

Analogue and Digital Electronics Problem Sheet

Operational Amplifiers

Q1 The circuit of figure 1a is a non-inverting amplifier based on an operational amplifier (op-amp). The op-amp has a gain-bandwidth product of 10 MHz. If $R_1 = 2 \text{ k}\Omega$ and $R_2 = 10 \text{ k}\Omega$, find

- (i) the gain, v_o/v_i , of the circuit. (6 V/V)
- (ii) the -3 dB bandwidth you would expect the circuit to have. (1.67 MHz)
- (iii) the risetime of the output in response to an ideal step input. (assume here that the step is small, i.e., the output is not saturated by the step.) (0.21 μs)

The circuit of figure 1a is modified by replacing resistor R_1 by the circuit of figure 1b in which $R_3 = 220 \Omega$, $R_4 = 2 \text{ k}\Omega$ and $C = 10 \text{ nF}$.

- (iv) Write down the high and low frequency gains of the modified circuit. (l.f. 6 V/V; h.f. 51.5 V/V)
- (v) Show that the transfer function, v_o/v_i , of the modified circuit is given by

$$\frac{v_o}{v_i} = k \frac{\left(1 + j \frac{f}{f_0}\right)}{\left(1 + j \frac{f}{f_1}\right)} \text{ where } k = \frac{R_2 + R_4}{R_4}, f_0 = \frac{R_2 + R_4}{2\pi C(R_2 R_4 + R_2 R_3 + R_3 R_4)} \text{ and } f_1 = \frac{1}{2\pi C R_3}$$

- (vi) Sketch magnitude and phase response Bode plots for the amplifier using the values given for R_2 , R_3 , R_4 and C .

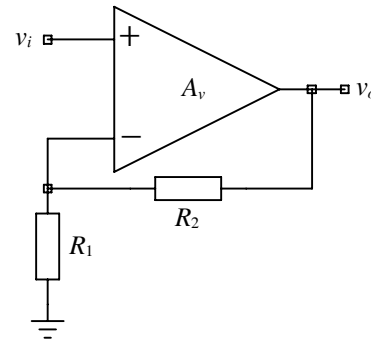


Figure 1a

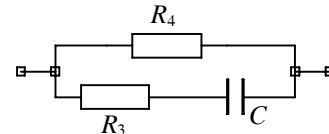


Figure 1b

Q2 Derive an expression for the gain-bandwidth product of the circuit of figure 2. (You should find that this inverting amplifier connection behaves slightly differently from the non-inverting case covered in the lecture notes.)

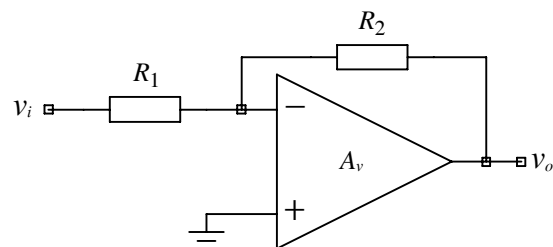


Figure 2

- Q3** In medical impedance imaging systems small voltages on the surface of a body are sensed by buffer amplifiers with a very high input impedance. If an op-amp voltage follower circuit is to be used as a sense amplifier which must not introduce a phase error greater than -0.1° at a frequency of 50 kHz, what gain-bandwidth product is required of the op-amp? (28.6MHz) (*remember that the buffer will be a first order system so you can write down its transfer function straight away.*)
- Q4** A particular op-amp for which you have no data is observed to have a step response of the form $k (1 - e^{-t/2.8 \times 10^{-6}})$ when wired to give a non-inverting gain of 250 V/V.
- (i) What is the gain-bandwidth product of the op-amp? (14.2MHz)
 - (ii) What 3dB bandwidth would you expect for a non-inverting gain of 10V/V? (1.42MHz)
 - (iii) What circuit risetime would you expect for the non-inverting gain of 10V/V? (246ns)
- Q5** A non-inverting amplifier circuit with a gain of 10 V/V uses an op-amp with a slew rate of 25 V/ μ s and a gain-bandwidth product of 15 MHz.
- (i) Evaluate $|\text{gain}|$ and phase shift of the amplifier at a frequency of 5 MHz. (2.87, -73°)
 - (ii) What is the maximum frequency at which a 20 V pk-pk sinusoidal output can be supported in undistorted (ie purely sinusoidal) form? (398kHz)
 - (iii) At what amplifier circuit gain would the exponential shape of the rising and falling edges of a 15 V pk-pk "square wave" output begin to be affected by the amplifier's slew rate capabilities? Would the exponential shape of the edges be affected by a gain of half this value? (56, Yes)
 - (iv) Why is the answer to part (iii) independent of the fundamental frequency of the square wave? (*assume that you can observe enough of the exponential response to identify its aiming level.*)

