ISSUED ON

25 OCT 2013

Engineering Tripos Part IB SECOND YEAR

Part IB Paper 5: Electrical Engineering

LINEAR CIRCUITS AND DEVICES

Examples Paper 2 : Operational amplifier circuits and power amplifiers

Straightforward questions are marked †
*Tripos standard questions are marked **

Operational Amplifier Circuits

†1. What is the function of the operational amplifier circuit shown in Fig. 1, and for what purpose is it used? If the amplifier has gain $A = 10^4$, input resistance $R_i = 10\ k\Omega$ and output resistance $R_0 = 200\ \Omega$, find the gain, input resistance and output resistance of the complete circuit using small signal analysis and the equivalent circuit.

How would you modify this circuit to produce a gain of 10?

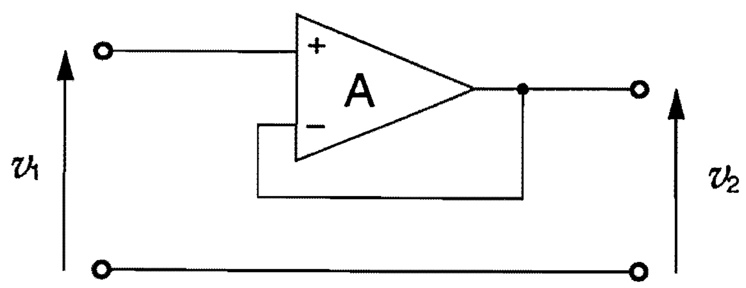

Fig. 1.

†2. In the circuit of Fig.2, k_1, k_2, k_3, k_4 are scaling factors with $k_1 + k_2 = k_3 + k_4$. Assuming that the operational amplifier is ideal, show that

$$v_0 = k_3 v_3 + k_4 v_4 - k_1 v_1 - k_2 v_2$$

In a practical amplifier circuit of this type, the output voltage will differ somewhat from the value given by the above expression. List the reasons for this departure from the ideal and discuss the precautions necessary to minimise the discrepancy.

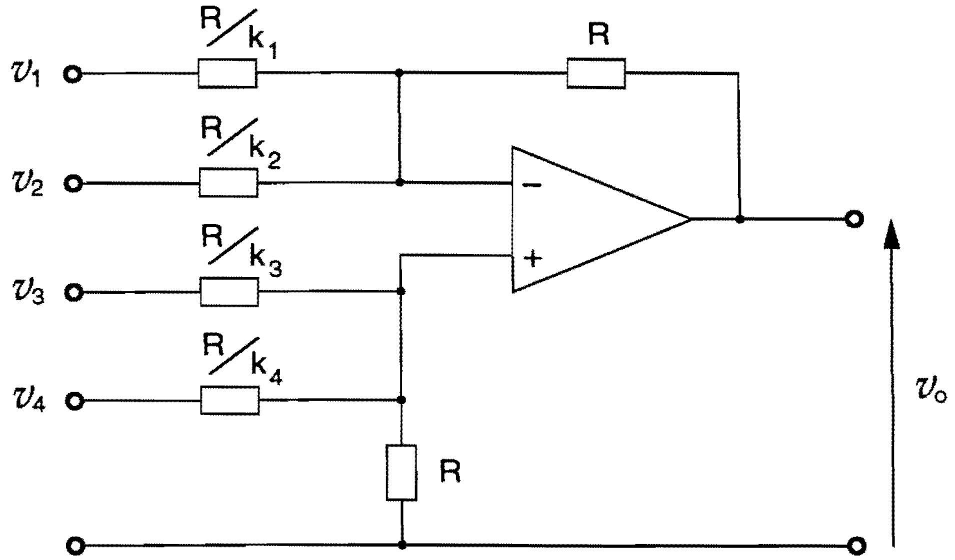

Fig. 2.

3. In the circuit of Fig. 3, the switches are moved simultaneously from position (1) to position (2) at $t = 0$. Assuming that the operational amplifier is ideal show that the output voltage is given by

