University of California at Berkeley
College of Engineering
Dept. of Electrical Engineering and Computer Sciences

EE 105 Midterm I

Spring 2002 | Prof. Roger T. Howe | March 6, 2002

Your Name: ______________________________

Student ID Number: ________________________

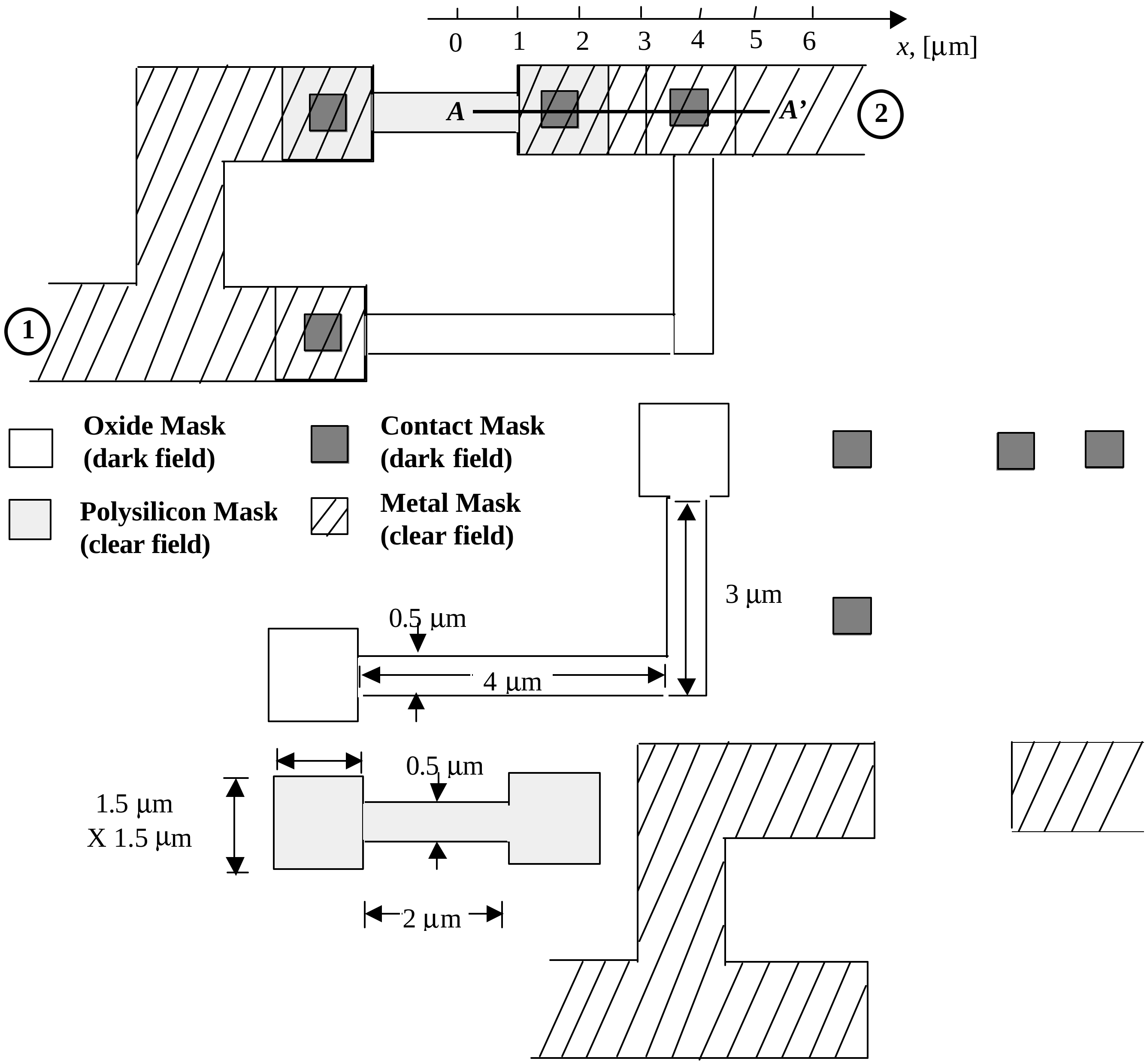
Guidelines

Closed book and notes; one 8.5" x 11" page (both sides) of *your own notes* is allowed.
You may use a calculator.
Do not unstaple the exam.
Show all your work and reasoning on the exam in order to receive full or partial credit.

