ENGINEERING TRIPOS PART IA

Tuesday 10 June 2003 9 to 12

Paper 3

ELECTRICAL AND INFORMATION ENGINEERING

Answer not more than ***eight*** *questions, of which not more than* ***three*** *may be taken from Section A and not more than* ***three*** *from Section B, and not more than* ***two*** *from Section C.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

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SECTION A

Answer not more than **three** *questions from this section.*

1 (a) Explain briefly what is meant by an ideal operational amplifier, with a finite differential gain A. [20%]

(b) For the circuit in Fig. 1(a), derive an expression for the output signal v_2 in terms of v_1, R_1, R_2 and A. For the case R_1 = 99 kΩ, R_2 =1 kΩ and $A = 10^4$, calculate v_2/v_1. [20%]

(c) For the circuit in Fig. 1(b), express v_4 in terms of v_3 for the case R_3 =1 kΩ, R_4 = 10kΩ, $C_4 = 0$ and A is infinite. [20%]

(d) Find an expression in terms of R_3, R_4, C_4 and the input frequency ω for v_4/v_3 in the case of a finite capacitance C_4 and A infinite. Then with R_3 and R_4 as in part (c), calculate the gain of the circuit in Fig. 1(b) when C_4 = 10 pF for the frequencies 10 Hz and 1.6 MHz. [20%]

(e) Briefly make a qualitative comparison of the input impedances and phase changes across the circuits in Fig. 1. [20%]

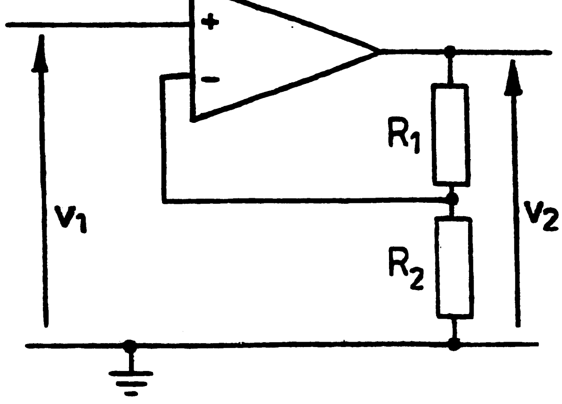

Fig. 1 (a)

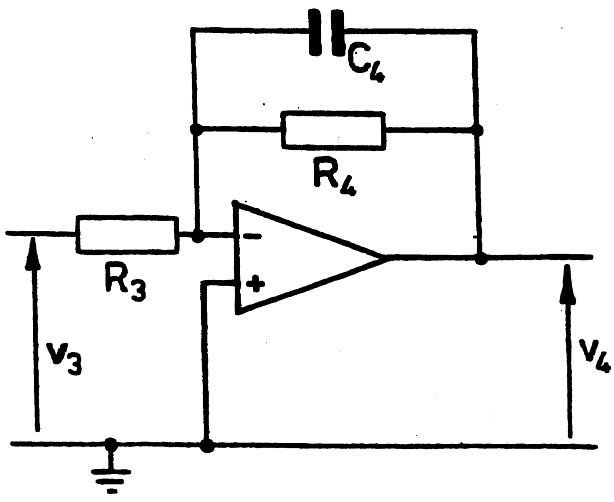

Fig. 1 (b)

2 (a) Describe the use of small signal a.c. models for FETs and discuss how they are derived. [20%]

(b) For the amplifier shown in Fig 2, draw the small signal equivalent circuit where the transistor has mutual conductance g_m and an effectively infinite drain resistance. [20%]

(c) Show that:

(i)

$$v_2 = \left(\frac{-g_m R_2 (1 + j\omega C_1 R_1)}{(1 + g_m R_1 + j\omega C_1 R_1)} \right) v_1$$

[30%]

(ii) $v_2 \simeq -75 v_1$ at high frequencies if $g_m = 5$ mS, $R_1 = 2.8$ kΩ, $R_2 = 15$ kΩ and $C_1 = 3$ μF.