$$v_2 = -10 \int_0^t v_1 \, dt - 2v_B$$

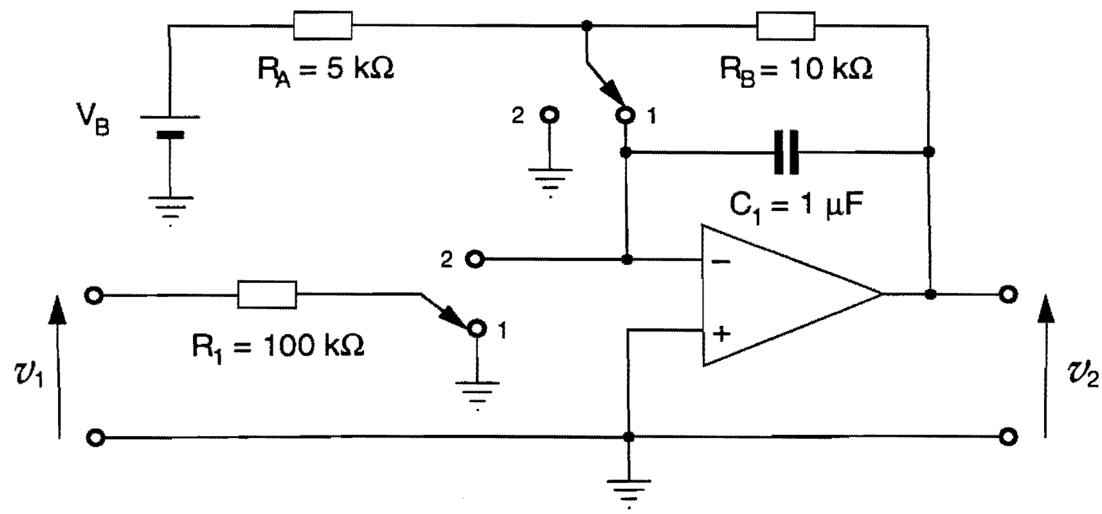

Fig. 3.

4. The amplifier circuit of Fig. 4 is used to amplify the differential 1 kHz signal from a transducer and reduce the effect of the superimposed common-mode 50 Hz signal.

Explain why the circuit of Fig. 4 is suitable for this application and find the value of resistor R to give 20 times amplification to the 1 kHz signal. Assume ideal amplifiers. Note that the amplifier A_1 behaves like the circuit of Q.2, but with only two inputs.

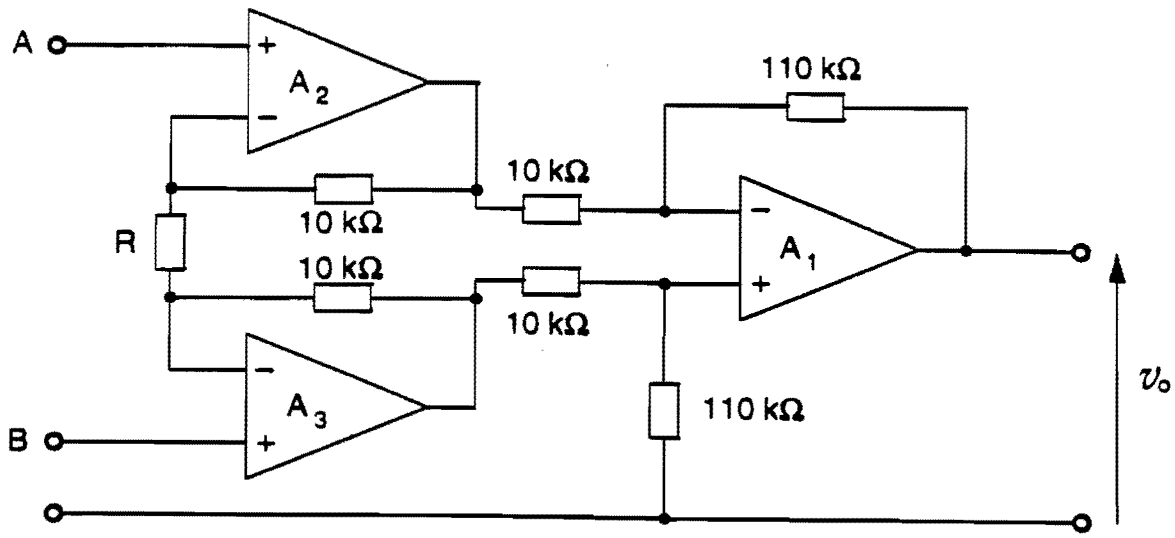

Fig. 4.

Negative Feedback

†5. An amplifier has a voltage gain of 10^4, upper half-power frequency of 300 kHz, and input resistance = 20 kΩ. Voltage feedback is used to reduce the gain to 100. What is the resultant upper half-power frequency and input resistance?

If the feedback amplifier must have an output resistance below 10Ω and its gain variation must be less than 0.1%, what should be the output resistance and gain variation of the amplifier without feedback?