Score

Problem	***Points*** Possible	Score
1	17	
2	17	
3	16	
Total	50	

1. IC resistors [17 points]

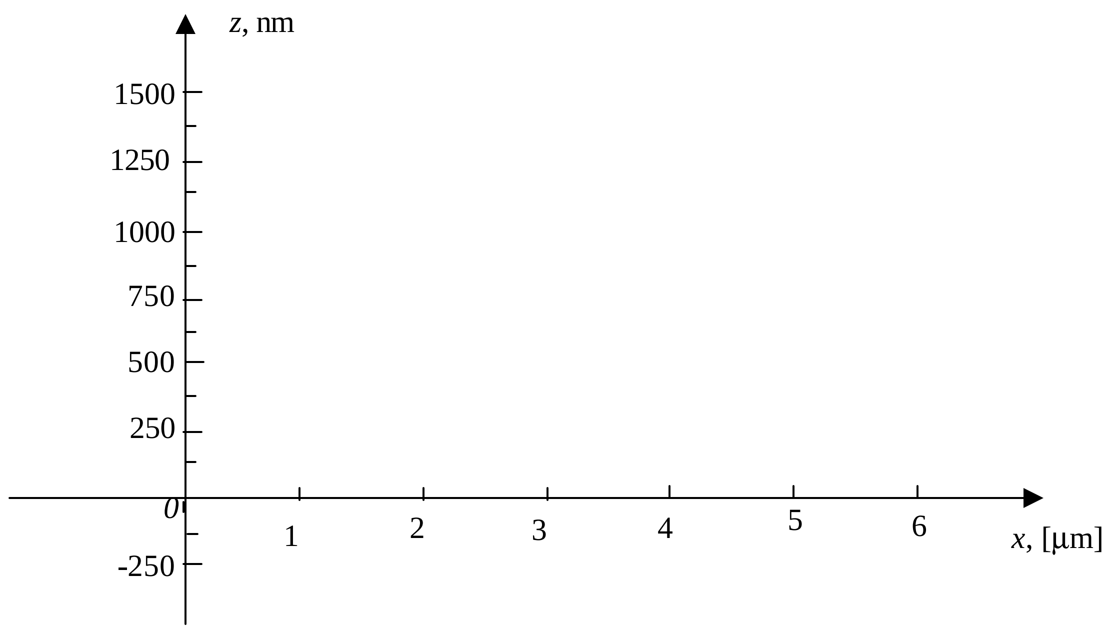


Process Sequence:

1. *Starting material*: p-type silicon wafer with a doping concentration of 1 x 10^{17} cm^{-3}
2. Deposit a 250 nm-thick SiO_2 layer
3. Deposit a 250 nm-thick layer of n-type polysilicon and pattern using the **Polysilicon Mask** (clear field).
4. Pattern the oxide using the **Oxide Mask** (dark field).
5. Implant phosphorus with dose Q_d = 5 x 10^{12} cm^{-2} and anneal to form a 250 nm-thick phosphorus-doped region.
6. Deposit a 250 nm-thick SiO_2 layer and pattern using the **Contact Mask** (dark field).
7. Deposit 250 nm of aluminum and pattern using the **Metal Mask** (clear field).

