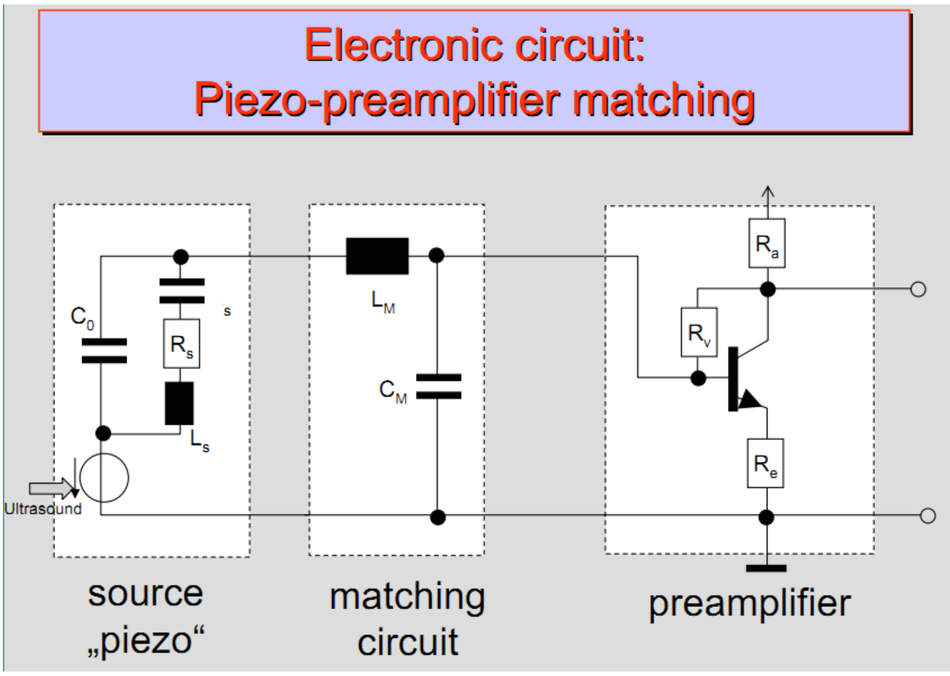
Medical Engineering:
Ultrasound Diagnosis Sensor and its Preamplifier

Name:	Matrikelnummer:



Part 1: Introduction to PSpice analysing a low-pass filter 1st order

Activities: First steps in the simulation software "LTspice" by analyzing a low-pass filter 1st order. Usage, drawing circuits, setting of simulation command and display of plots and diagrams.

Aim: Knowledge about simulation of electrical circuits using numerical methods as "SPICE". Understanding of basic analyzing tools as Nyquist Plot and Bode Diagram for validation of frequency response in electrical systems.

Analysis: Operating-point-analysis and AC-analysis with graphical display of the Nyquist plot and Bode diagram

Part 2: Frequency Response of an ultrasound piezo-crystal using an RCL-model

Activities: Drawing of electrical circuit corresponding to a model of a piezo crystal. Nyquist plot of the electrical impedance and validation of the impedance at ultrasound transmitting frequency f_T = 2MHz

Aim: Validation of a source impedance of a sensor at a certain frequency using AC-analysis and Nyquist Plot with possibilities of cursor measurements.

Analysis: Operating-point-analysis and AC-analysis with graphical display of the Nyquist plot and cursor measurements

Part 3: Frequency Response of a low-pass filter 2nd order as a matching filter for impedance transformation

Activities: Drawing of electrical circuit and profile setting for parameter variation of a resistive load using Bode Diagram of the voltage-transfer-function.

Aim: Simulation of electrical circuits by numerical methods using "LTspice". Understanding of the basic methods using a Bode Diagram for frequency transfer function of an electrical system.

Analysis: Bias-point-analysis and AC-analysis with graphical display of the Bode diagram

Part 4: Preamplifier and matching to the sensor "piezo"

Activities: Drawing of the electrical circuit of a transistor-preamplifier and analyzing the circuit with a sinusoidal source signal (2 MHz) with validation of the input impedance of the preamplifier. Matching of the input impedance by variation of the "emitter"-resistance of the transistor.

