Please be sure to show all work, keep it neat and readable, if I can't find your answer or follow your derivation I can't give credit. Partial credit will be given if I can figure out what you are thinking...Please use this sheet for your calculations if you need extra room use the backside.

Note: If assuming a diode or Transistor junction is forward biased and on, assume that the forward biased voltage drop is 0.7 V.

1) For the following circuit calculate the effect of:

![Circuit Diagram]

a) Finite input offset current of the non-ideal opamp (Io), on Vout.

\[ V_+ = I_o R_1 \]
\[ V_- = I_o R_1 \]
\[ I_{R2} = I_o \frac{R_1}{R_2} \]
\[ I_{R3} = I_o + I_o \frac{R_1}{R_2} \]
\[ V_c = V_- + V_{R3} \]
\[ = I_o R_1 + (I_o + I_o) \frac{R_1}{R_2} R_3 \]
\[ = I_o \left[ R_1 + R_3 + \frac{R_1 R_3}{R_2} \right] \]
b) The amplifier above is intended to operate over the entire audio band (50Hz-20,000Hz). If the slew rate limit of the opamp is one megavolt per second what is the largest amplitude audio signal (amplitude, as in $A \sin(\omega t)$) that the amplifier above can handle without distortion from this effect.

$$V(\omega t) = A \sin(\omega t)$$
$$|\frac{dV}{dt}| = |\omega A \cos(\omega t)|$$
$$|\frac{dV}{dt}|_{\text{max}} = \omega A_{\text{max}}$$

so
$$10^6 = \omega_{\text{max}} A$$

$\omega_{\text{max}}$ is $20,000$Hz x $2\pi$

$$A = \frac{10^6}{2\pi \cdot 2\times10^4} \approx 7.95 \text{ V}$$

c) Assuming the unity gain bandwidth of the opamp is 0.2 MHz what is the transfer function and -3dB bandwidth of the resulting amplifier above. Assume that $R_1=100\Omega$, $R_2=1000\Omega$, $R_3=4000\Omega$ and $R_L=1000\Omega$.

1. **Find Gain**

$$I_{R_3} = \frac{V_o - V_{in}}{R_3} = I_{R_2} = \frac{V_{in}}{R_2}$$

so
$$\frac{V_o}{R_3} = V_{in}\left(\frac{1}{R_2} + \frac{1}{R_3}\right)$$

finally
$$\frac{V_o}{V_{in}} = 1 + \frac{R_3}{R_2} = 5 \leftarrow \text{Gain}$$

2. **Find Bandwidth**

$$GBW = 2\times10^5 = 5 \Delta f$$

$\Rightarrow \Delta f = 40,000$Hz

-3dB Bandwidth

3. **Transfer Function**

$$A(f) = \frac{5}{1 + j\frac{f}{4\times10^4}}$$
d) What is the maximum phase shift through this amplifier over its design bandwidth (the audio band).

\[ \Delta A(s) = -\tan^{-1} \frac{f}{4 \times 10^4} \]

This is maximum at the highest frequency of 20,000 Hz

\[ = -\tan^{-1} \frac{20,000}{40,000} \]

\[ = -26.6^\circ \text{ or } 0.464 \text{ rad.} \]
2) a) For the circuit below find the current through the diode.

\[ I_R - V_d = 2R_I_d \]
\[ I_d = \frac{I_R - V_d}{2R} \]
\[ = \frac{10mA}{300} - 0.7 \]
\[ = 3.83 mA \]

Easiest using mesh analysis
Let \( R = 320 \Omega \)

For \( I_d \) loop
\[ -I_d R - V_d + (I-I_d)R = 0 \]

b) Now repeat the calculation assuming the measured diode I-V characteristic shown below.

\[ V_d = 0.88V \]

\[ I_d = 3.7mA \]

Solve using load line analysis.

1. Find Thévenin Equivalent of the network seen by the diode.

\[ V_{oc} = 10mA \times 300 \Omega = 3V \]

2. Equivalent Circuit

\[ \text{Diode current is equal to the load current @ } I_d = 3.7mA \text{, } V_d = 0.88V \]

3. Draw load line on the diode I-V curve.

\[ R_m = \frac{V_{oc}}{I_d} = 666 \Omega \]
c) Fill in the “rule of thumb” table below to indicate using arrows (up for an increase down for a decrease sideways for no change) how each of the quantities across the top changes as the quantity in the left column is *increased*.

<table>
<thead>
<tr>
<th></th>
<th>Current through the diode</th>
<th>Voltage across R2</th>
<th>Total Power dissipated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current source I</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>R3</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Diode Junction Area</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
3. For the transistor bias circuit shown below find the maximum value that the transistor $\beta$ can have before the transistor goes into saturation.

\[ V_{be} = 0.7 \text{V} \]

Transistor enters saturation when $V_c = V_{be}$ ($V_{bc} = 0$) when heavily saturated $V_c = 0.2 \text{V}$

Assume $V_{bc} = 0$.

\[ V_c = V_{cc} - R_c I_c \]

Need $I_c$

\[ I_c = \beta I_b \]

So

\[ V_c = V_{cc} - R_c \beta I_b \]

For $V_c = 0.7 \text{V}$

\[ 0.7 = 5 - 5000 \times 10 \times 10^{-6} \beta \]

\[ \beta_{\text{max}} = \frac{4.3}{0.05} = 86 \]

\[ 4.8 = 0.05 \beta \]

\[ \beta_{\text{max}} = 96 \]

Moral of the story: Bad circuit because $\beta$ changes can easily throw this into saturation.
4) Draw the midband small signal equivalent circuit for the following. Assume $V_{cc} > 0$, $V_{ee} < 0$ and that the transistor is biased in the forward active region.

b) Simplify your circuit as much as possible by combining components etc. Give the values of the circuit elements in your simplified schematic in terms of the original circuit quantities given above.