Given: mobilities for this problem are μ_n = 500 $cm^2/(Vs)$ and μ_p = 200 $cm^2/(Vs)$ for both silicon and polysilicon). The saturation electric field for electrons in polysilicon or silicon is E_{sat} = 2 x10^4 V/cm and their saturation velocity is v_{sat} = 10^7 cm/s. The mobile electron concentration in the polysilicon is n = 10^{17} cm^{-3} at the end of the process. Count the "dogbone" contact areas as 0.65 square each and the corner square as 0.56 squares in finding the resistance.

(a) [5 pts.] Sketch the cross section ***A-A'*** on the graph below **after step 7**. Identify all layers clearly.



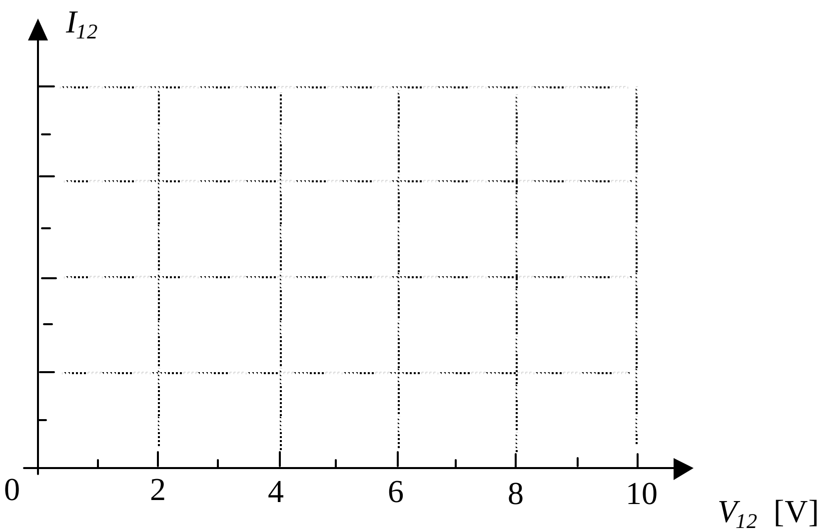
(b) [3 pts.] What is the sheet resistance R of the 0.25 µm-thick silicon region formed in step 5?

R =

(c) [3 pts.] What is the maximum current I_{max} in μA through the polysilicon resistor?

I_{max} = μA

(d) [3 pts.] Plot the current-voltage curve between terminals 1 and 2 over the range indicated on the graph below. Use the mask layout to determine the number of squares of each resistor; there is no need to account for the spreading of dopants during annealing.



