Electronics
EECE2412 — Spring 2013
Exam #1

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Name: Solutions : Row # ______ : Seat # ______

General Rules:

- Write your name, row number, and seat number above. Row #1 is at the front. Seat #1 is to the left as viewed by the students.
- You may make use of one sheet of notes, 8.5–by–11 inches, using both sides of the page.
- You may use a calculator.
- Present your work as clearly as possible. I give partial credit if I can figure out that you know what you are doing. I do not give credit for putting down everything you know and hoping I will find something correct in it.
- Each question has a vertical black bar providing space for your work and a box for numerical answers. Please write your answer to each question clearly. If it happens to be correct, I give you points quickly and move on to the next problem. Please show your work in the space provided, or on extra pages, clearly labeled with the problem number. If the answer is wrong, this will make it easy for me to find ways to give you partial credit.
- Avoid any appearance of academic dishonesty. Do not talk to other students during the exam. Keep phones, computers, and other electronic devices other than calculators secured and out of reach.

1 Operational Amplifiers

The figure below shows an operational amplifier circuit with two inputs. Consider the case where

$$R_A = 1 \text{ kOhm} \qquad R_B = 4 \text{ kOhm} \qquad R_F = 20 \text{ kOhm} \tag{1.1}$$

and the power supply voltages are

$$V_{supply} = \pm 12 \text{ Volts.} \tag{1.2}$$

The amplifier has a bandwidth of 1 MHz at unity gain, and an open–circuit voltage gain of 10^5.

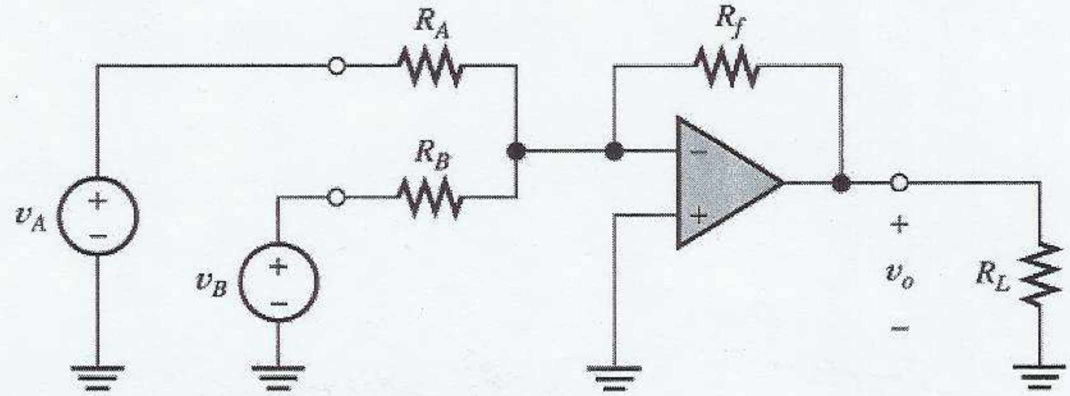


Figure from Hambley, *Electronics, 2nd Ed.*

1.1 Gain

What is the voltage gain in decibels for each input?

$A_v = -\frac{R_2}{R_1}$ $\quad -\frac{R_f}{R_A} = -\frac{20{,}000}{1000} = -20$

$20\log_{10}(20) = 26\text{ dB}$

$20\log_{10}(5) = 14\text{ dB}$ $\quad -\frac{R_f}{R_B} = -\frac{20{,}000}{4{,}000} = 5$

Gain for Input A: 26 dB   Gain for Input B: 14 dB dB

1.2 Saturation

What input voltage will cause saturation of this amplifier on Input A?

$V_{out} = 12\text{ V}$ $\quad \frac{V_{out}}{|A_v|} = \frac{12\text{ V}}{20} = 0.6\text{ V}$

600 mV ✓

1.3 Bandwidth

What is the bandwidth of each channel?

$A_v f_B = 1 * 10^6 Hz$

$10^6 Hz / 20$ $10^6 Hz / 5$

For Input A: 50 k Hz For Input B: 200 k Hz

2 Diode Small–Signal Model

The diode in the circuit below is a laser diode. That fact isn't particularly important to the question, but it provides motivation for the problem. We want to bias the diode to provide a DC current, and then modulate the current (and thus the laser power) with an AC "signal." The diode has a saturation current of

