INF3410 - ANALOG MICROELECTRONICS

LAB 3

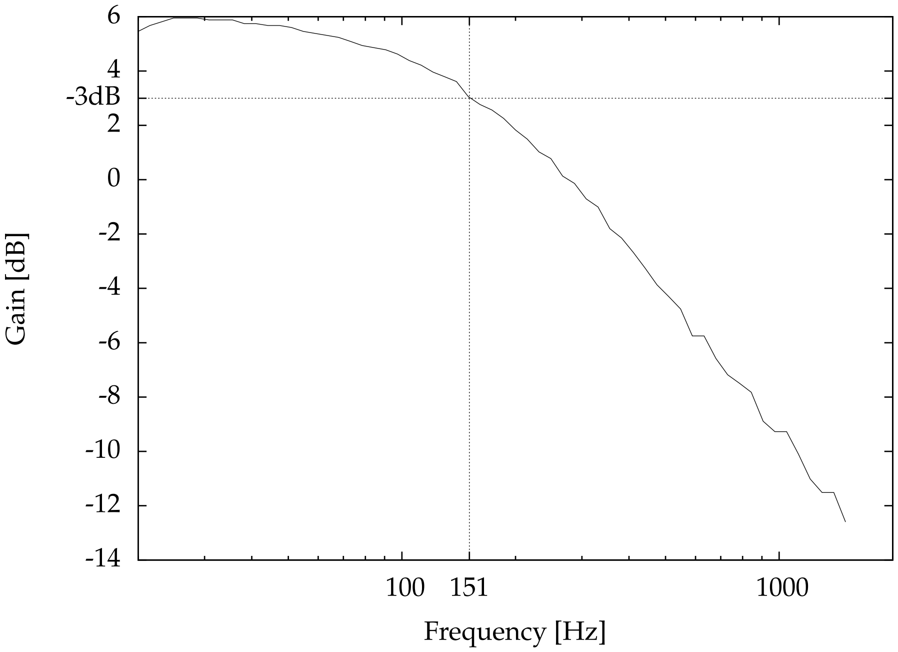
FREQUENCY RESPONSE OF CMOS OP-AMPS

Eino Juhani Oltedal(einojo)
einojo@student.matnat.uio.no

Maris Tali(maristal)
maristal@student.matnat.uio.no

Group: 1
Date: 21. november 2012

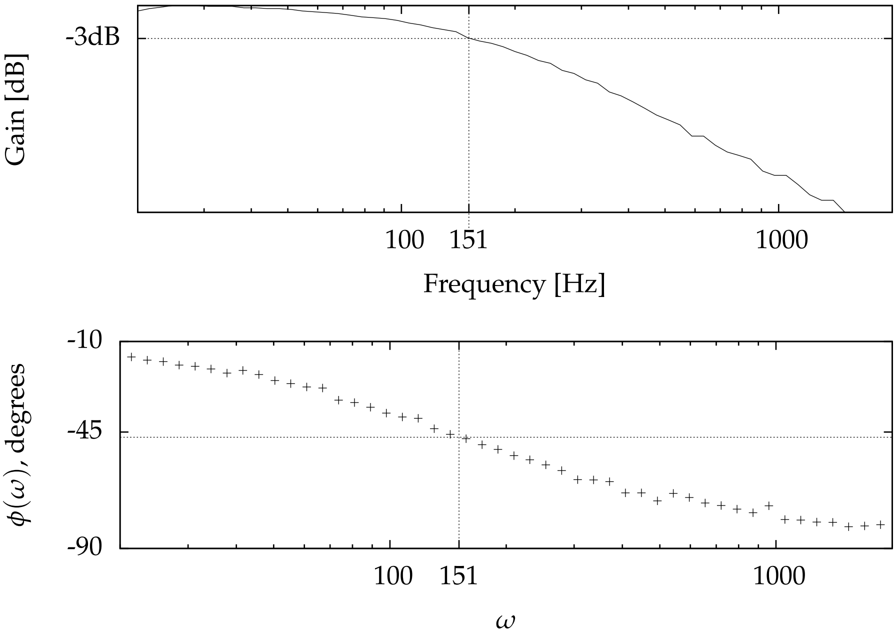
Question a



Figur 1: BODE-plot of first order RC filter with corner frequency marked

The exercise called for measuring from 100Hz to 1MHz, but since the theoretical corner frequency is $\frac{1}{2\pi RC} = \frac{1}{2\pi 100\text{k}\Omega 10\text{nF}} = 159\,\text{Hz}$ we concluded that a reasonable sweeping range was 20Hz to 1.5kHz, after which no usefull data is found. When measuring