Aim: Understanding of basic analysis in time domain using sinusoidal signals with current and voltage measurements. Matching of the input impedance by variation of a certain resistor.

Analysis: Bias-point-analysis and time domain-analysis with graphical display over time and cursor measurements.

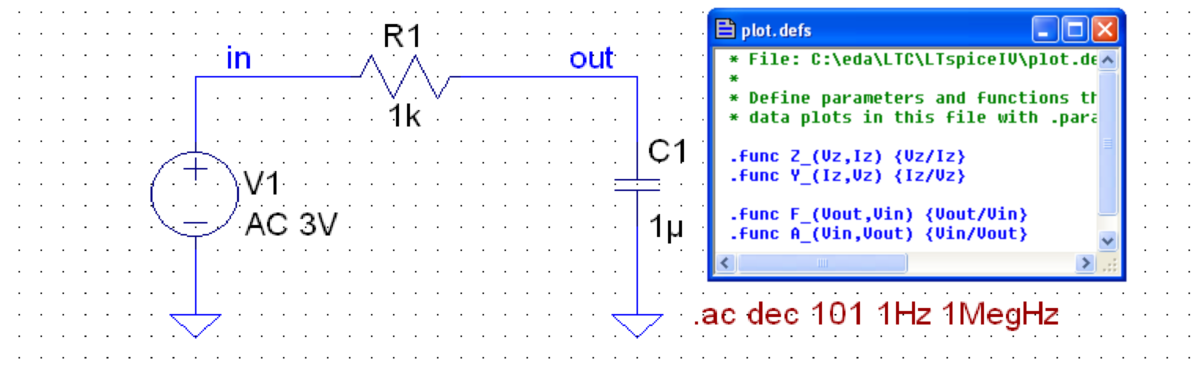
1 Low-pass filter 1st order

1.1 Drawing electrical circuit

At first, please generate a new schematic like shown in Figure 1.1.
Use the "LTspice Getting started" or the "LTspice_Qick" manual for reference.

Please use the parts ***"voltage"***, ***"R"***, ***"C"*** and ***"Ground"*** and mark the lines by node-with names (***"in"*** ; ***"out"***) for better orientation
In addition, add some function definitions to calculate input impedance and admittance and set up an ***AC-Analysis*** from ***1Hz to 1MHz*** with ***101 points / decade***.

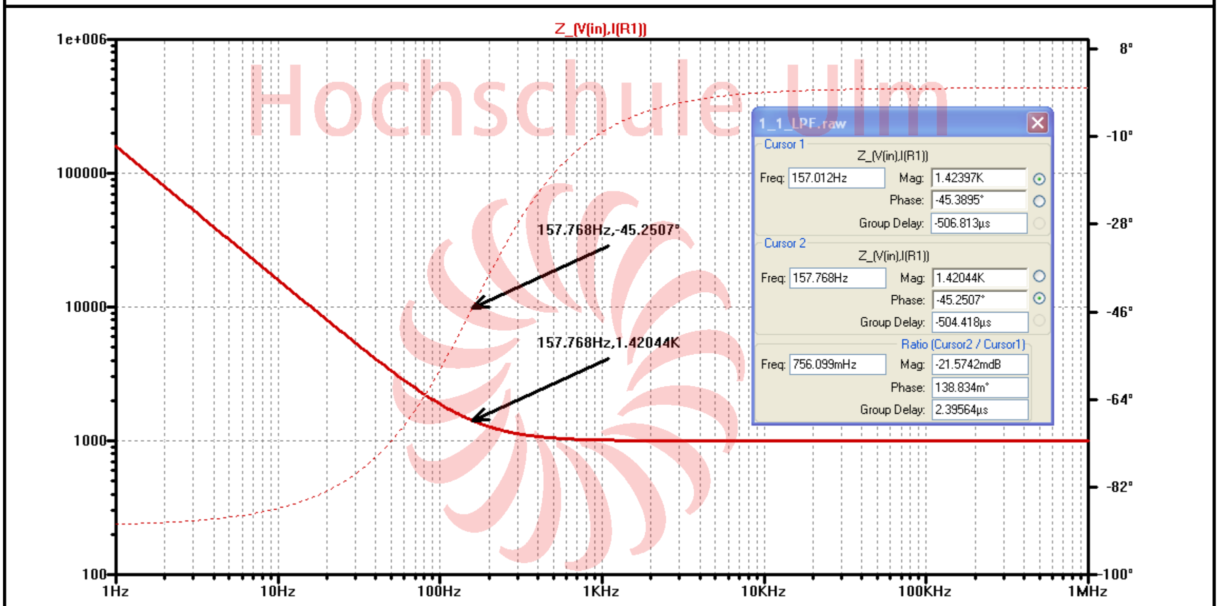
Fig. 1.1:: Electrical circuit of the low-pass filter of the 1st order / function