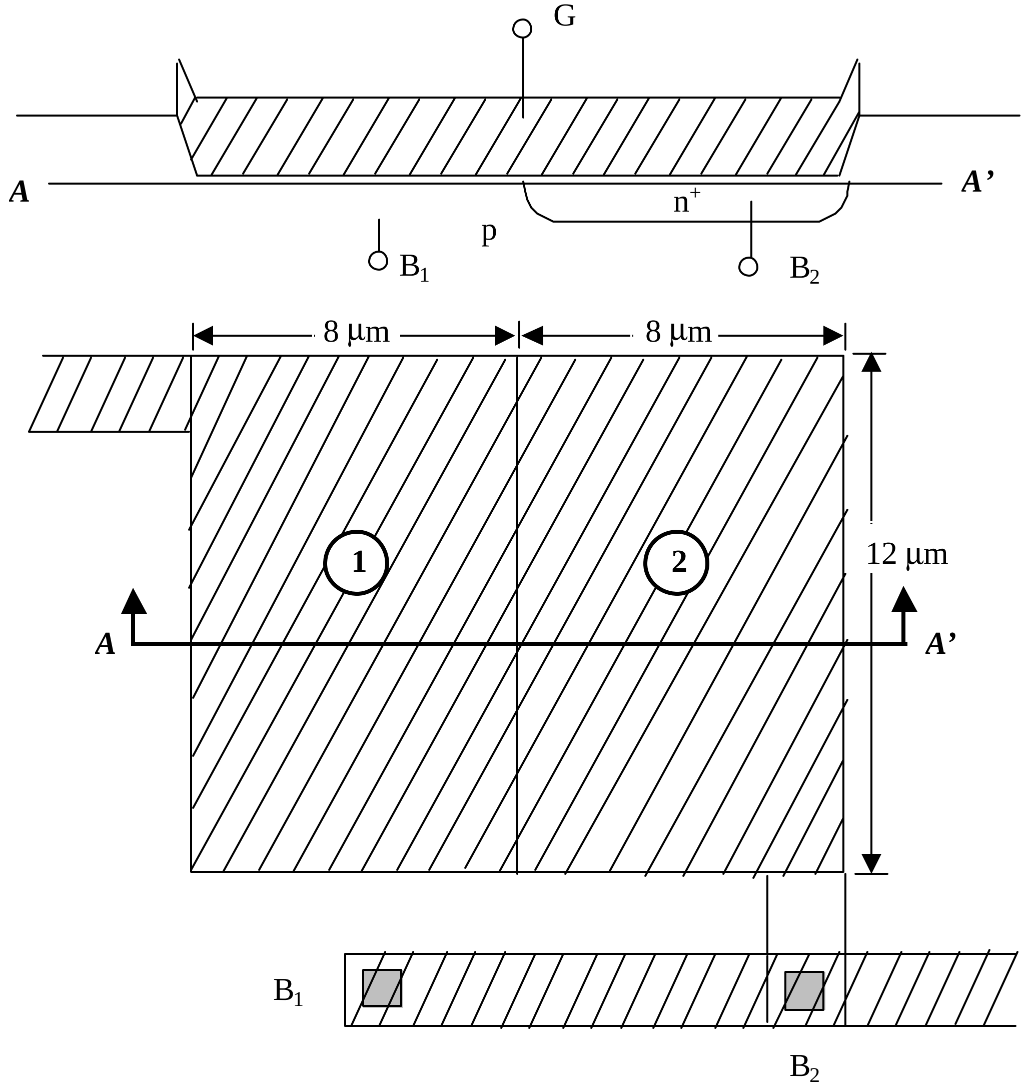
(e) [3 pts.] The total voltage between terminals 1 and 2 is:

$$v_{12}(t) = V_{DC} + v_{ac}\cos(wt)$$

with V_{DC} = 7.5 V and v_{ac} = 5 mV. What is the small-signal component of the current between terminals 1 and 2?

$i_{12}(t) =$

2. MOS charge-storage element [17 pts.]



The MOS structure shown in cross section and top view above has a metal gate and two bottom electrodes, B_1 (p substrate) and B_2 (n^+ layer). The bottom electrodes are contacted by a metal line and shorted together, as indicated on the top view. The oxide thickness is t_{ox} = 11.5 nm for the MOS structure and the oxide permittivity is ε_{ox} = 3. 45 x 10^{-13} F/cm.

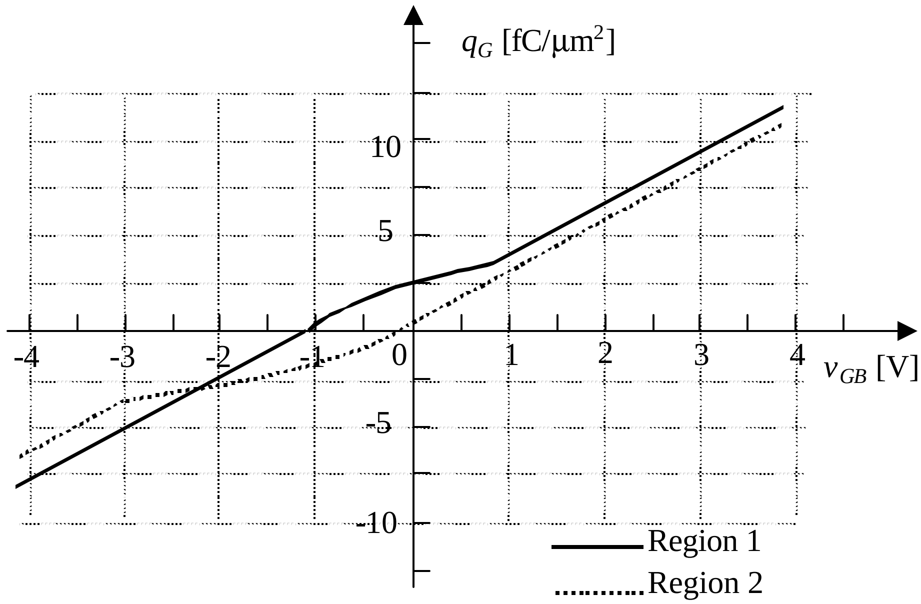
In region 1, the p-type substrate is the bottom electrode and the MOS parameters are:

V_{FB} = -1.2 V, V_{Tn} = 0.8 V

In region 2, the n^+ layer is the bottom electrode and the MOS parameters are:

V_{FB} = -0.2 V, V_{Tp} = -3 V

The charge storage curves for the two regions are provided on the graphs below of gate charge per unit area versus the gate-bottom electrode potential, v_{GB}. Since $B_1 = B_2$, we use "B" to represent the potential of the bottom electrode for each region.



(a) [4 pts.] For v_{GB} = 1 V, find the total charge on the gate (units: femtoCoulombs = 10^{-15} C).

$q_{G,Total}$ =	fC

(b) [4 pts.] For v_{GB} = -1.5 V, identify the *substrate* charge in regions 1 and 2 by circling the correct description(s). Note: the correct answer may have more than one item circled.

Region 1. ionized acceptors accumulated holes inversion-layer electrons

Region 2. ionized donors accumulated electrons inversion-layer holes

(c) [4 pts.] For v_{GB} = +1.5 V, identify the substrate charge in regions 1 and 2 by circling the correct description(s). Note: the correct answer may have more than one item circled.

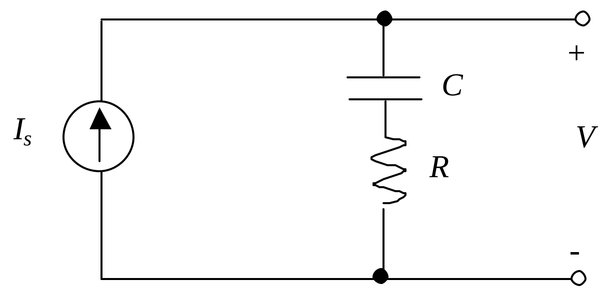
Region 1. ionized acceptors accumulated holes inversion-layer electrons

Region 2. ionized donors accumulated electrons inversion-layer holes

(d) [3 pts.] If we apply a voltage $v_{GB}(t)$ = 0 V + $v_{gb}\cos(\omega t)$, where v_{gb}=5 mV and $\omega = 2\pi(10^6)$ rad/s, find the current $i_{gb}(t)$ into the gate terminal in nA from the charge-storage curves.

(e) [2 pts.] The maximum capacitance of the MOS structure is C_{max}. If the DC component of v_{GB} is 1.5 V, what is the maximum amplitude of its small-signal component $v_{gb}(t)$ for which the current remains exactly proportional to C_{max}.