on the filter we found that it starts with a 6dB gain, the -3dB point is $6dB - 3dB = 3dB$ which looking at the graph in figure 1 corresonds to 151Hz. This is very close to the theoretical corner frequency.

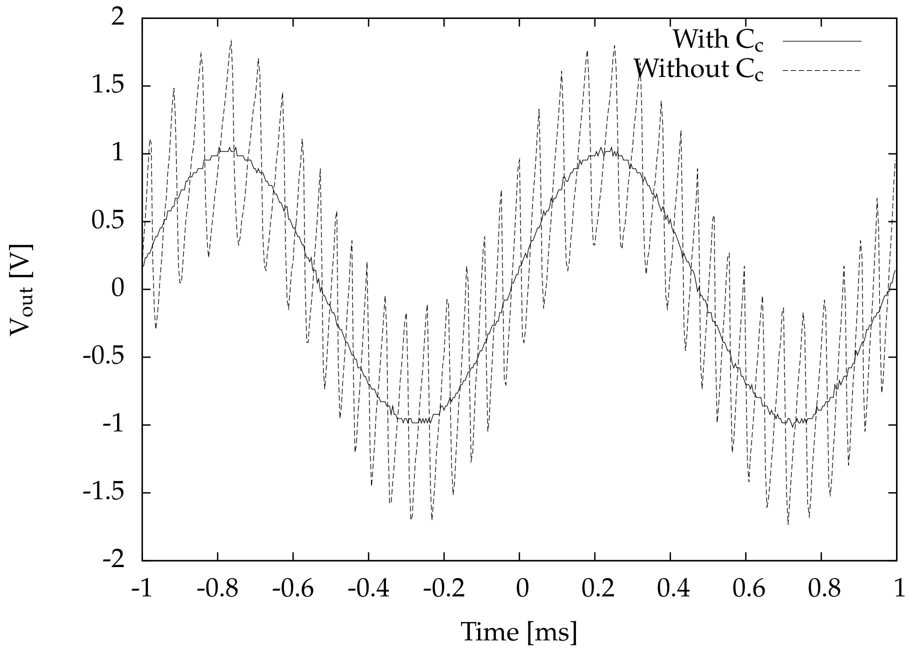
Question b



Figur 2: BODE-plot of both phase and gain

Analytically the phase curve starts to fall with 45 degrees per decade one decade before the corner frequency, so at corner frequency th phase would be at -45 degrees. It would stop falling one decade after the corner frequency and end up at -90 degrees. Our results show that the phase is at -47 degrees at he -3dB point (corner frequency), which is reasonably close to what was expected.

