Unit 49 Frequency response of op-amps

- The open loop frequency response of a 741 op-amp has a corner at 10 Hz and 100 dB.

- The open loop gain decreases by 20 dB for every factor of 10 increase in frequency above 10 Hz.

- The frequency response of a real amplifier is determined by the lower of:

  - The theoretical response set by the feedback components.
  - The response of the op-amp.

We have, until now, assumed that op-amps amplify signals at all frequencies with equal efficiency. This is not the case.

Since an op-amp has a high open loop gain, any spurious positive feedback from the output to the noninverting input can cause the amplifier to oscillate violently from full positive output to full negative output. Such positive feedback occurs most easily at high frequencies because the impedance of any stray capacitance between the output and the input causing positive feedback decreases with increasing frequency. Op-amps are therefore designed to have an open loop gain which decreases with increasing frequency so as to reduce the risk of positive feedback at higher frequencies. This is achieved by including a capacitor, fabricated on the silicon chip, in the op-amp internal circuit. This capacitance can be seen in the 741 op-amp circuit shown in Figure 35.5.

The open loop voltage gain of a typical op-amp such as the 741 is shown in Figure 49.1. This characteristic gain curve is very important and you should be able to sketch it without having to refer to Figure 49.1. Essentially the open loop gain is constant at 100 dB from DC up to 10 Hz. From 10 Hz upwards in frequency, the gain decreases by 20 dB for every factor of 10

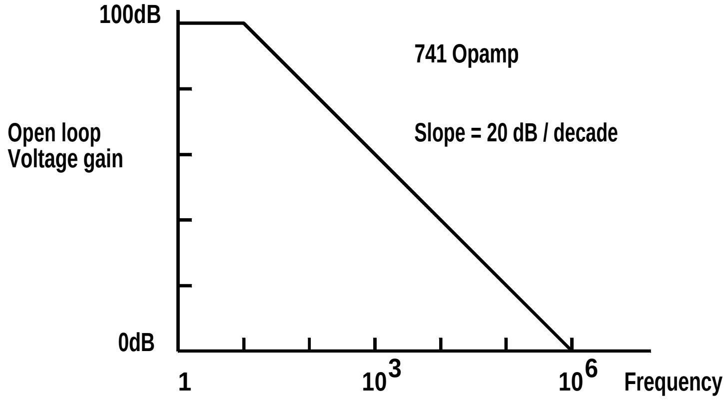

Figure 49.1: Open loop gain as a function of frequency for the 741.

increase in frequency, reaching a gain of 0 dB at a frequency of 10^6 Hz. The key feature is the corner at 10 Hz and 100 dB.

This curve is measured using a circuit such as that in Figure 49.2 in which the signal is applied directly between the two inputs to the op-amp without any negative feedback being used; hence the term open loop.

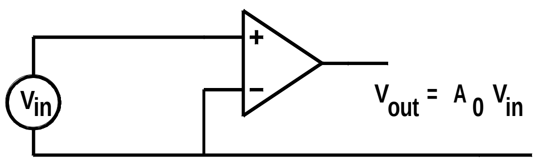

Figure 49.2: Circuit used to measure open loop gain.

Now let us examine how this op-amp frequency response affects the response of amplifiers built using op-amps.

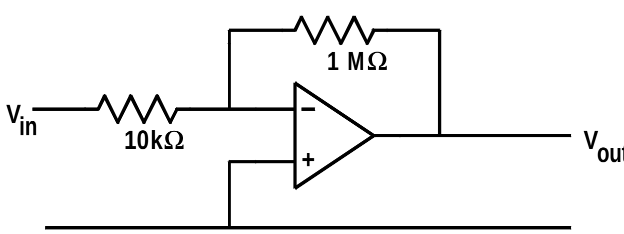

Figure 49.3: Inverting amplifier.

Figure 49.3 shows an inverting amplifier which has a gain of:

$$A = 20 \log \left(\frac{1\,\mathrm{M}\Omega}{10\,\mathrm{k}\Omega} \right) = 40\,\mathrm{dB}$$

In theory the gain is 40 dB at all frequencies. However, if we take the op-amp response and draw a line corresponding to a nominal 40 dB amplifier gain on the op-amp response curve we get Figure 49.4.