[30%]

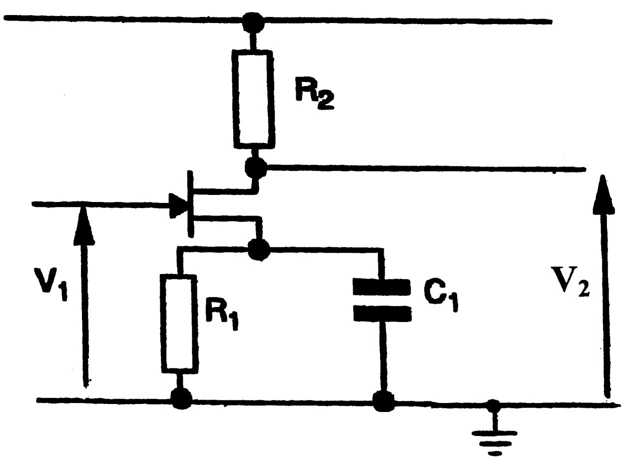

Fig. 2

3 (a) Explain briefly how the techniques of *mesh current analysis* and *loop current analysis* are used in the analysis of d.c. and a.c. electrical circuits. [20%]

(b) Figure 3 shows the circuit for a Wien bridge. The voltage source energising the bridge supplies a sinusoidal waveform of frequency ω. At balance the current through the meter A is zero. Using current loop analysis, or otherwise, find the condition for balance in terms of R_1, R_2, Z_3 and Z_4 (where Z_3 is the combined impedance of R_3 and C_3, and Z_4 is the combined impedance of R_4 and C_4). [30%]

(c) Hence find an expression for the frequency ω at which the bridge balances, in terms of R_1, R_2, R_3, R_4, C_3 and C_4. [50%]