- Q6** For the circuit of figure 6, show that

$$v_o = \frac{2}{CR} \int v_i dt$$

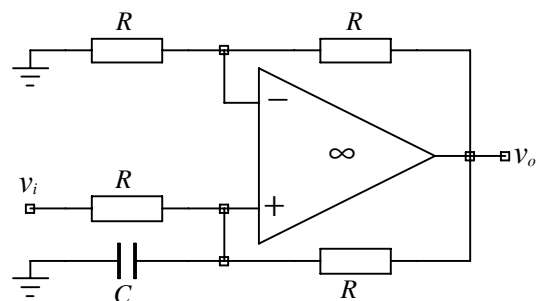


Figure 6

- Q7** Demonstrate that the finite gain defect of the op-amp in figure 7a can be represented by the equivalent circuit of figure 7b where the op-amp is ideal. (This process expresses the effects of finite A_v in terms of normal circuit elements and thus makes them easier to interpret.) **Hint:** approach the problem by showing that both circuits have the same transfer function.

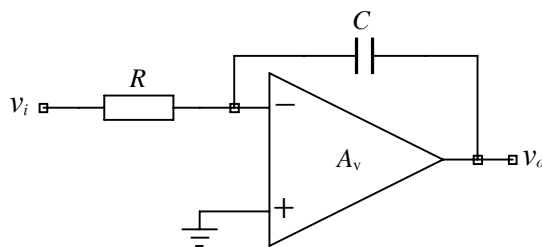


Figure 7a

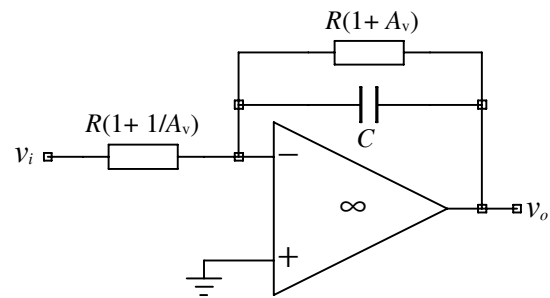


Figure 7b

- Q8** Choose values of R_2 , R_3 , and C in figure 8 to give pole and zero frequencies of 10 Hz and 500 Hz respectively and a high frequency gain of 10 V/V. Sketch the amplitude and phase response of the system. (4.99M Ω , 91.6k Ω , 3.13nF)

If an RC low pass circuit with a time constant of 79 μ s is attached to the op-amp output, sketch the overall frequency response of the circuit. (The overall response is a close approximation to the equalisation characteristic necessary to get a flat response from a magnetic record player cartridge.)

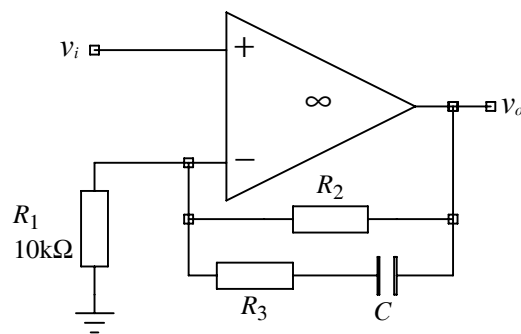


Figure 8