†6. Two identical voltage amplifiers have gains which may vary from 50 to 100 without any significant phase shift. The two amplifiers are to be used in the negative feedback circuits of Fig. 5 to produce an amplifier with an overall gain of at least 100. Calculate the gain variation for each circuit, and hence select the one most useful for this application.

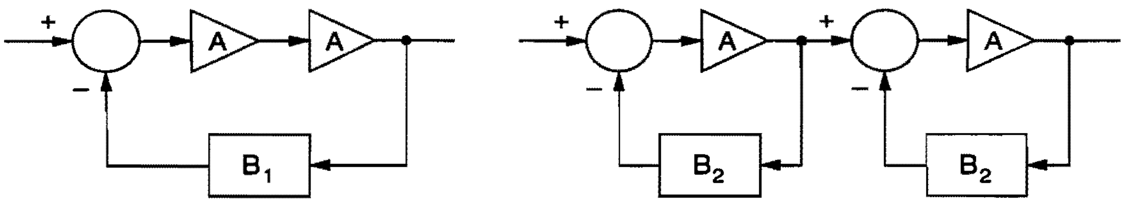

Fig. 5.

7. In the operational amplifier circuit of Fig. 6, the linear integrated circuit has open-loop gain, $A = 3 \times 10^4$, half-power bandwidth $f_1 = 100$ Hz, input resistance, $R_I = 500\ k\Omega$, and output resistance, $R_O = 100\ \Omega$. Estimate the loop gain of the operational amplifier circuit and hence, using negative feedback principles, write down its gain, half-power bandwidth, input resistance and output resistance. Would the results be different if R_1 and R_2 were (a) increased, (b) decreased by a factor of 100? Why?

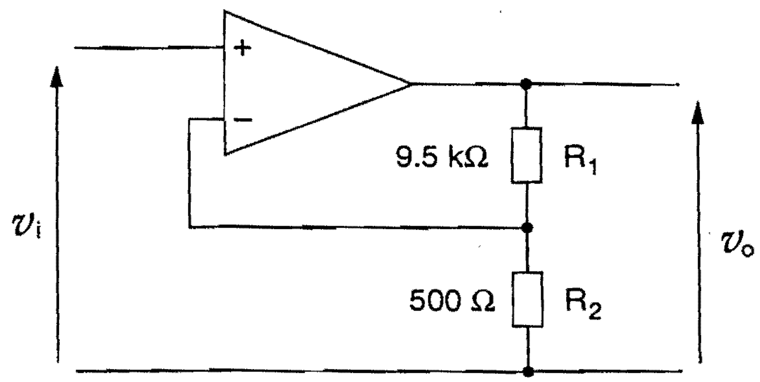

Fig. 6

Large signal and power amplifier circuits

8. Part of a power amplifier circuit is shown in Fig. 7. Q1 and Q2 form a class B output stage. At a certain operating point, the small-signal equivalent circuit parameters of all transistors are $h_{fe} = 100$, $h_{ie} = 1\ k\Omega$, h_{oe} and h_{re} can be neglected. Find the small-signal output impedance of the circuit at this operating point.

   * Making reasonable assumptions about the large-signal characteristics of the transistors, sketch the v_c (the voltage at the collector of Q3) to v_0 voltage transfer relation of the amplifier and comment on its features. How might the circuit be improved?

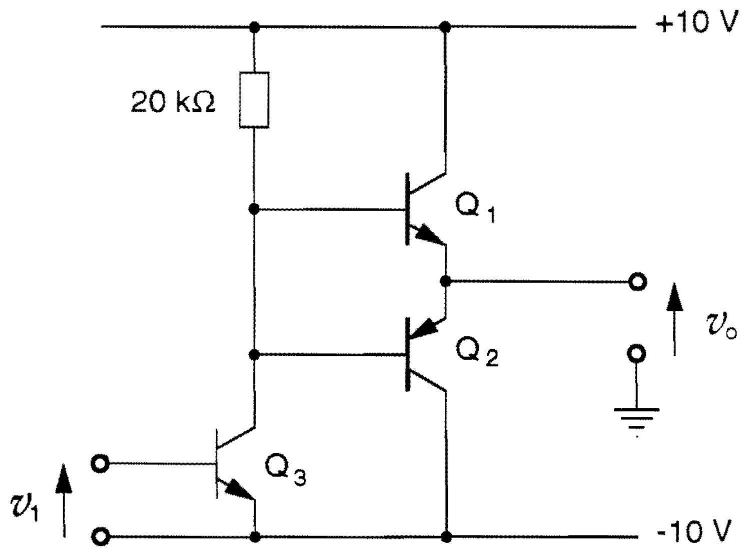

Fig. 7

9. A basic complementary emitter follower power amplifer is shown in Fig. 8. For Vcc = ± 30 V calculate the maximum sine wave power output and the efficiency taking the load resistance to be 8 Ω. Ignore any power dissipated in the base drive circuits. Assume that the minimum voltage drop across the power transistors is negligible – is this assumption justified?