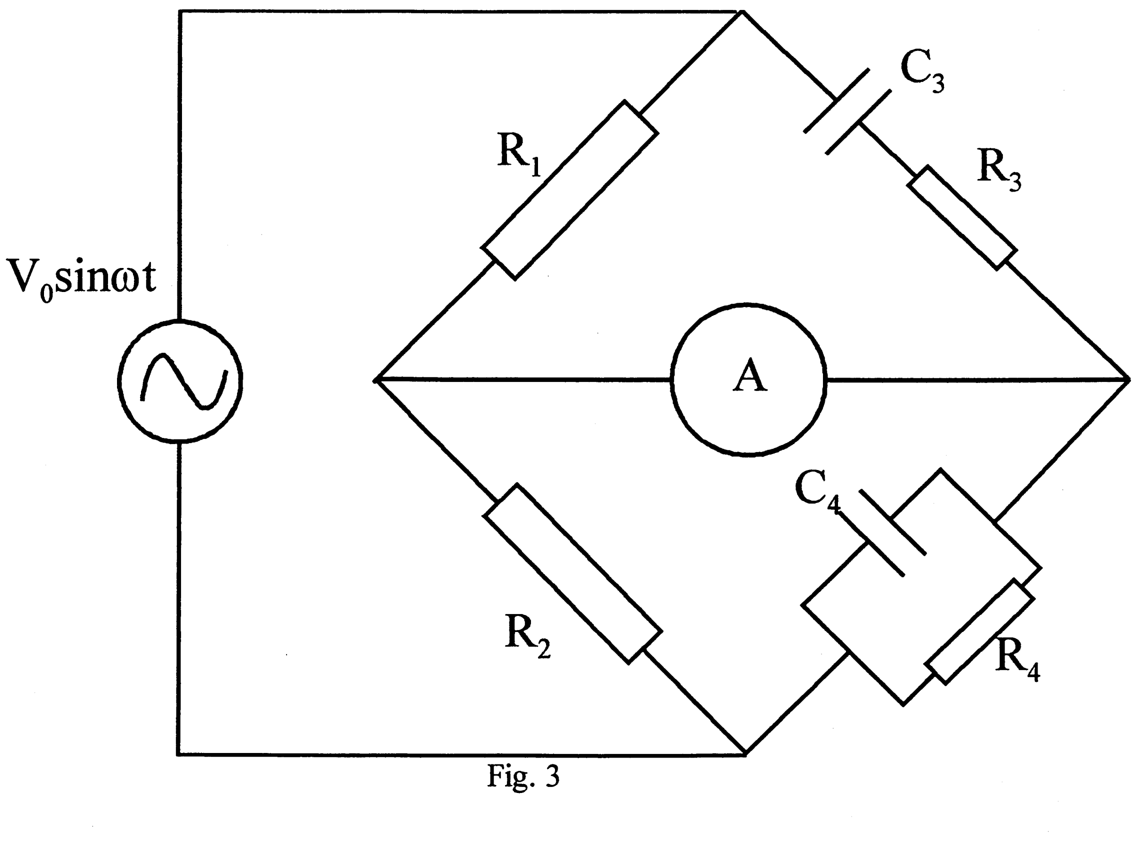

Fig. 3

4 A factory consumes 200 kW and when it is connected to a 50 Hz supply the voltage across the factory terminals is 230 V. The power factor of the factory is 0.8 lagging.

The line supplying the factory has an impedance of $0.08 + j0.15\ \Omega$.

(a) Find:

(i) The total current in the line supplying the factory;

(ii) The power lost in the line;

(iii) The voltage supplied by the power station for a factory voltage of 230 V. [50%]

(b) Power factor correction is applied to the factory to correct the power factor to unity. Find:

(i) The required size of the capacitor connected across the factory terminals;

(ii) The new current in the line;

(iii) The new power lost in the line;

(iv) The new voltage required. [50%]

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SECTION B

Answer not more than **three** *questions from this section.*

5 (a) Explain the operation of a right/left shift register, with parallel loading, and draw the logic diagram to help your explanation. [30%]

(b)

(i) What is meant by 2's complement representation of negative numbers, and why is it important? [20%]

(ii) In 8-bit 2's complement code what are the largest positive and negative numbers that can be represented? [20%]

(c) Design a 4-bit, 2's complement ripple-carry adder/subtractor. Draw the logic diagram and explain how the design works in adder mode and in subtract mode. [30%]

6 An assembly line has 3 failsafe sensors and 1 emergency shutdown switch.

The line should keep moving unless any of the following conditions arise:

(i) If the emergency switch is pressed;

(ii) If sensor 1 and sensor 2 are activated at the same time;

(iii) If sensor 2 and sensor 3 are activated at the same time;

(iv) If all three sensors are activated at the same time.

(a) Derive the 'truth table' for this system. [30%]

(b) Design, using Karnaugh Map techniques, a minimum gate network for this system and draw the resulting digital circuit diagram using only AND gates, OR gates and inverters. [20%]

(c) Design a digital circuit to implement the minimal AND - OR gate network found in (b) using:

(i) NAND gates only;

(ii) NOR gates only.

Assume in your answer to part (c), that each logic gate can have any number of inputs and that inverted inputs are available. [30%]

(d) The time delay experienced by a NAND gate is 8 ns and that experienced by a NOR gate is 10 ns. Which implementation of (c) is faster and by how much? [20%]

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7 (a) In the context of microprocessor architecture, what is meant by 'memory-mapped input and output'? [20%]

(b) Explain the functions of the 'Program Counter' and the 'Index Register' in the programming model of the Motorola 6800 microprocessor. [20%]

(c) A sequence of 6800 instructions for a processor with clock frequency 1MHz is shown below:

Assembly code	Comment
$LDAA$ #00	Load accumulator A with 00.
$LDAB$ \$50	Load B with contents of $50H$.
$CMPB$ \$51	Compare B with contents of $51H$.
BEQ 01	Branch forward one location if equal.
$COMA$	Complement A.
$STAA$ \$$E$001	Store A in location $E001H$.

Copy out the code, label each line and state the addressing mode used in each instruction. [20%]

(d) The first instruction is stored at memory location 0. What is the time taken to execute the sequence if:

(i) The numbers in locations $50H$and $51H$ are equal ?