Question c



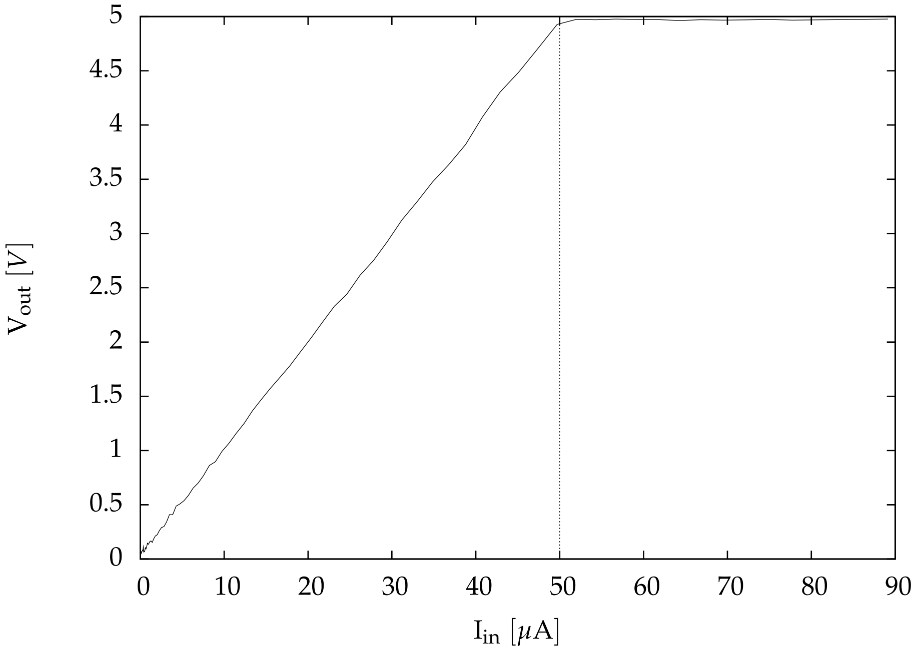
Figur 3: V_{out} of a voltage follower plotted against time with and without a compensation capacitor $C_c = 0.1nF$. $V_{in} = 2V@1kHz$

From figure 3 we can see that without the compensations capacitor the signal has a consideerbale amount of noice in the output signal (an oscillation with an amplitude of about 1.5V).

The capacitor removes this extra oscillation and the output signal follows the input signal at 1000 Hz.

The purpose of the compensation capacitor C_c is to move the lowest frequency pole of the amplifier lower and the higher frequency pole event higher, this increases the stabillity of the amplifier and avoids oscillation and improves step respons. However this also reduces the slew rate.

