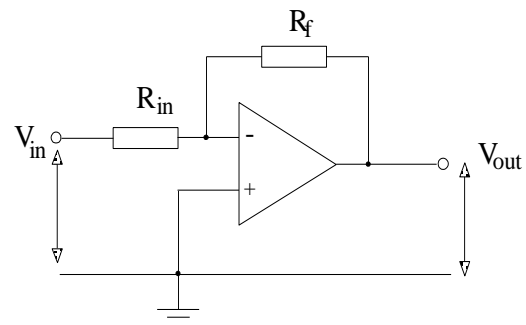


Problem Sheet 4

1.

The figure to the right shows an op-amp inverting amplifier design. Using the ideal-amplifier approximation, show that the voltage gain is given by

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}.$$



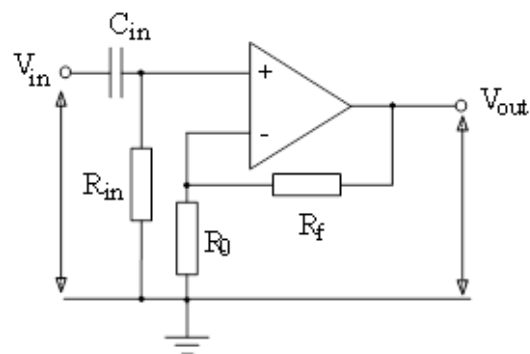
2.

(a) The figure to the right shows an AC amplifier. This is a non-inverting design with a high-pass filter at the input. For what situations might this circuit be used?

(b) For $R_{in} = 100 \text{ k}\Omega$, $R_0 = 20 \text{ k}\Omega$, $R_f = 1 \text{ M}\Omega$ and $C_{in} = 0.1 \text{ }\mu\text{F}$, what is the voltage gain of the circuit,

1. at 10 kHz?
2. at 10 Hz?

(c) If the circuit has a -3 dB point at 80 kHz followed by a gain roll-off of -20 dB/decade, make a rough sketch of the magnitude term of its Bode plot



3. SEMINAR QUESTION I

(a) We saw that an amplifier operated in 'closed-loop' (with negative feedback) has a gain given by:

$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{A}{1 + \beta A} \quad [\text{Eqn.1}]$$

where A is the open-loop gain and β is the fraction of the output voltage V_{out} fed-back into the input. For the ideal-amplifier approximation this becomes

$$\text{Gain} = \frac{1}{\beta} \quad [\text{Eqn. 2}]$$

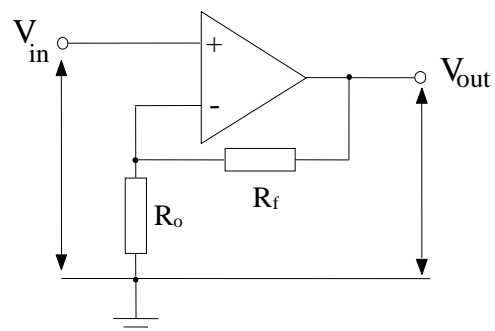
The figure shows a non-inverting amplifier. Derive the expression for β in terms of R_f and R_0 .

(b) For the ideal amplifier approximation, show that equation (2) is valid and agrees with the β derived above.

(c) For finite gain A , show that equation (1) is valid.

(d) For $R_0 = 10 \text{ k}\Omega$ and $R_f = 990 \text{ k}\Omega$, what is the gain of the system (ideal approximation)?

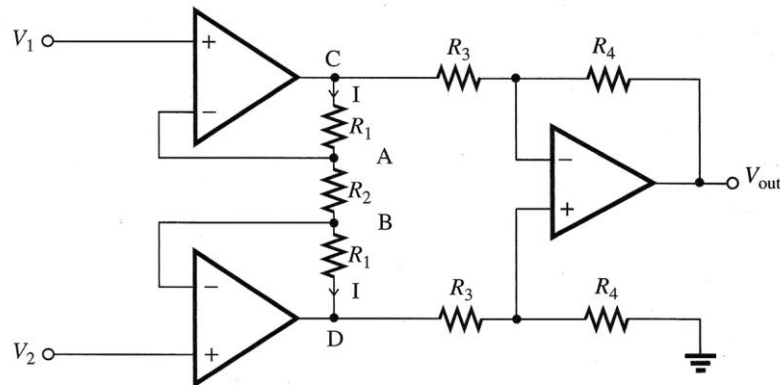
(e) For 'real world' op-amp amps with open loop gains of 10^9 , 10^6 and 10^3 what is the error on the gain compared to that for the ideal amplifier?



Instrumentation

4.

(a) The figure below shows the design of the Instrumentation Amplifier. This is implemented as a single-chip design in the Burr-Brown INA114 model. In this case, the resistances $R_1 = R_3 = R_4 = 25\text{k}\Omega$ are set on the chip and laser-trimmed to provide a near-perfect match. The resistor R_2 is connected external to the chip in order to set the gain to be anything from 1 to 10,000.



If we choose $R_2 = 1\text{k}\Omega$ then what is the differential gain of the amplifier?

(b) The data sheet from Burr-Brown quotes a common-mode rejection ratio of 120 dB. Calculate the common-mode gain and use this to calculate V_{out} for a differential input of 0.1 V with a common-mode input of zero. What happens when the common-mode input is changed to 10 V (keeping the same differential input)?

5. SEMINAR QUESTION II

You have a pair of signal generators which you can set up to produce simple sinusoid waveforms such as $A \cos \omega t$, $3A \cos 2\omega t$, etc. (you can assume that the signal generators can be synchronised to have zero phase difference at $t = 0$). You wish to produce the waveform $-A \cos^3 \omega t$. Design a circuit to do this.

You may want to do the calculation in stages. You can use as many op-amps and resistors as you like.

However, there is one elegant solution which uses just one op-amp and three resistors. Can you describe it?

Numerical Answers and Hints

1. Find the virtual ground then calculate the current through each resistor; apply Kirchhoff's current law
2. Note that since the op-amp has a very high input impedance it doesn't load the filter at all so we can consider the filter and amplifier as two separate circuits which each have a separate gain. (b) 51, 27 (c) This device will have both an upper and lower frequency cut-off, i.e. it looks like a band-pass filter with gain.
3. (c) Rule 1 does not apply, so calculate the output voltage based on the difference between the two inputs (d) 100 (e) $10^{-5}\%$, $10^{-2}\%$, 10%
4. Use the formula given in the hand-out for the output voltage of the instrumentation amplifier (a) 51 (b) 51×10^{-6} , 5.1V, 5.10005V
5. Find a trig identity for $\cos^3 x$. The summing amplifier may be adjusted to weight the input signals differently by using different resistors, and we can set the overall scaling of the result by choosing the feedback resistor. This is tricky.