1.2 Simulation of the input impedance of the low-pass filter

Please create a XY-diagram (Bode Plot) of the input impedance and its phase. Add some function definitions to the plot definitions file via ***Plot Settings | Edit Plot Defs File.***
Display "Z" in a logarithmic scale (not in dB) and ensure that the graphs are not congruent with the axes, by adjusting the vertical axis settings !
Find the cut-off frequency with the cursors and mark the points using the Annotations menu.

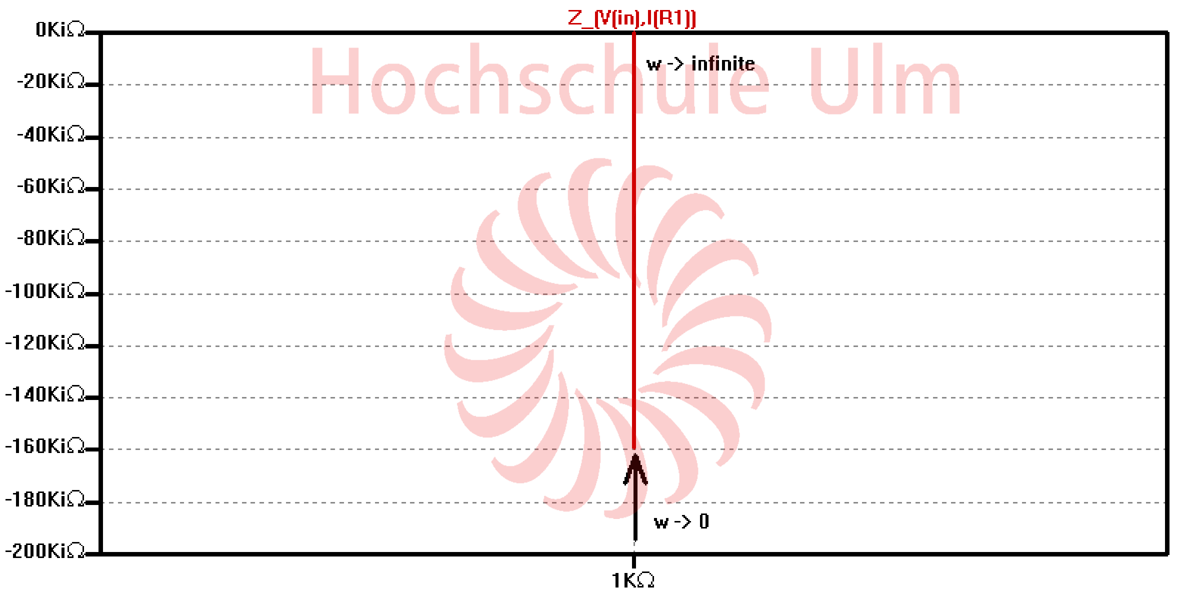
Fig. 1.2: Documentation: xy-diagram of the input impedance



Now create the Nyquist plot of the input impedance Z of the filter by changing the representation mode in the left vertical axis settings dialog.

Add comments / arrow to show the run of the curve and mark frequencies 0Hz and infinite.