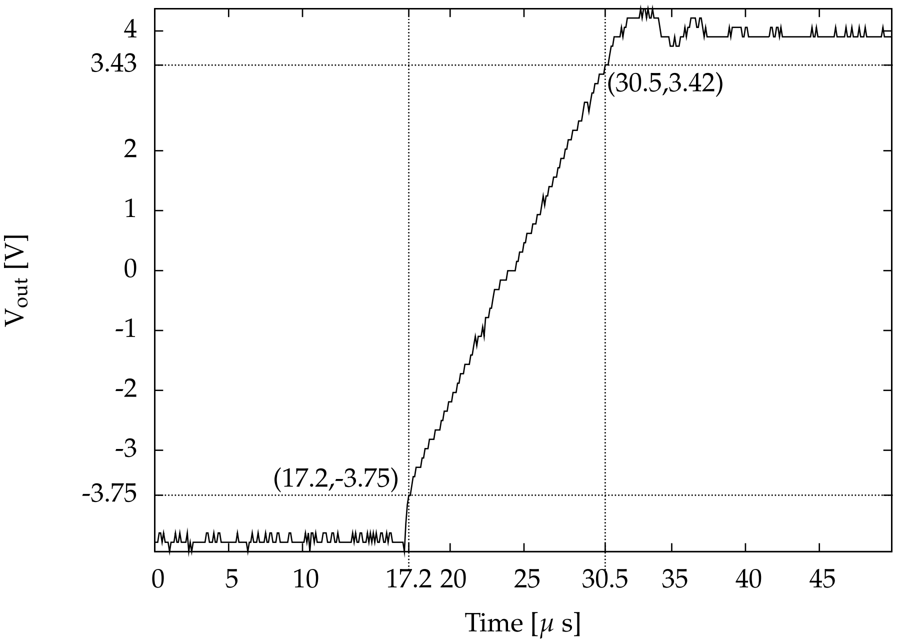
Question d



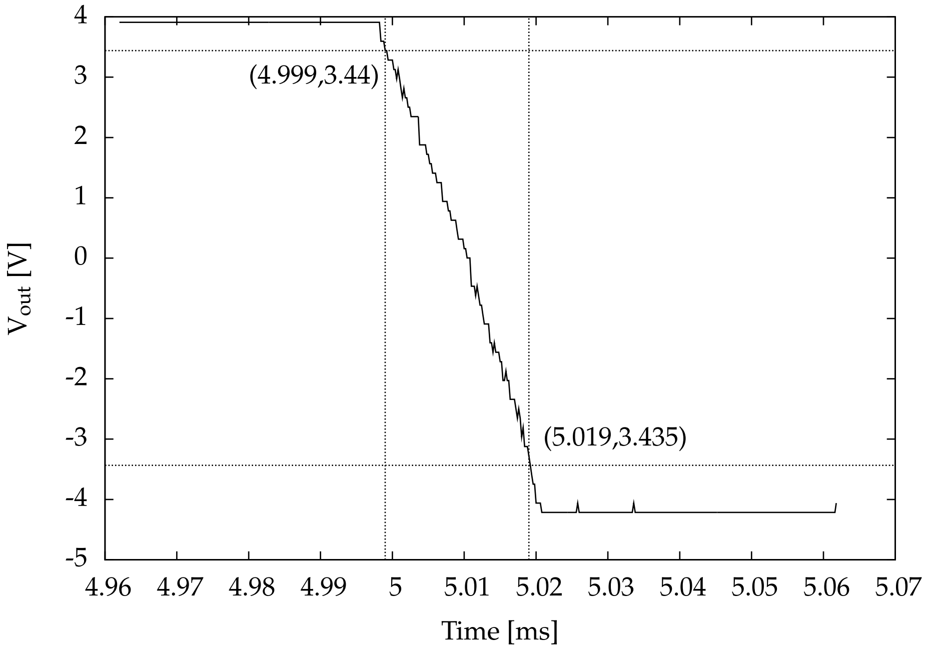
Figur 4: Output voltage plotted against input current of a transimpedance amplifier

We used an NMOS current sink as a current source and varied the input current by varying the V_{gs} of the current sink. The plot in figure 4 shows that the transimpedance amplifier has a linear operating range between 0 and 50 μA.

Question e



Figur 5: V_{out} plotted agains time of a voltage follower with a large swing input signal. Showing positive going transistion.



Figur 6: V_{out} plotted agains time of a voltage follower with a large swing input signal. Showing negative going transistion.

The slew-rate of the positive going transistion is:

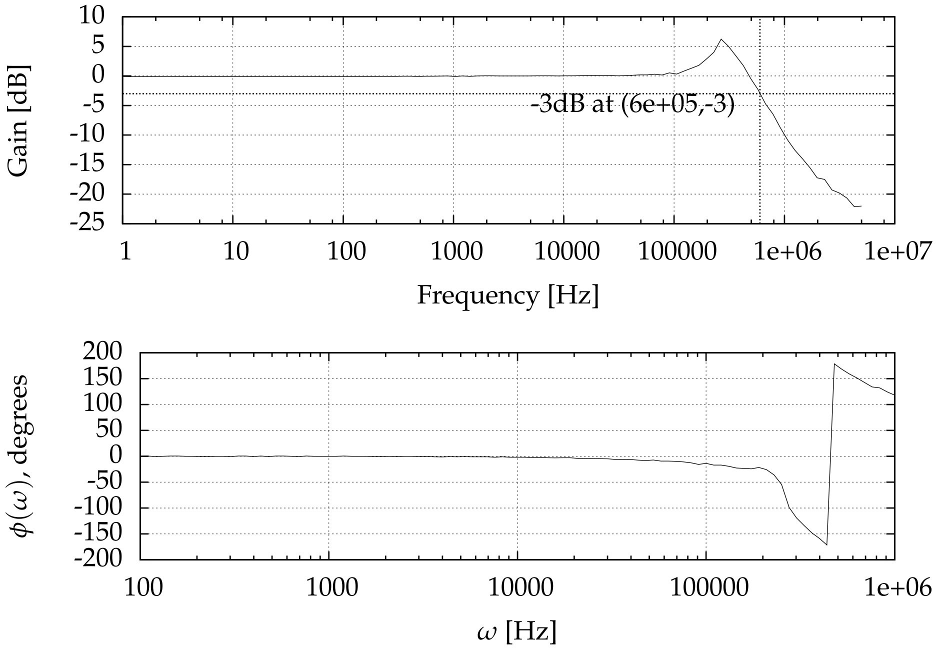
$$slewrate = \frac{3.43\text{V} + 3.75\text{V}}{30.5\mu\text{s} - 17.2\mu\text{s}} = 0.53\text{V}/\mu\text{s} \tag{1}$$