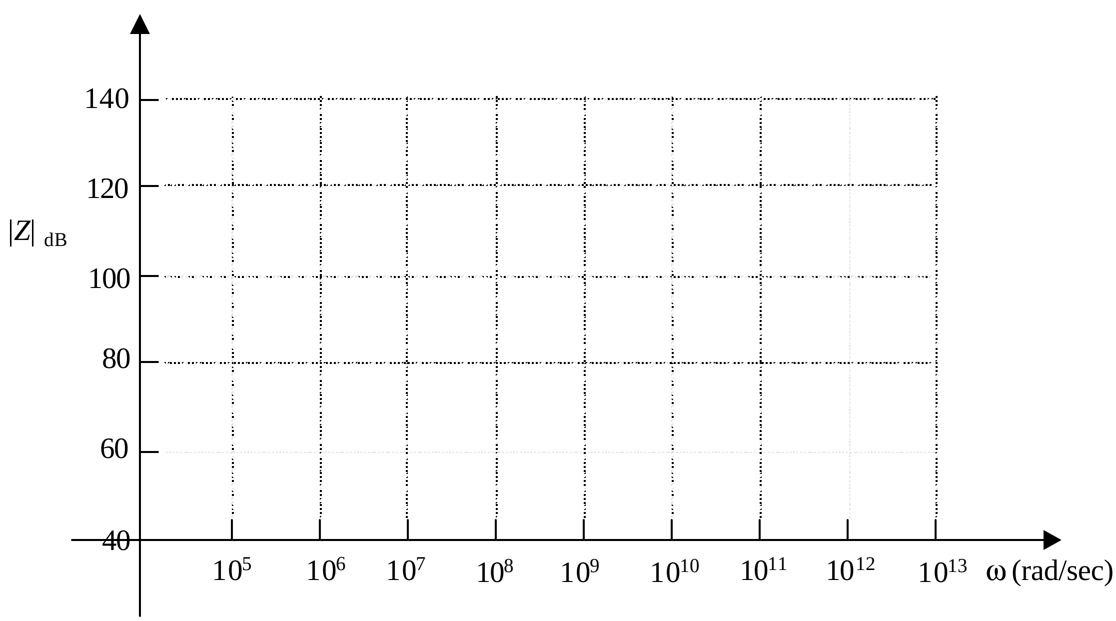
3. Impedance measurements [16 pts.]



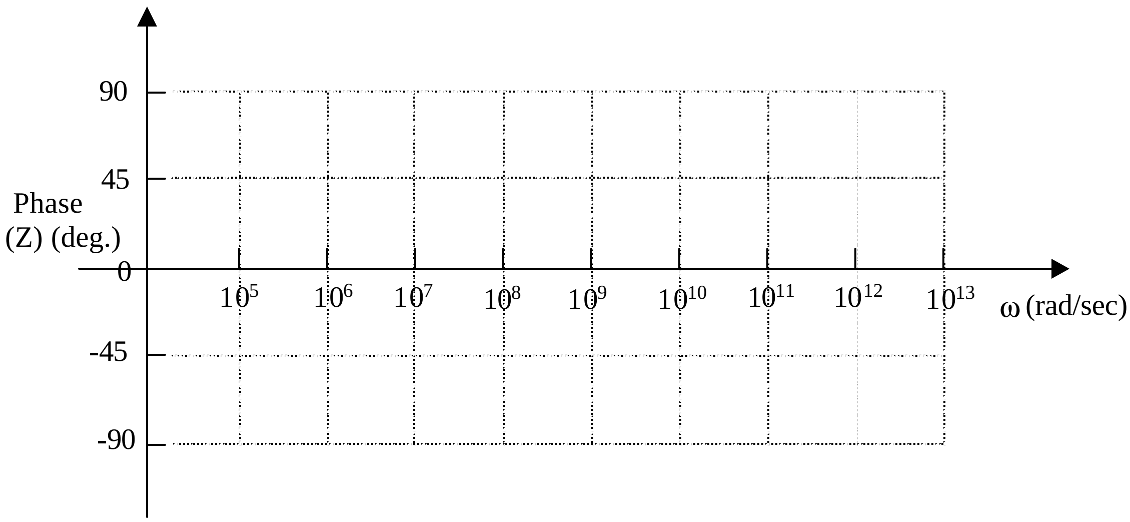
The capacitance C = 1 pF and the resistance R = 1000 Ω.

(a) [4 pts.] Find an expression for the impedance $Z = V / I_S$. Your result should contain the term $(1 + j\,\omega\tau)$.