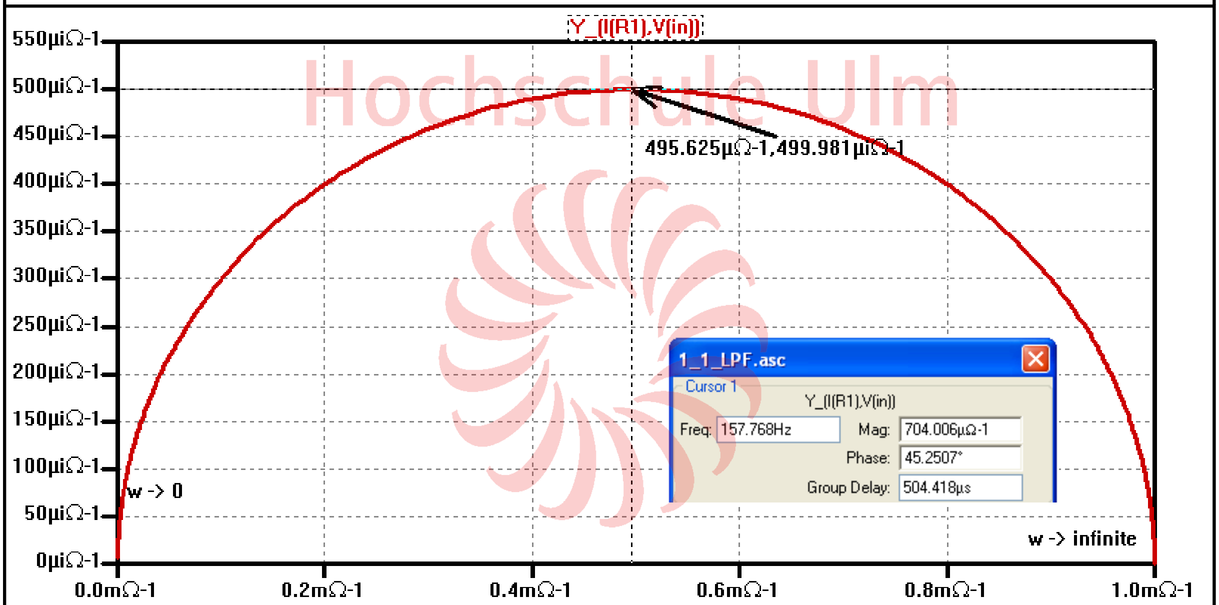
Fig. 1.3: Documentation: Nyquist plot for the input impedance



Further on, please generate a Nyquist-plot of the input- admittance Yin = 1/Zin of the low pass filter. Please add comments / arrow to show the run of the curve and mark frequencies 0Hz and infinite.

Try to find the cut-off frequency with the cursor and mark this point via the menu
| ***Plot Settings*** | ***Notes & Annotations*** | ***Label Curs. Pos.*** |