The slew-rate of the negative going transistion is:

$$slewrate = \left| \frac{3.44\text{V} + 3.435\text{V}}{0.004999\text{s} - 0.005019\text{s}} \right| \cdot 10^{-6} = 0.344\text{V}/\mu\text{s} \tag{2}$$

Question f

We applied a ±150mV sinusodal to the input of the voltage follower. When the phase drops below 180° the oscilloscope starts measuring the positive phase instead of the negative, because it measures the phase shift closes to the input signal.



Figur 7: Frequency and phase characteristics of the voltage follower when a ±150mV sinusodal is applied to the input.

From figure 7 We can see that the -3dB point is at 600kHz, which means that the bandwidth of the amplifier is 600kHz.

Question g

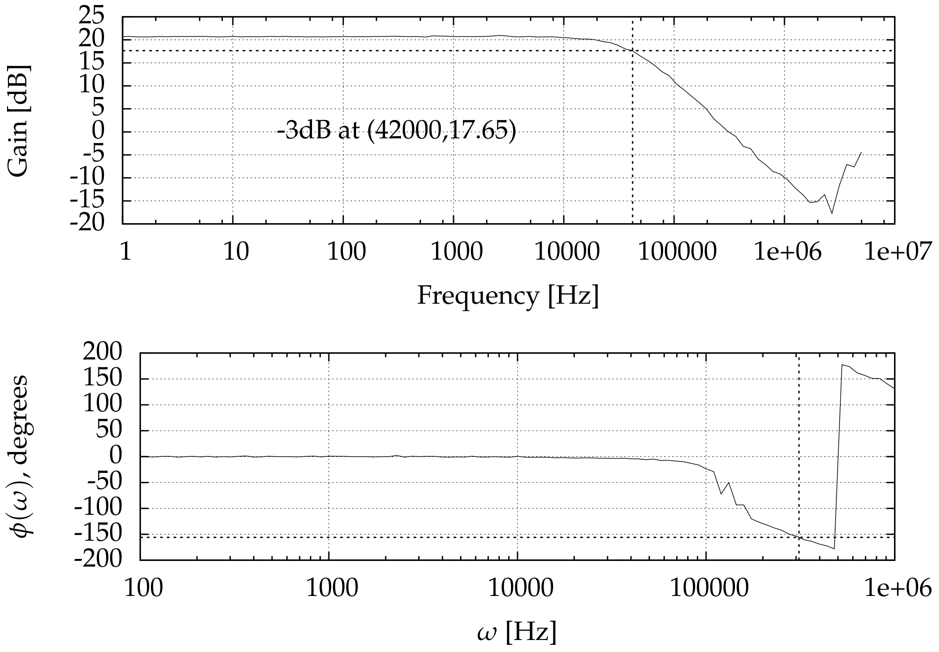
Assuming that the OP-AMP is ideal the current through the 1MΩ resistor has to be the same as the current through the 100kΩ resistor, because there is no current going from V_- to V_+ because of the infinite input impedance. The voltage difference between the inputs is zero, therefore:

$$\begin{aligned}
V_{in} =& V_+ = V_- \\
I =& \frac{V_{in}}{100\text{k}} = \frac{V_{out} - Vin}{1\text{M}\Omega} \\
\frac{V_{out} - Vin}{V_{in}} =& \frac{1\text{M}\Omega}{100\text{k}} \\
\frac{V_{out}}{V_{in}} - 1 =& \frac{1\text{M}\Omega}{100\text{k}} \\
\frac{V_{out}}{V_{in}} =& \frac{1\text{M}\Omega}{100\text{k}} + 1 \\
\frac{V_{out}}{V_{in}} =& 10 + 1 \\
\frac{V_{out}}{V_{in}} =& 11
\end{aligned} \tag{3}$$

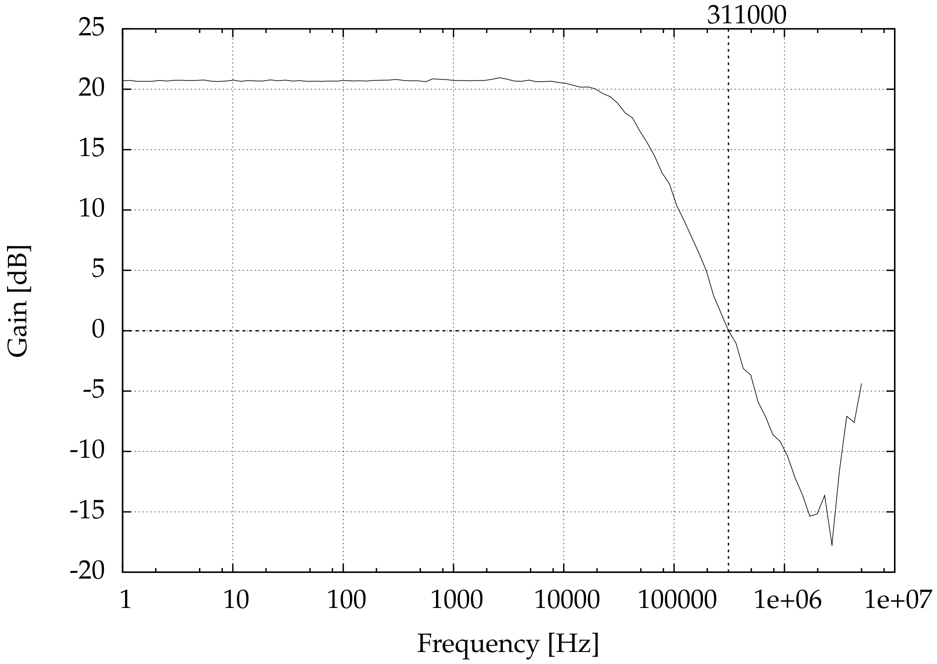
The expected closed loop gain of the amplifier is 11.

Question h

We applied a ±150mV sinusodal to the input of the voltage follower. When the phase drops below 180° the oscilloscope starts measuring the positive phase instead of the negative, because it measures the phase shift closest to the input signal.



Figur 8: BODE-plot gain and phase of non-inverting amplifier with a gain of 11.



Figur 9: BODE-plot gain of non-inverting amplifier with unity gain marked.

From figure 8 we can see that the corner frequency is 42kHz, which means that the bandwidth is 42kHz. The bandwidth is now 558kHz lower than in the voltage follower. The unity gain frequency is the frequency at which the gain of the amplifier is 1 (0 dB,unity). From figure 9 we see that for this configuration the unity gain frequency is 311kHz.

