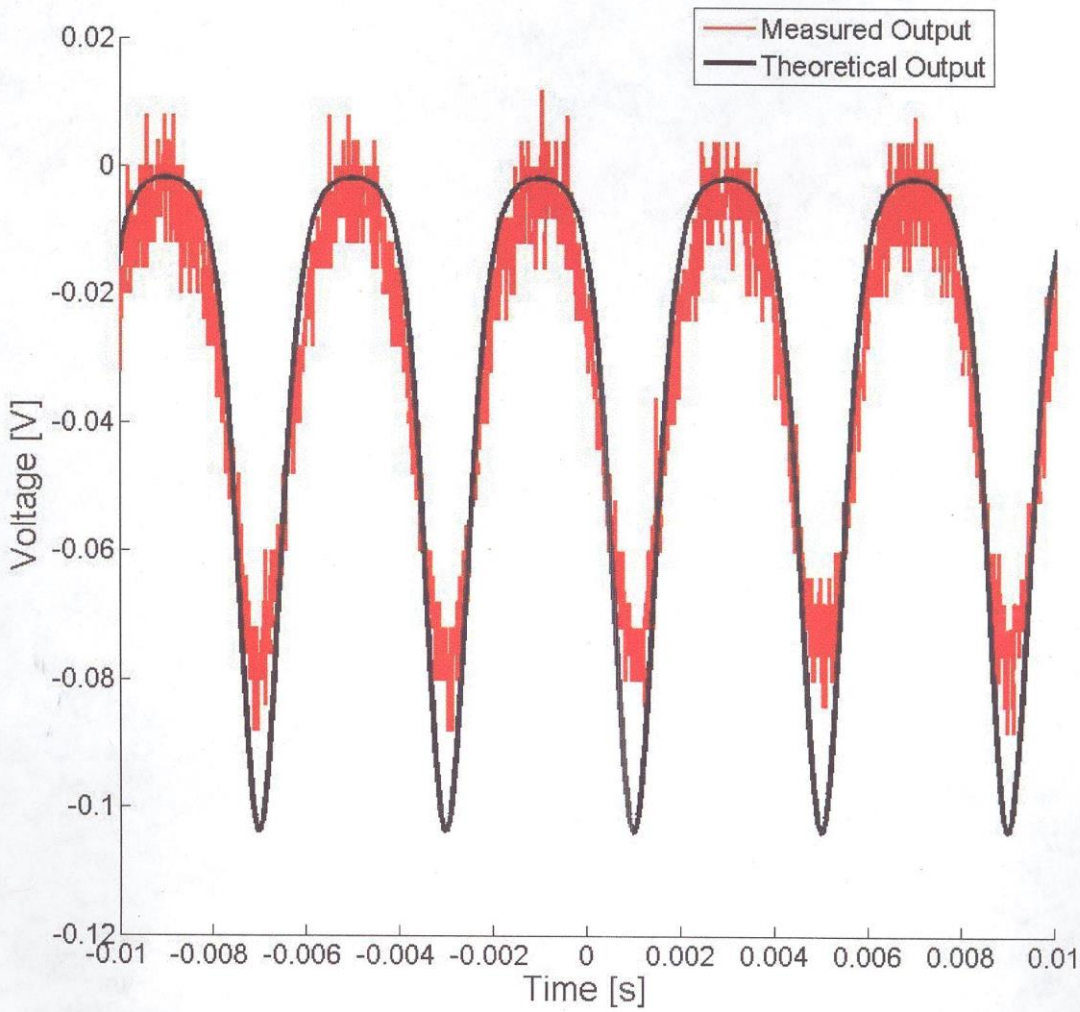


Fitting parameters:

$I_0 = 3.3 \times 10^{-9}$ A

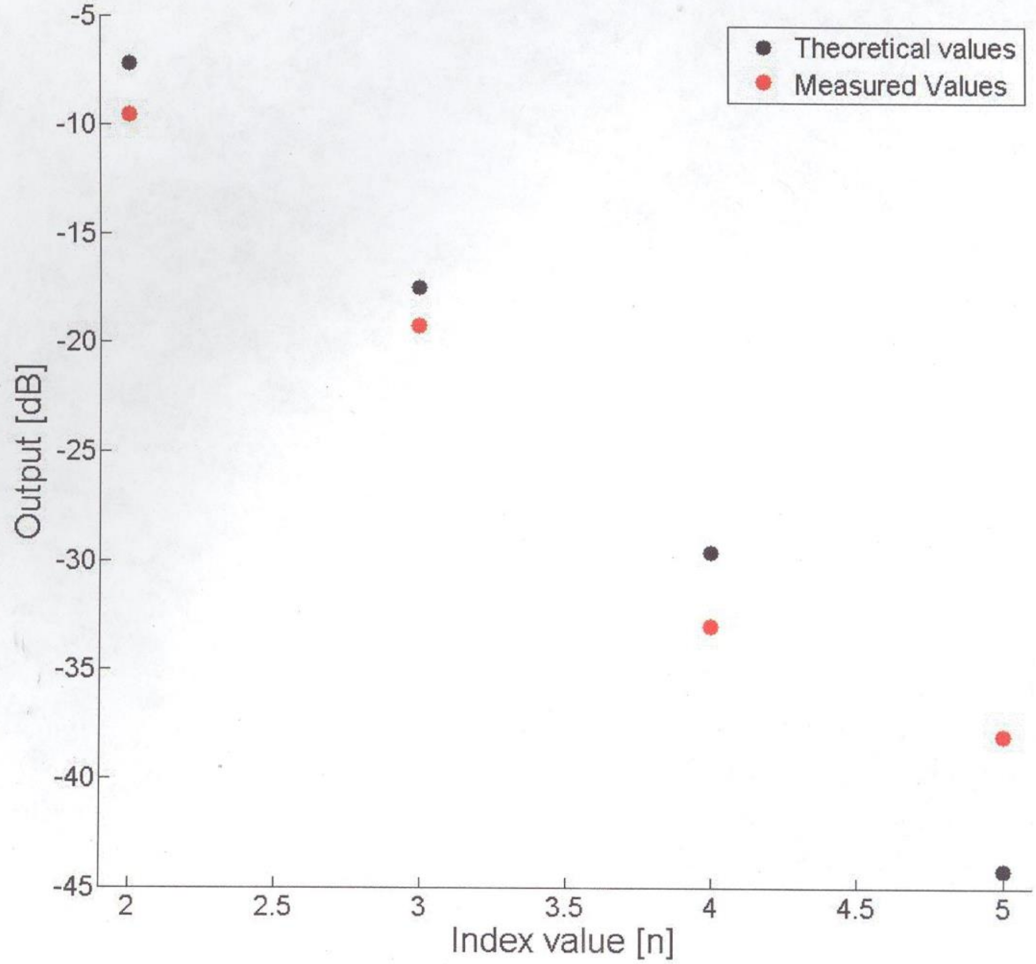
$\eta = 1.92$

Question 1.6:



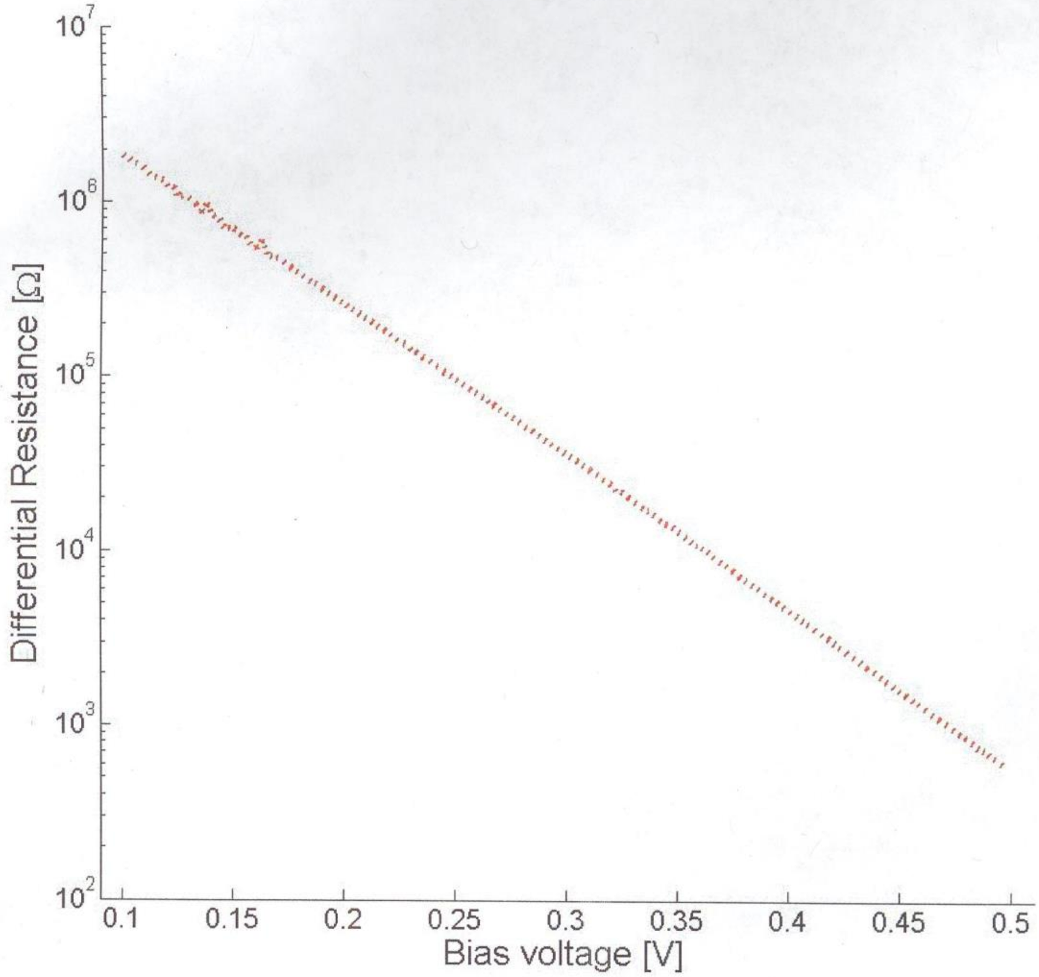
Measured Output
Theoretical Output
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
Voltage [V]
-0.01
-0.008
-0.006
-0.004
-0.002
0
0.002
0.004
0.006
0.008
0.01
Time [s]

Question 1.7:



Theoretical values were generated the same way they were in the pre-lab portion 1.3 of this lab, only now the ideality factor you measured from post-lab portion 1.5 should be used in the calculation. The measurement of index n=5 will likely not agree with your theoretical prediction as at this harmonic the noise begins to overwhelm the signal.

Question 1.8:



The differential resistance I measured at the bias point of 400 mV was around 4.6 kΩ. Measured values should be reasonably close given a measured diode ideality value close to 1.92.