Fig. 1.4: Documentation: Nyquist plot for the input admittance

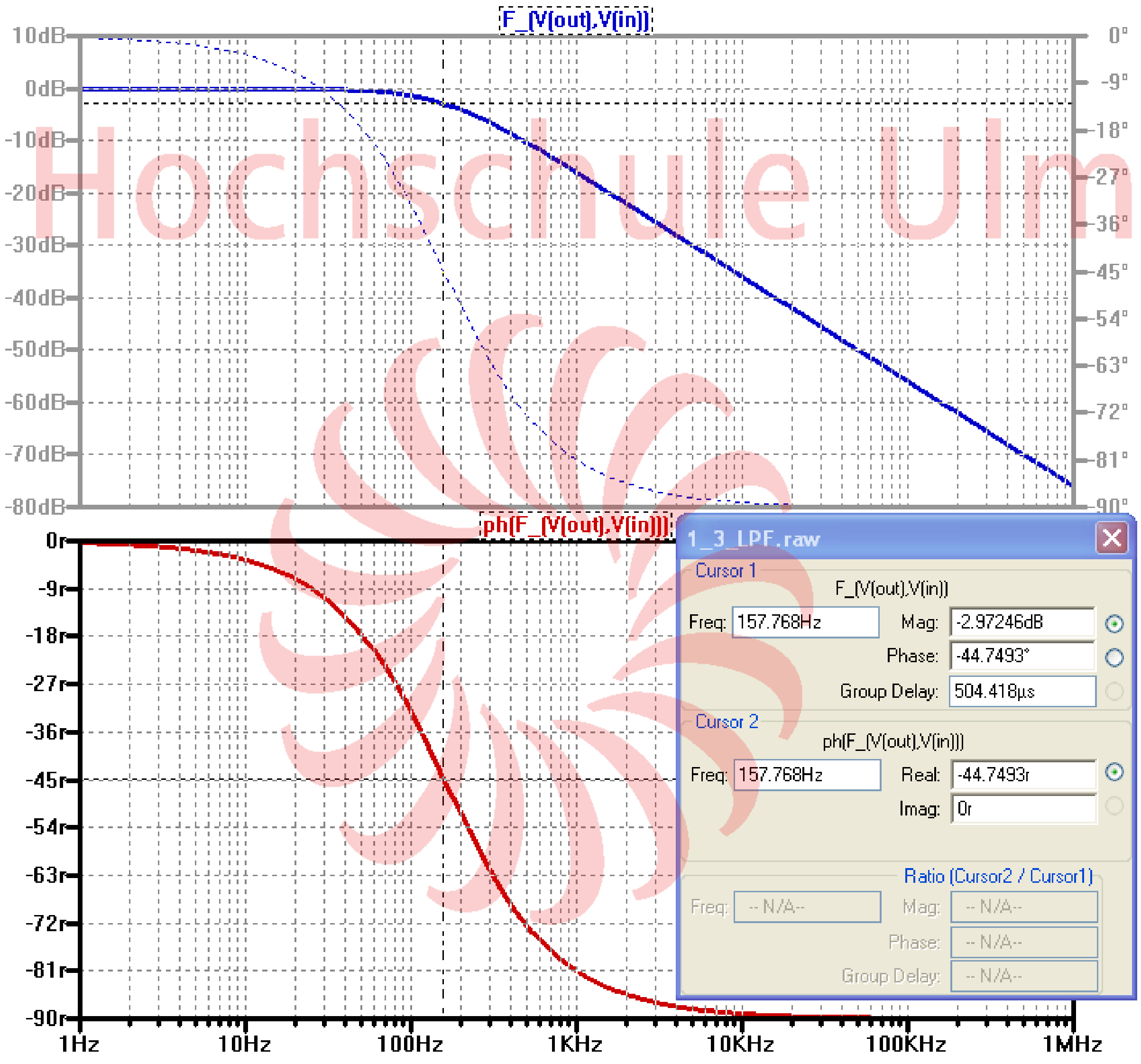


1.3 Simulation of the transfer function and display as a Bode Diagram

Please add a directive for the transfer function $F = U_{out} / U_{in}$ in the schematic editor window and document the Bode Diagram within the specified frequency range (1Hz to 1MHz).

Try to create two separate plots, one for the magnitude and one for the phase of the transfer function and label the frequency with φ = -45° in the diagrams using cursor measurements.