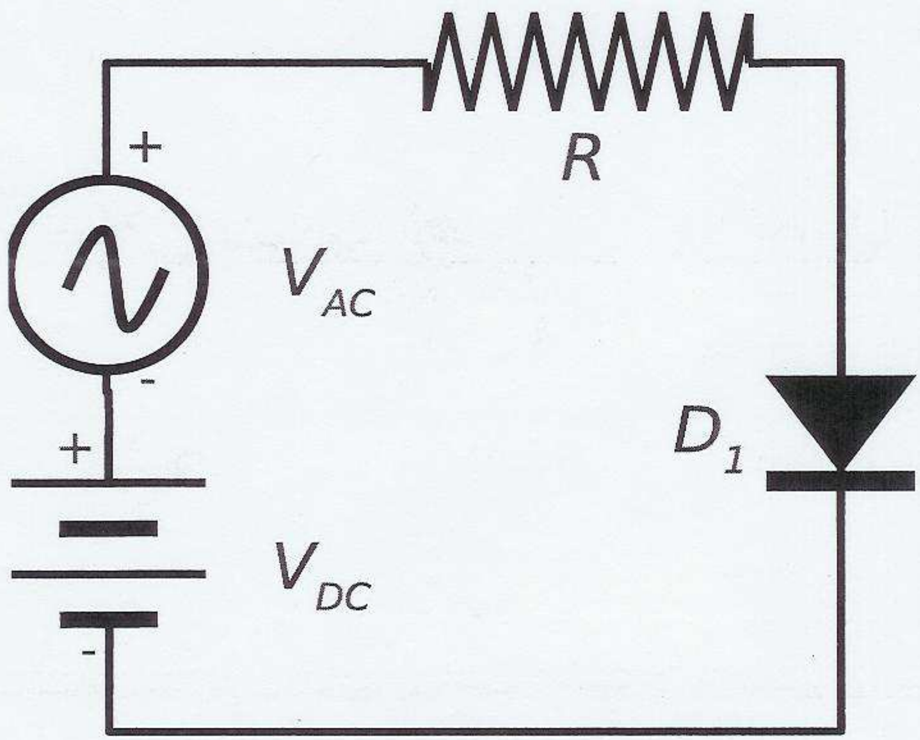
$$I_s = 10 \text{ picoAmperes.} \tag{2.1}$$

The resistor has a value

$$R = 100 \text{ Ohms,} \tag{2.2}$$

and the DC current desired is

$$I_{DC} = 75 \text{ milliAmperes.} \tag{2.3}$$



2.1 Bias Point

Find the DC voltage required of the source and the DC voltage across the diode, making the usual assumptions.

$$I = I_s\left(e^{V/V_T} - 1\right) \simeq I_s e^{V/V_T}$$

$$V = V_T \ln \frac{I}{I_s} = 0.025\,V * \ln \frac{75\times 10^{-3} A}{10^{-11} A}$$

$$= 0.57\,V$$

$$V_{DC} = 0.57\,V + IR$$
$$= 0.57\,V + 75\times10^{-3} A * 100\,\Omega$$
$$= 8.1\,V$$

Supply Voltage: 8.1V Diode Voltage: 0.57V

2.2 Power

How much power is consumed by the diode, and how much is consumed by the resistor?

$$P_D = 75\times10^{-3} A \times 0.57\,V \simeq 0.0426$$

$$P_R = (75 * 10^{-3} A)^2 \times 100\,\Omega = 0.5625$$

In the Diode: 43mW In the Resistor: 560 mW

2.3 Small–Signal Parameters

Now we can replace the diode with a battery and a resistor. What is the value of the resistor? What AC voltage signal, V_{AC} in the figure, will produce a current equal to 10% of the DC current?

$$r_{eq} = \frac{V_T}{I(DC)} = \frac{0.025V}{75\times10^{-3}A} = 0.33\Omega$$

0.33 Ohms.

$$V_{AC} = i_{AC} * (R + r_{eq})$$

$$= \frac{I_{DC}}{10}(R + r_{eq}) = 7.5\times10^{-3}A * 100.33\Omega$$

$$\approx 750mV$$

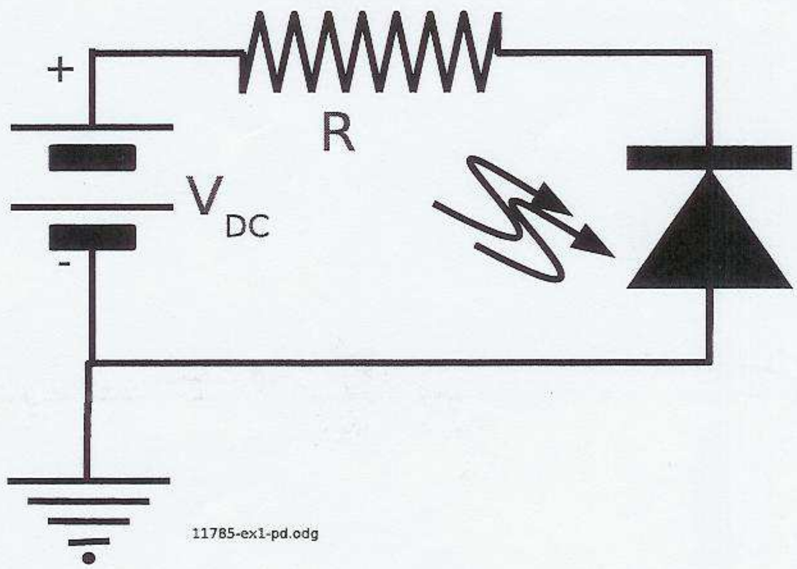
3 Photodiode

The following figure shows a photodiode with a typical DC bias circuit. The diode has a saturation current of 1 picoAmpere, and the photocurrent is given by