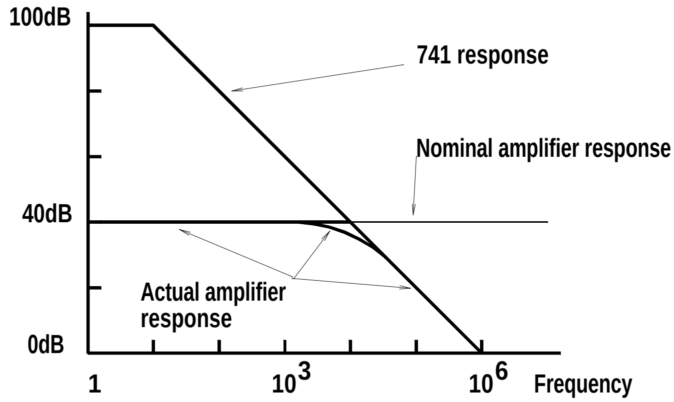

Figure 49.4: Concatenation of 741 response with amplifier response.

For frequencies below 10^4 Hz, the nominal amplifier response is below the op-amp open loop response so there is gain to spare for negative feedback. For frequencies above 10^4 Hz, the nominal gain is greater than the op-amp gain so the amplifier response is limited by the op-amp response and follows the op-amp response downwards. This is indicated as the actual amplifier response on the curve.

The general procedure is therefore to plot the gain as determined by the feedback components onto the op-amp response and then to obtain the actual response as the envelope of the lower of the two curves. The shape of the response is similar to that of an *RC* low pass filter not only in the dB response shape but also in the fact that on the downward part of the response there is a phase shift of 90° between the input and output signal at these high frequencies.

The bandwidth is usually defined as the frequency range over which the response is constant to within 3 dB. In this example the bandwidth extends from DC or 0 Hz up to 10 kHz and the bandwidth is then 10 kHz.

It can easily be seen that if resistors are chosen to give a high gain amplifier the penalty is that the bandwidth is low. If the gain is low then a high bandwidth is available.

The op-amp frequency response also affects the performance of the active filters examined in Unit 48. With active filters it is best to use a moderate gain so that the frequency response is determined by the filter design and not by the op-amp response. It is easy to obtain broadband gain with a later amplifier stage. It can also be seen that op-amps such as the 741 are not of significant use at frequencies above about 100 kHz. Special high frequency op-amps are available for high frequency work but are more expensive and are much more prone to instability unless great care is taken with the circuit design and layout.

49.1 Problems

49.1 Calculate the gain of the amplifier in Figure 49.5. Sketch the frequency response for the amplifier. Determine the bandwidth of the amplifier.

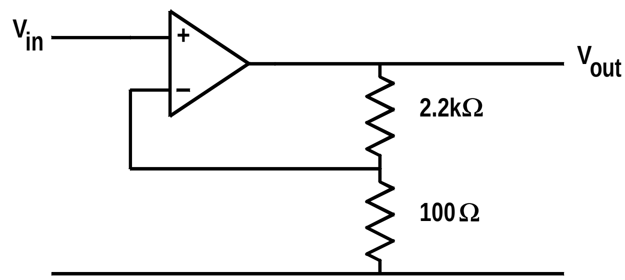

Figure 49.5: Problem 49.1.

49.2 What is the bandwidth of an inverting amplifier which uses a 741 op-amp and has a gain of −50? Sketch a suitable circuit with component values.

49.3 Design a noninverting amplifier which has a bandwidth from DC to 300 Hz. What will be the maximum gain that can be obtained if a 741 op-amp is used?

49.4 Derive an expression for the magnitude of the ratio of the output to input signals for sinusoidal signals for the differentiator circuit shown in Figure 49.6. Plot this response on the frequency response curve for the 741 op-amp and obtain the amplifier frequency response.

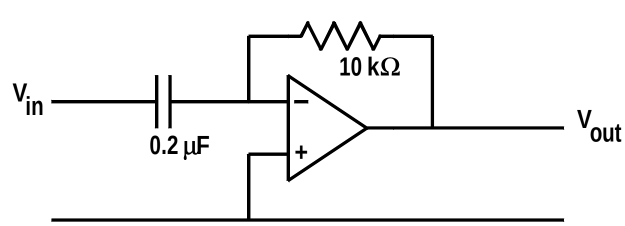

Figure 49.6: Problem 49.4.