Fig. 1.5: Bode diagram of the low-pass filter 1st order



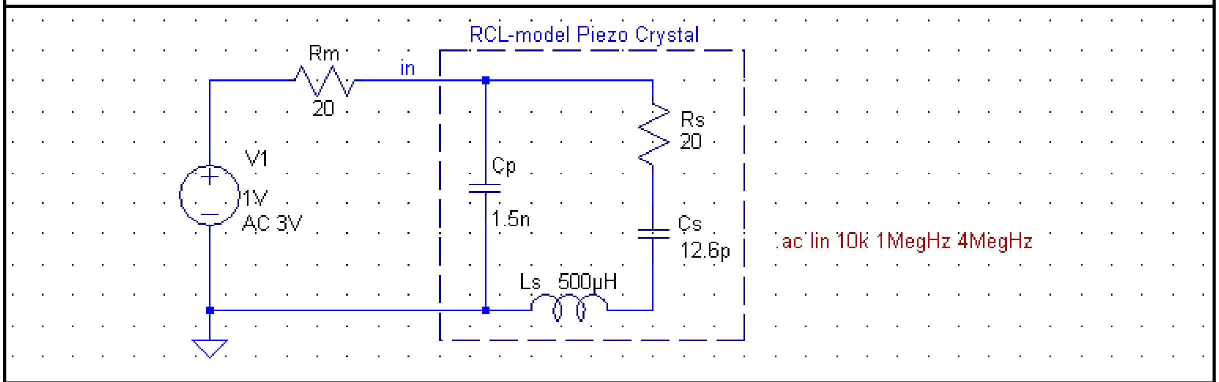
Value for the upper cutoff-frequency: ω_{cu} |{ φ = 45°} =

2 Frequency response of the piezo-crystal using RCL-model

2.1 *Drawing the electrical circuit model for piezoelectric crystal*

Draw the electrical circuit model of the ultrasound crystal.
Please label input line of the model by net-name "in" for better orientation.

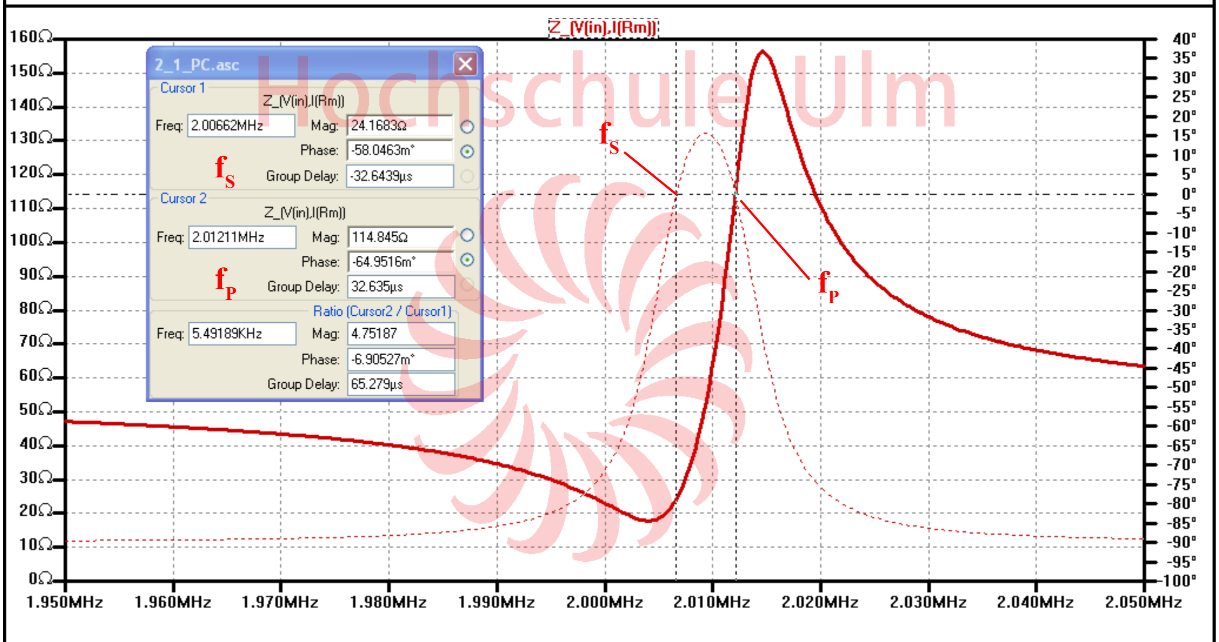
Fig. 2.1: Electrical circuit / model of the ultrasound crystal



2.2 *Simulation of Piezo impedance around its characteristic frequency*

Please define a the SPICE-directive (simulation command) for a linear AC-analysis from 1MHz to 4MHz and create an XY-diagram for $Z_{crystal}$ and its phase over frequency.