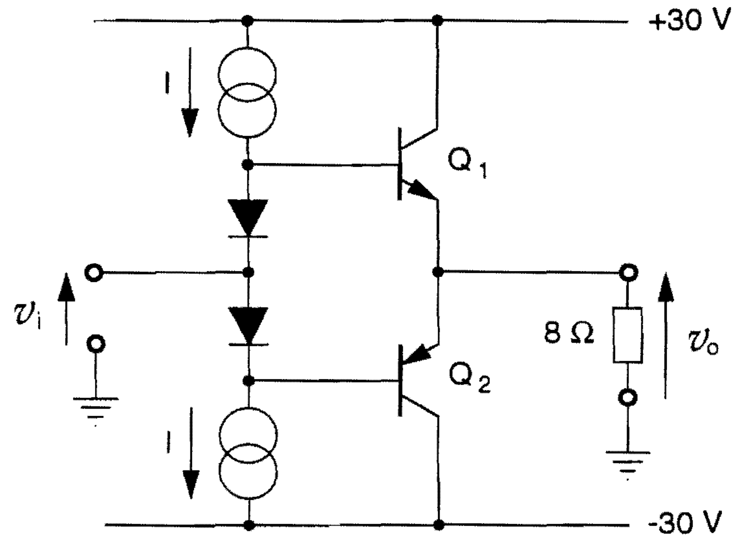

Fig. 8

Oscillators

*10. The amplifier A in the circuit of Fig. 9 has a very high input resistance and negligible output resistance. Assuming that $R_1 = R_2 = R$, show that

$$\frac{v_2}{v_1} = \frac{1}{3 + j(\omega RC - 1/\omega RC)}$$

Show also that the frequency of oscillation $f = 1/2\pi RC$, and that the gain of the amplifier must be equal to 3 for steady oscillations. If the amplifier is to be constructed from a number of FET common-source amplifier stages, what is the minimum number that it must contain?

The oscillator is constructed with an amplifier of input resistance of $1\,M\Omega$, output resistance $10\,k\Omega$, and capacitors of $0.01\,\mu F$. What values are required for the resistors R_1 and R_2 in the phase-shift circuit for an oscillation frequency of 160 Hz.

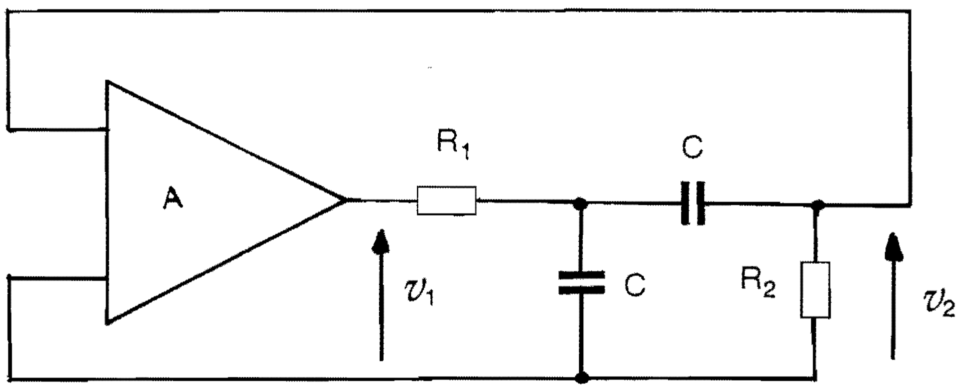

Fig. 9

ANSWERS

1. 1.0; 100 MΩ, 20 mΩ

4. 24.4 kΩ

5. 30 MHz, 2 MΩ, 1 kΩ, 10%

6. 100 – 103, 100 – 123

7. 1500, 20, 150 kHz, 750 MΩ, 0.07 Ω

8. 208 Ω

9. 56.25 W, 78.5%

10. 2, R_1 = 90 kΩ, R_2 = 111 kΩ

Suitable Tripos Questions

2008 is not in library
2007 IB Paper 5 Q1
2006 IB Paper 5 Q2
2005 IB Paper 5 Q1 part (d), Q 2
2004 IB Paper 5 Q2(a)