$$i_{photo} = 0.65 \text{ Amperes/Watt} \times P_{optical} \tag{3.1}$$

where $P_{optical}$ is the optical power falling on the diode. The resistor and supply voltage are

$$R = 10 \text{ kOhms} \qquad V_{DC} = 9 \text{ Volts.} \tag{3.2}$$



I gave some bonus points on this problem if it looked like you understood parts of it.

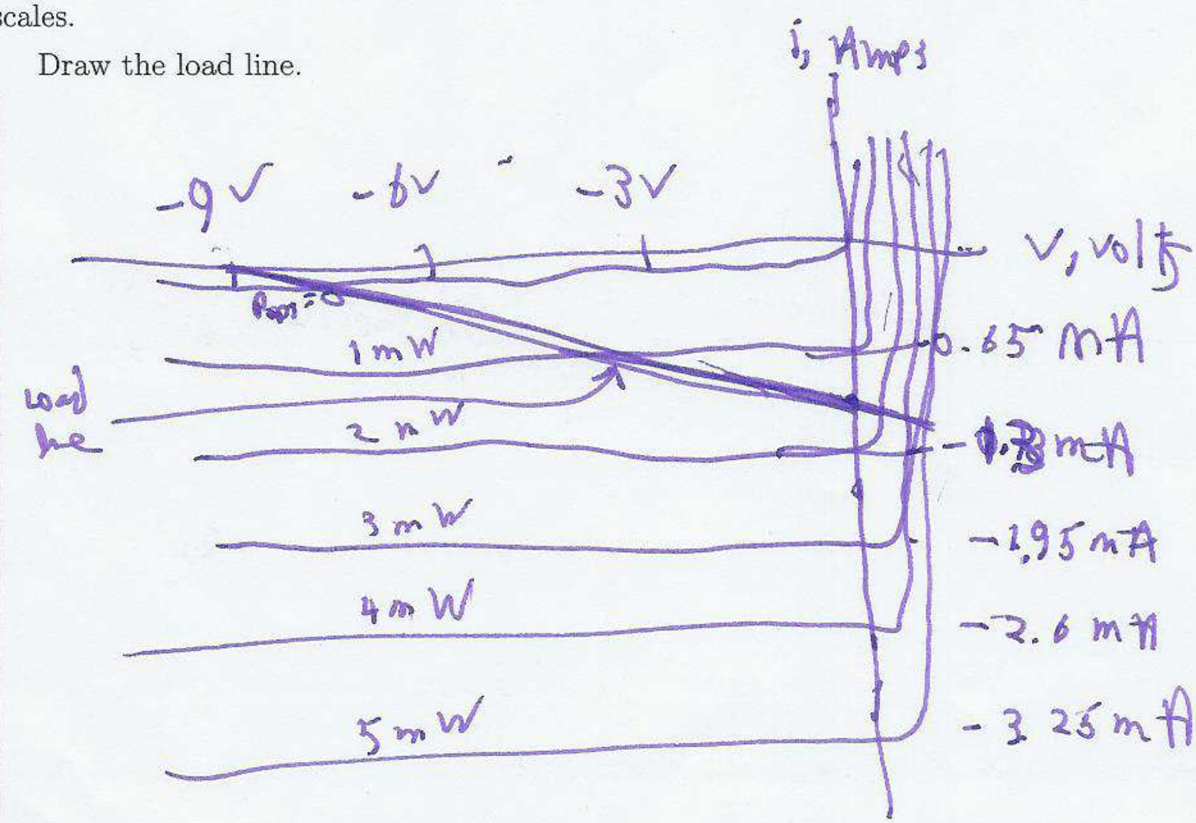
3.1 Equation, I–V Curves and Loadline

Write the equation for the detector current as a function of both detector voltage and optical power.

$$i = I_s \left(e^{V/V_T} - 1\right) - \frac{\eta q}{hf} P_{optical}$$

Draw the current versus voltage for the diode with the optical power in "parametric" mode, with the optical power as a parameter? Use units such as Volts, milliAmperes, and Watts as appropriate. Use optical power from zero to five milliWatts in steps of one. Pick appropriate current and voltage scales.

Draw the load line.



current intercept $\frac{9V}{10^4\Omega} = 0.9$ mA

3.2 Dark Operating Point

With no optical power on the diode, what are the voltage across the diode and the current through it? You may use appropriate approximations.

