1) (9 Points)
Consider a typical 4 terminal black box with two inputs and two outputs as shown in Figure 1. Design a simple RC filter circuit using only one resistor and one capacitor that, when put into the black box, results in the following characteristics at the frequencies $f$ indicated:

- $Z_{in}|_{f=0} = \infty$ (no load attached)
- $Z_{in}|_{f=\infty} = 1 \text{k}\Omega$ (no load attached)
- $Z_{out}|_{f=0} = 1 \text{k}\Omega$ (with an ideal voltage source connected to the input)
- $Z_{out}|_{f=\infty} = 0$ (with an ideal voltage source connected to the input)
- $\left| \frac{V_{out}}{V_{in}} \right|_{f=\infty} = 1$
- $\left| \frac{V_{out}}{V_{in}} \right|_{f=\text{kHz}} = \frac{1}{\sqrt{2}}$

In your drawing, clearly label the values for all the components.

2) (9 Points)
For the circuits in Figures 2, 3 and 4 calculate $V_x$ (with respect to ground.) You may assume that the diode forward voltage drop, $V_{Diode\text{ON}} = 0.6V$. 
3) (7 Points)
The modified common emitter amplifier circuit, shown in the figure on the right, suffers from a large dependence on the transistor’s $\beta$. Relying on the assumption that the transistor has a $\beta$ close to 100, the components for the circuit were selected to produce a quiescent output voltage of 8 V to give the amplifier its largest dynamic range (the maximum amplification that can be achieved without distorting the output signal). Unfortunately, after building the circuit it was found to have quiescent output voltage of only 2 V (making the dynamic range substantially smaller than planned). Based on that information, what was the “real” $\beta$ of the transistor?

Assume that the transistor operates in its unsaturated regime and that the transistor has a base-emitter drop of 0.6 V. You may use appropriate approximations; i.e., if your results are accurate to within 10%, i.e., $\beta + 1 \cong \beta$, and the methods are appropriate, you get a full credit.

a) First calculate the quiescent collector current, $I_C$ given that $V_{out} = 2.0$ V.

b) What is the actual $\beta$ of the transistor if the quiescent output voltage, $V_{out} = 2.0$ V? (Hint: What can be calculated easily after you get the collector current? Then what?)
1) Since \( \frac{|V_{out}|}{|V_{in}|} \leq 1 \) it is a lowpass filter with \( f_{-3dB} = 1000 \text{ Hz} \).

\[
\text{Since } \frac{|V_{out}|}{|V_{in}|} = \frac{1}{\sqrt{2}},
\]

\[
f_{-3dB} = \frac{1}{2\pi RC} = 1000
\]

Since \( Z_{in} \mid_{f = a} = 1k \Omega \) \( R = 1k \Omega \) so-

\[
C = \frac{1}{2\pi RF} \approx 160 \text{ nF}
\]

(Note all \( Z_{in}, Z_{out} \) requirements are met!)

2) \( I_1 = \frac{\Delta V}{R} = \frac{8V - (-2V)}{1k + 9k} = 1 \text{ mA} \)

\[
V_x \text{ so } V_x = 8V - I_1 R,
\]

\[
= 8V - (1 \text{ mA})(1k) = 7V
\]

For Figure 3, note since \( V_x > \text{ GND} \),

diode is reverse biased, i.e., has

no bearing on \( V_x \). Therefore,

Figure 3: \( V_x = 7V \)

For Figure 4, since \( V_x > \text{ GND} \),

diode is forward biased, forcing

\[
V_x = V_{GND} + V_{diveon} = 0.6V
\]
3)

a) \[ I_C = \frac{V_{CC} - V_{Out}}{R_C} \]

\[ = \frac{15V - 2V}{10k} = \frac{13V}{10k} = 1.3 \text{ mA} \]

5) Find \( \beta \):

since \( I_C \approx I_E = 1.3 \text{ mA} \)

\[ V_E = R_E I_E = 1.3 \text{ V} \]

\[ V_B = V_E + 0.6 \text{ V} = 1.9 \text{ V} \]

\[ I_B = \frac{V_{CC} - V_B}{R_B} = \frac{15V - 1.9V}{2M} = \frac{13.1V}{2M} \]

\[ = 6.55 \mu A \]

finally \( \beta I_B = I_C \)

\[ \beta = \frac{I_C}{I_B} = \frac{1300 \mu A}{6.55 \mu A} \approx 200 \]