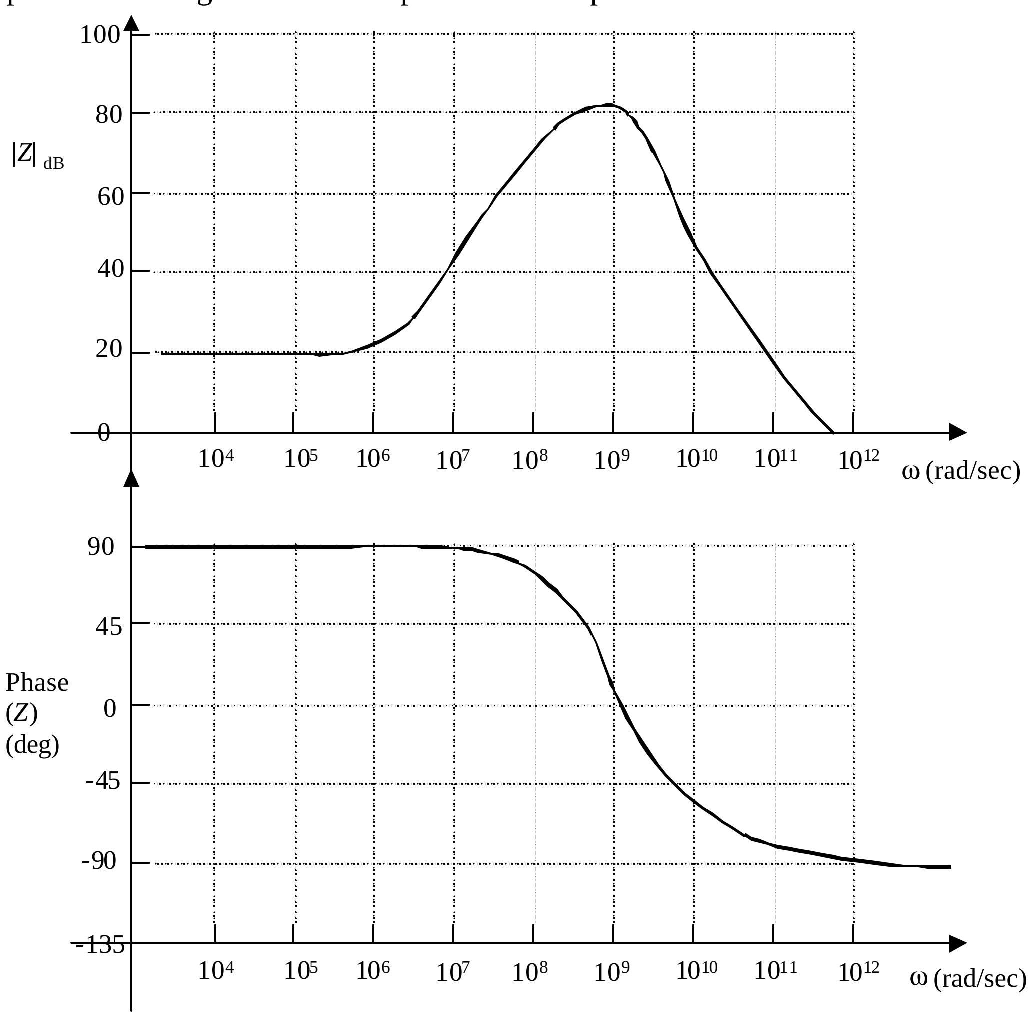
(b) [4 pts.] Sketch the magnitude Bode plot for the impedance Z (units: 20 $\log_{10}$(Ω)) on the graph below using straight-line approximations.



(c) [4 pts.] Sketch the phase of the impedance Z (units: degrees) on the graph below using straight-line approximations.



(d) [4 pts.] You hook up another two-terminal circuit and measure its impedance. The Bode plots of the magnitude and the phase of Z are plotted below.



If a phasor current $I_s = (2.5mA)e^{j0^\circ}$ at a frequency of 10^8 rad/sec, what is the voltage waveform $v(t)$ based on the information in the Bode plots?