Fig. 2.2: Documentation - crystal impedance over frequency

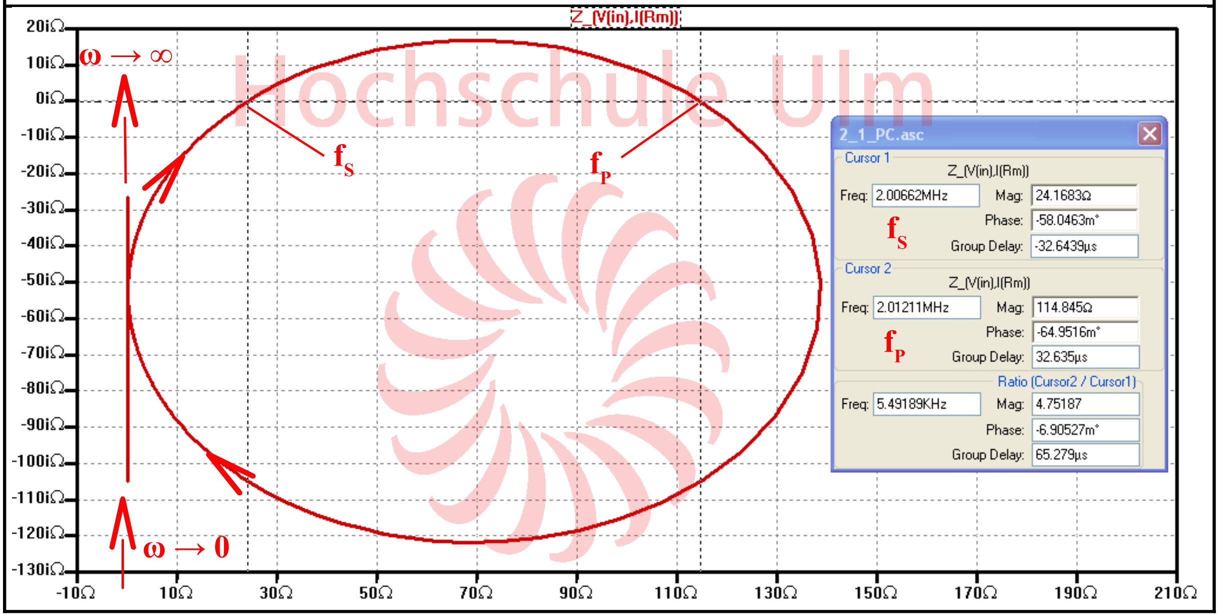


Measure the impedance at the serial resonance frequency for the phase φ = 0°, where the optimum power is transmitted to the preamplifier.

Cursor-measured Value: Z_c |{ f_s = MHz} = Re{Z_c} + j Im{Z_c} = Ω + j0 Ω

In addition please generate a Nyquist-plot (Gaussian plain) of the crystal-impedance Zc. Measure the resonance frequencies with the cursors and copy the plot inclusive the cursor-window for documentation.

Fig. 2.3: Documentation: Nyqist plot of the crystal impedance



Please refine the documentation with your text procession tool:

- label the cursors with “fs” / “fp”
- add some arrows to show how the curve runs
- add labels for $\omega \rightarrow 0$; $\omega \rightarrow \infty$