~0, more accurately $-I_s$

Current: ~0 milliAmperes

Voltage: −9 Volts

3.3 Daylight Operation

planned to ask for 1 mW

Now suppose that the optical power rises to

$$P_{optical} = 4 \text{ milliWatt.} \tag{3.3}$$

What are the voltage and current now? Again, make appropriate approximations.

saturated so $i \approx \frac{V_{DC}}{R} = \frac{-9V}{10^4 \Omega} = -0.9mA$

Current: −0.9 mA milliAmperes

Voltage: 0.7 Volts

3.4 Saturation

How much optical power is required to cause the diode to reach the saturation point, beyond which increasing the power does not change the voltage or current? Answer to the nearest milliWatt.

$i_{photo} = i_{sat} = \frac{V_{DC}}{R} = 0.4mA$

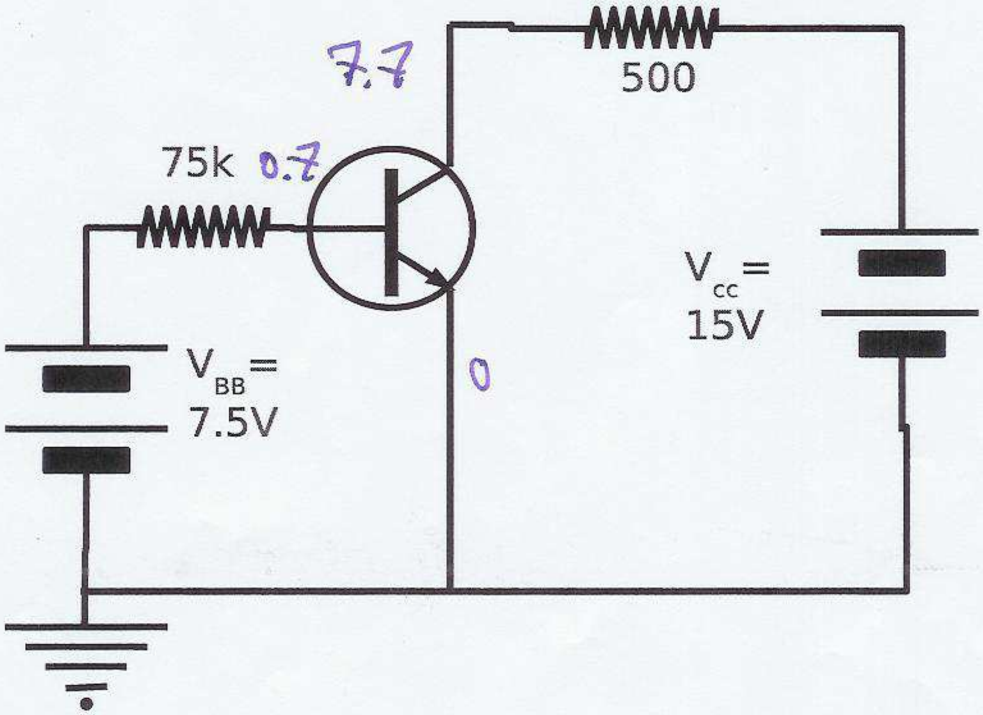
$P_{opt} = \frac{0.9mA}{0.65A/W} = 1.4mW$

~~= 0.6 mW~~

1 mW milliWatts

4 BJT Biasing

The figure below shows a BJT amplifier. Here we will only do the DC analysis. Later in the course, we will consider this circuit as an amplifier. For DC analysis, assume the capacitor is an open circuit. Assume that $\beta = 160$.



4.1 DC Analysis

Compute all the voltages and currents, with positive current being defined in the direction from the top of the page to the bottom or from left to right.

$V_{BE} = 0.7\ V \quad I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{7.5v - 0.7v}{75{,}000\Omega}$

$= 9\ uA$

$I_C = \beta I_B = 1.4\ mA \quad I_E \approx I_C$

$V_C = V_{CC} - I_C R_C = 15v - 14 \times 10^{-3} A * 500\Omega$

Base Voltage, V_B 0.7 V Current, I_B 90uA

Emitter Voltage, V_E 0 Current, I_E 14 mA

Collector Voltage, V_C 7.7V Current, I_C 14mA

Is the transistor in active mode?

7.7 V_C

0.7 V_B

0 V_E

yes

4.2 Small–Signal Parameters

Compute the transconductance and the resistance for the "pi" model. Don't forget the units.

$$g_m = \frac{I_c^{(DC)}}{V_T} = \frac{1.4 \times 10^{-3}\ A}{25 \times 10^{-3}\ V}$$

$$= 0.58$$

$$r_\pi = \beta / g_m = \frac{160}{g_m} = 276$$

$g_m =$ 0.58

$r_\pi =$ 276