(ii) The numbers in locations $50H$ and $51H$ are not equal?

[20%]

(e) Write a sequence of program in 6800 assembly code to introduce a time delay of exactly 84 clock periods by loading a number into an accumulator and counting down until the number reaches zero. [20%]

8 (a) Draw a diagram to show how two NAND gates may be connected to form a simple bistable circuit. [20%]

(b) Explain the operation of a Master-Slave flip-flop. Draw the logic diagram for the flip-flop and describe in detail the two-stage nature of its operation, and in particular explain why a Master-Slave configuration is preferable to an SR flip-flop. [40%]

(c) Explain using diagrams the modifications required to convert (b) into a JK flip-flop with asynchronous set and reset inputs. Why are these inputs a useful addition to the standard Master-Slave flip-flop? [40%]

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SECTION C

Answer not more than **two** *questions from this section.*

9 A designer is having trouble with a circuit board and suspects that it may be due to stray capacitances from the flying leads attached to the board. One of the leads appears as shown in Fig. 4. The lead is long and the distance d between it and the board is much greater than its radius r.

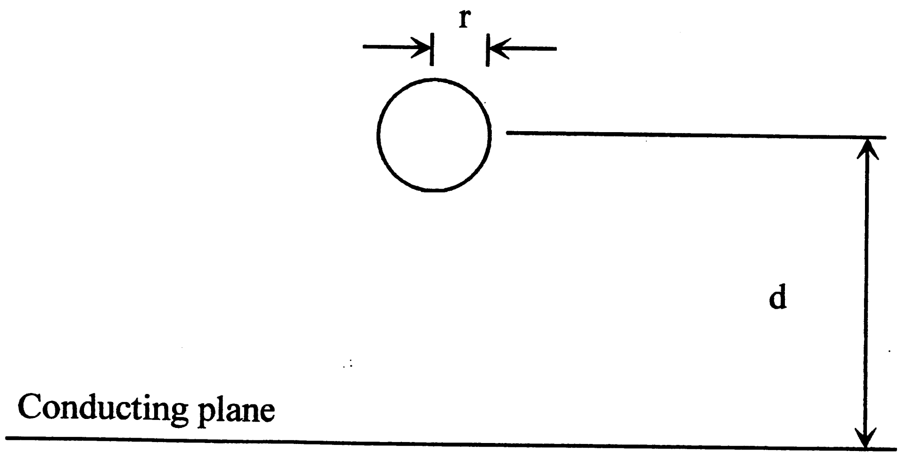

Fig.4

(a) Derive an expression for the capacitance, C, between the lead and the board. [30%]

(b) If the lead carries a current, I, derive an expression using Ampere's law for the magnetic flux density, B, as a function of distance from the conductor axis. [30%]

(c) As well as capacitance the designer is worried about magnetic fields in the plane of the board and knows that these can be cancelled entirely by placing a second wire carrying the same magnitude of current as the first. Indicate on a sketch where the second wire should be placed and derive an expression for total magnetic field at a distance R from the original wire anywhere along a straight line joining the two. [30%]

(d) Calculate the force per unit length between the two wires. For this force, what is its direction ? [10%]

10 A scrap-yard owner installs a back-up power system for a lifting magnet and wants to know the current which will be required to lift a car of mass 1200 kg. The electromagnet is a horseshoe with a cylindrical cross section of radius 0.05 m and 2000 turns. The initial distance between the electromagnet and the car top is 0.01 m as shown in Fig. 5. The μ_r of the electromagnet is 10^4 and the μ_r of the car roof is 10^4.

