1. On your first assignment as a newly hired bioengineer in a medical device company you are tasked with the design of a photodetector for pulse oximetry. You decide to look into a photodiode as the transducer device to convert incident light into an output voltage. The relationship between current \( I \) and voltage \( V \) across the photodiode (or any diode, for that matter) is given by

\[
I = I_s \left( \exp\left(\frac{V}{V_{th}}\right) - 1 \right)
\]

where \( I_s \) is the diode saturation current and \( V_{th} \) is the thermal voltage. The photodiode is different from a normal diode in that the current is not externally supplied but internally generated through recombination of electron-hole pairs excited by the incident light. The photocurrent \( I \) is directly proportional to incident light intensity \( \Phi \):

\[
I = k \Phi
\]

where \( k \) is the light responsivity.

(a) Write the photodiode transducer output voltage \( V \) as a function of incident light intensity \( \Phi \).

(b) Find the sensitivity at very low light levels.

(c) Show that the sensitivity drops substantially at higher light levels. Find the level of light sensitivity \( \Phi \) at which the sensitivity drops to half of its peak value.

(d) Disillusioned by the nonlinear response and the poor sensitivity at high light levels necessary for pulse oximetry, you decide to look into other ways to measure light intensity using the same device. Thanks to your former classmate (who was also recently hired and with whom you share a cubicle), you get hold of a transimpedance amplifier with a tunable transresistance \( R \). This very versatile instrument takes an input current \( I_{in} \) at zero input voltage, and returns an output voltage \( V_{out} \) that is directly proportional, \( V_{out} = R I_{in} \). Show that the combination of the photodiode and the transimpedance amplifier yields a linear transducer with constant sensitivity that is tunable through the transresistance \( R \).

2. Consider the following filter circuit with voltage input \( V_{in} \) and voltage output \( V_{out} \), driving an output load \( Z_L \). The values for the internal components are \( R_1 = 200 \, k\Omega \), \( R_2 = 100 \, k\Omega \), \( C = 1 \, nF \), and \( L = 1 \, nH \).

![Filter Circuit Diagram]
(a) Find the input impedance, and output impedance. *Hint:* assume an ideal load $Z_L$ as usual.

(b) Derive the Thevenin equivalent of the circuit at the input, and at the output.

(c) Write the transfer function $V_{out}(j\omega)/V_{in}(j\omega)$, and graph your result as a Bode plot (log amplitude and phase vs log frequency).

(d) At steady state for $V_{in} = 2V$, find the power dissipated by the circuit. Assume there is no output load ($Z_L = \infty$).

(e) Now find the power transfer efficiency (ratio of power delivered to the load, over power delivered by the source) at steady state as a function of the load $Z_L$ added to the output. What value of $Z_L$ gives maximum efficiency?

3. **Design Problem:** Action potentials, or “spikes”, are fast pulsing voltage events generated by electrically active cells such as neurons in the brain. They can be recorded from multiple neurons simultaneously using a microelectrode array (MEA) inserted in neural tissue; however, reliable measurement of spikes requires proper filtering of the electrode signals to eliminate signal interference and noise. In this problem we will design a bandpass filter for spike recording from a MEA that eliminates both low-frequency contaminating signals such as slow local field potentials, and high-frequency noise in the electrode and measurement circuits.

Design a voltage-in, voltage-out continuous-time analog bandpass filter with unity gain in the mid-band, 1 kHz and 100 kHz -3dB corner frequencies, and 20dB/decade roll-off outside the midband (*i.e.* +20dB/decade below the 1 kHz frequency corner, and −20dB/decade above the 100 kHz frequency corner). You may use any combination of resistors, capacitors, and inductors. Your circuit should not draw more than 1 µW of power from the input ranging −1 V to +1 V. Be sure to justify your choice of component values, and give consideration for their practical realization.

**General note for design problems:** For this and all future design problems, make sure to sketch your design and outline the solution approach. Label all electronic parts with values, and label other components (*e.g.* label switches with the type of switch, a sensor with its type, and also their function). Show the equations you used to get the values or results. State your assumptions, if any. If a part or component value was arbitrarily chosen, indicate this in the solution. You will be graded not only on the final answer, but also the design approach and presentation of the problem and its solution. Neatness counts!