Question i

On the phase plot of figure 8 we found a phase shift of 156° at unit gain frequency, this gives a phase margin of $180^\circ - 156^\circ = 24^\circ$.
To estimate the phase margin we find the -3dB frequency in figure 8 and we subtrac from 180° the phaseshift caused by the -3dB at unit gain frequency:

$$\begin{aligned} PM =& 180^\circ - \arctan(\frac{\omega_t}{\omega_p}) \\ PM =& 180^\circ - \arctan(\frac{311kHz}{42kHz}) \\ PM =& 180^\circ - 82.31^\circ \\ PM =& 97.7^\circ \end{aligned} \tag{4}$$

The difference between the analytical and measured phase margin is so big due to the fact that we did not take into account additional poles created by the capacitances related to the transistors.

Question j

Gain bandwidth product of voltage follower (see figure 7):

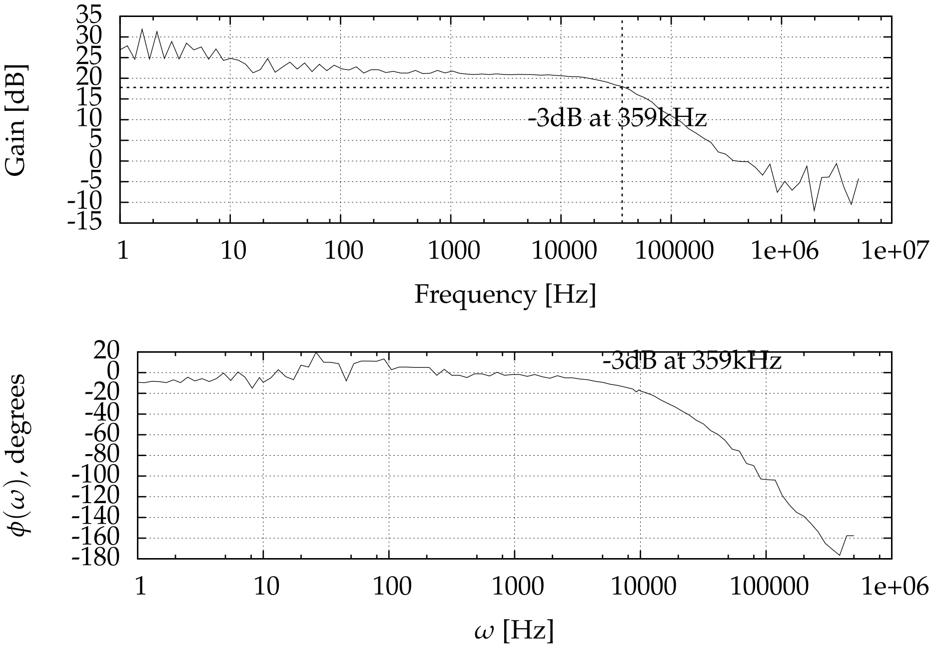
$$\begin{aligned} GBW =& A_v(f=0) \cdot f(A_v=0) \\ GBW =& 1 \cdot 600\text{kHz} = 600\text{kHz} \end{aligned} \tag{5}$$

Gain bandwidth product of amplifier with a gain of 11(see figure 8):

$$\begin{aligned} GBW =& A_v(f=0) \cdot f(A_v=0) \\ GBW =& 11 \cdot 42\text{kHz} = 462\text{kHz} \end{aligned} \tag{6}$$

The gain bandwith product of the both experiments should be equal, however they vary by 138kHz. This variation probably comes from inaccurate measuremeants, human error, and instrument errors.

Question k



Figur 10:

We calculated the -3dB point by subtracting 3 from the initial gain 20.8. From figure 10 we can see that the estimated corner frequency of the amplifier with capacitive feedback is 359kHz, which means that the bandwidth is also 359kHz.

Question l

Trade-offs for larger capacitive values:
We get a higher breakdown voltage, but the capacitors becomes larger and use more current.

Trade-offs for smaller capacitive values:
The capacitors become smaller and require less current, however the breakdown voltage becomes lower.