Calculate:

(a) The magnetic flux density in the air-gap between the magnet and the car roof as a function of current. State any assumptions made. [30%]

(b) Using the result found in (a) (or otherwise) calculate the minimum current to lift the car. [30%]

(c) Assuming that the current is 1% greater than the value found in (b) calculate the velocity of the car as it hits the electromagnet. Assume that air resistance is negligible and that the flux is regulated to keep it constant. [30%]

(d) The above calculations assume that the car roof has a linear permeability i.e. that flux saturation does not occur in the car roof. What would be the effect of saturation on the above results ? [10%]

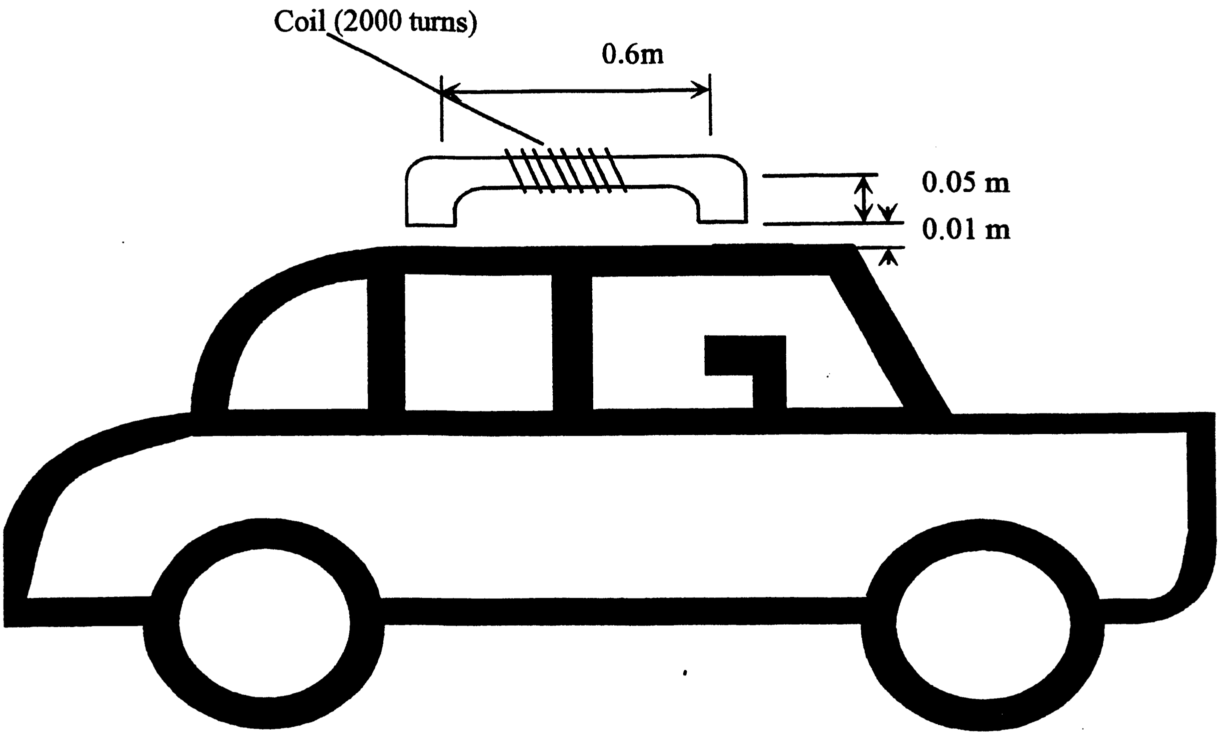

Fig. 5

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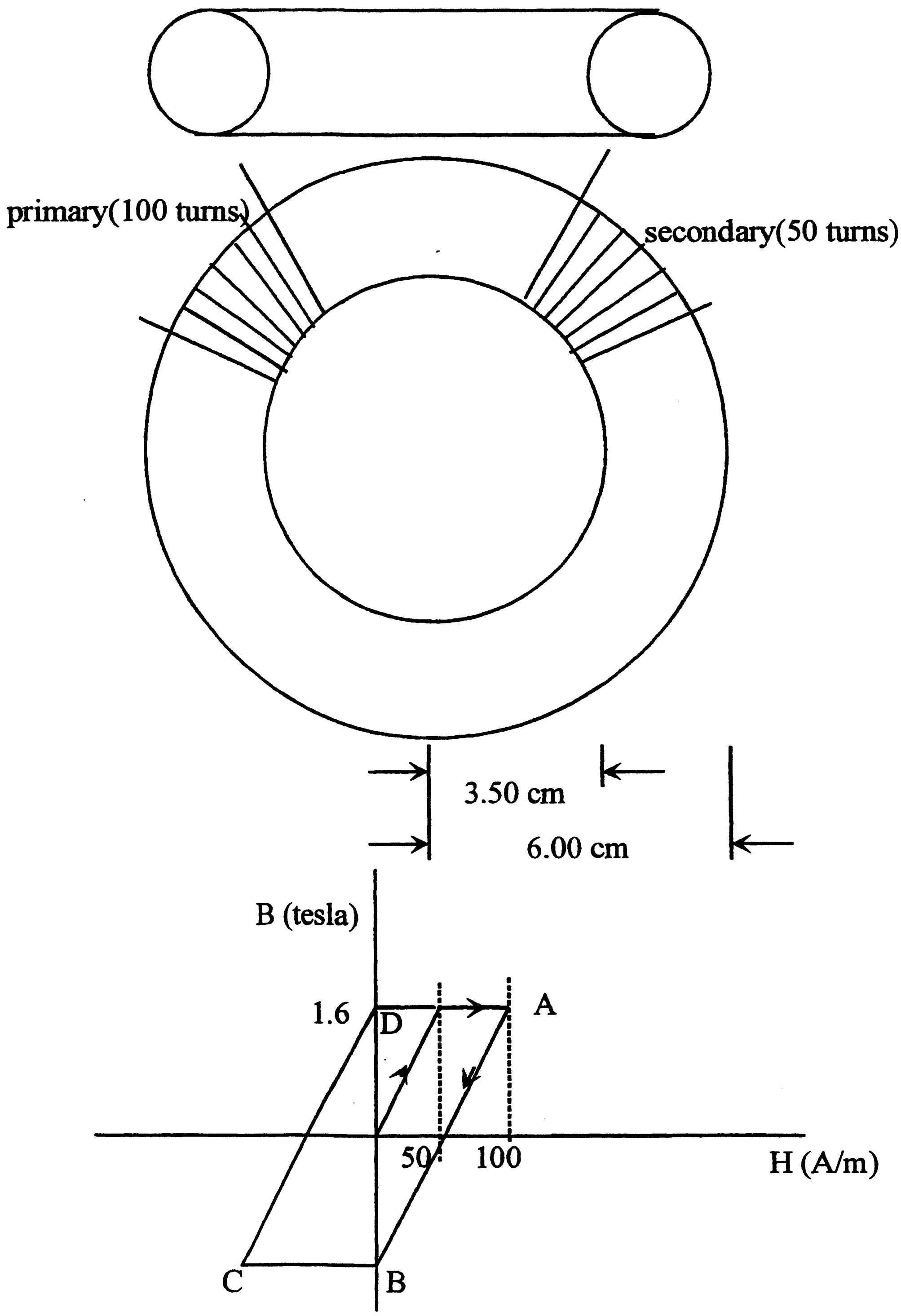
primary(100 turns)
secondary(50 turns)
3.50 cm
6.00 cm
B (tesla)
1.6
D
A
50
100
H (A/m)
C
B

Fig. 6

11 A Hi-Fi system suffers considerable distortion in the sound coming from the speakers when the volume is turned up to maximum. Since the speakers are known not to be at fault, it is suspected that the distortion is due to losses in the toroidal transformer in the amplifier. Tests on the steel used in the transformer have resulted in the BH curves shown in Fig. 6, which indicate that the transformer is lossless, and therefore ideal, up to H = 50 A/m at 100 Hz.

(a) Calculate the current to, and the voltage across, the primary at the point where losses start to occur. [40%]

(b) Find the total losses in one cycle, that is, going round the BH loop ABCDA. [30%]

(c) The secondary drives a purely resistive load of 8 Ω. Using the voltage found in part (a), and, assuming the resistance of the windings is negligible, calculate the power transferred to the load and compare this to the magnetic losses calculated in part (b) if the driving frequency is 100 Hz. [30%]

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