Question 1.9 :

a) In making a small circuit model of the exp. amplifier one should realize that within the small signal regime the device is essentially behaving entirely linearly, thus the small signal voltage gain is given by the familiar ideal op-amp (inverting) voltage gain expression:

$$V_{out} = \frac{-R_2}{r_d} V_{in}$$

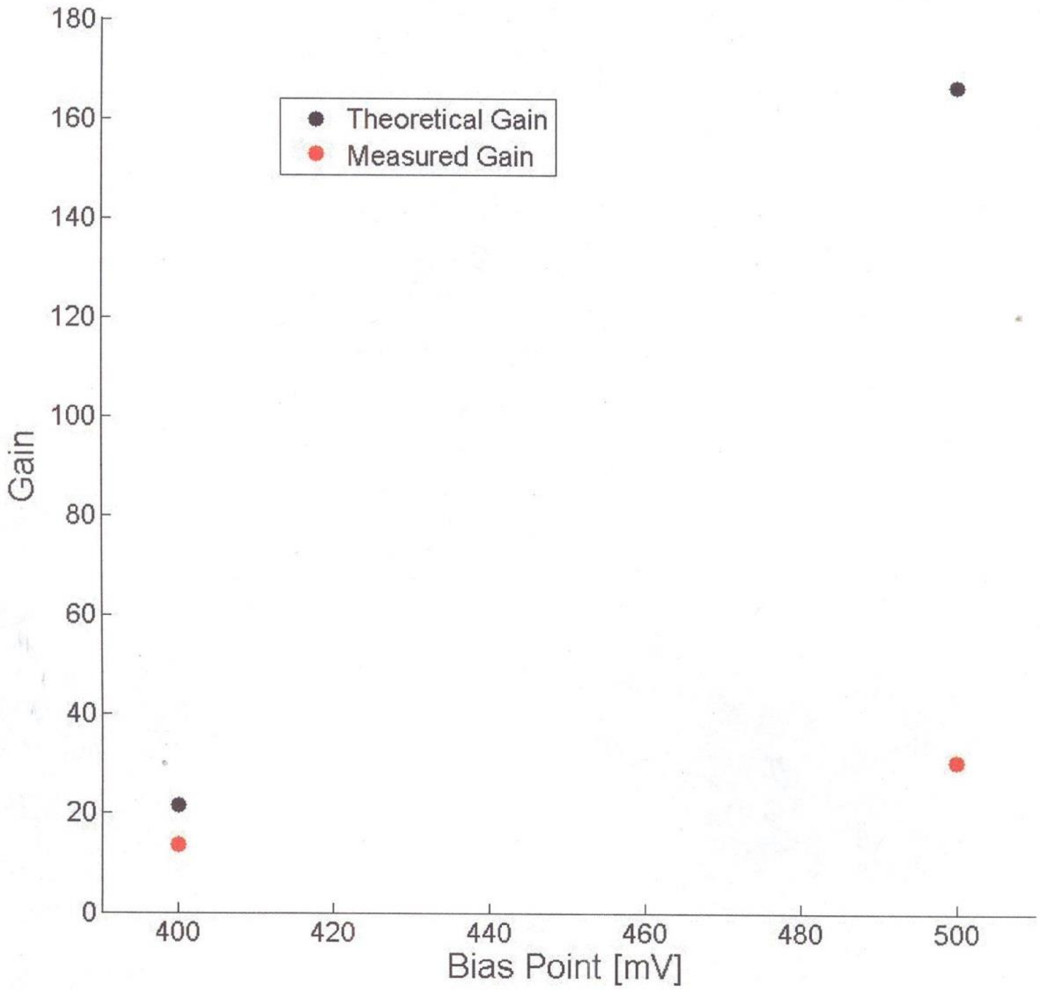
where r_d is the differential resistance of the diode (calculated in section 1.8)

$$\Rightarrow \frac{V_{out-1}}{V_{in-1}} = -\frac{R_2}{r_d}$$

$$\Rightarrow A_v = -\frac{R_2}{r_d}$$

b) plot found on next page

Question 1.9 b):



My measured gain for the 500 mV case was very far from the theoretical value. I think this will be a common problem as both the output and input were very small and noisy in these small signal measurements. It is good just to realize that as the bias is increased, the gain should increase as well since the differential resistance decreases with increasing bias (question 1.8). Exact theoretical values will vary between students as different differential resistance curves were measured.