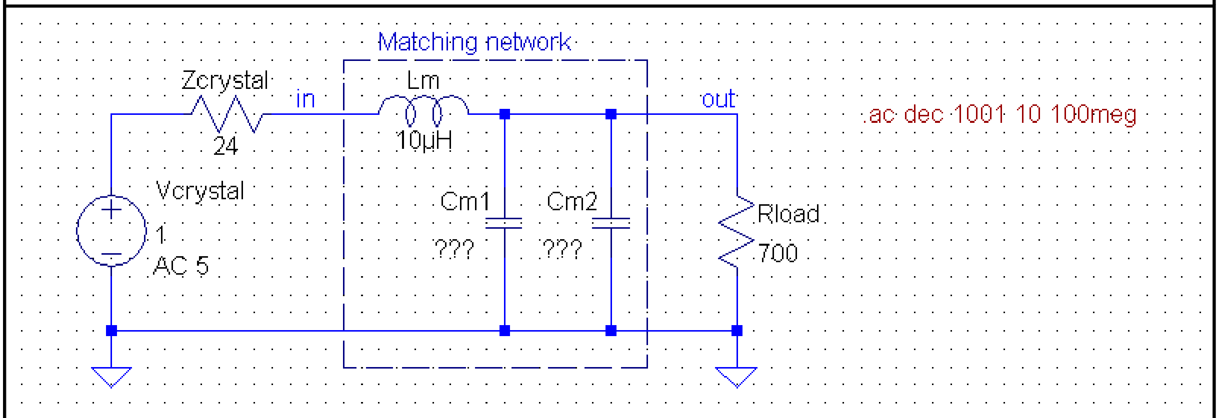
3 Frequency response of a low-pass filter 2nd order

3.1 Drawing of the electrical circuit

At first generate a new schematic called "LowPassFilter2" that will be used to adopt a load of 700Ω to the ~24Ω impedance of the ultrasound crystal, at the frequency of 2MHz.
- Please calculate the theoretical values for L and C of the matching filter. (spread sheet ?)
- Try to use values from the E12 series for the components.
- You may use two capacitors in parallel tow get a more precise result.

Please label input and output line by net-names "in" and "out" for better orientation.
For the following measurements around this resonance frequency please use an average value from the theoretical 2MHz and the one determined in Chapter 2.

Fig. 3.1: Electrical circuit for simulating low-pass filter 2nd order

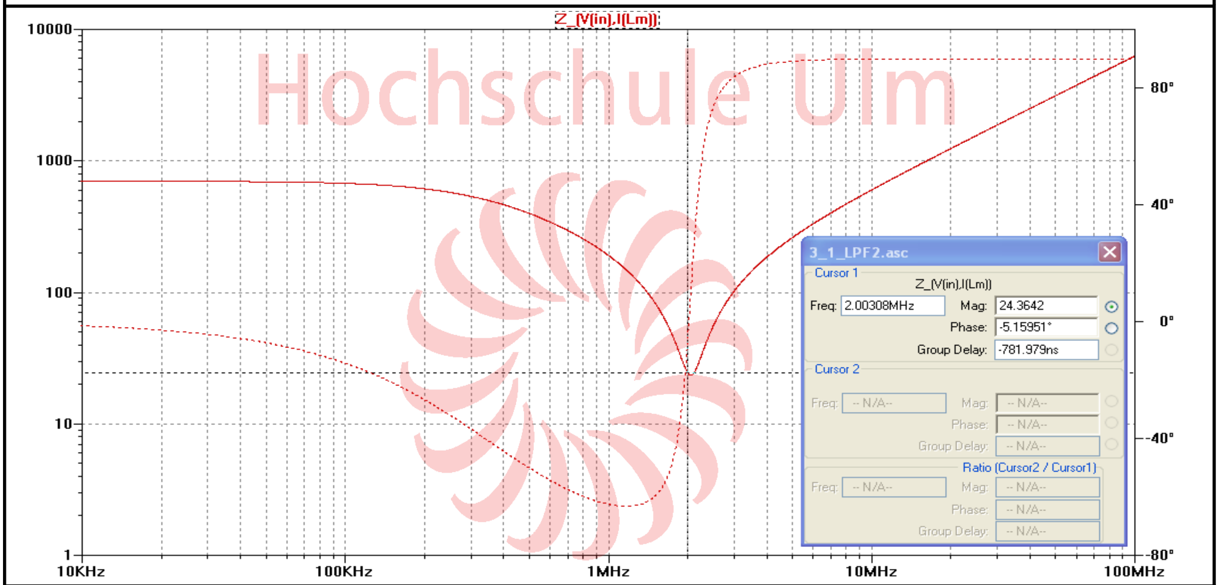


Calculation of the transfer network components:
- Create Formular for Zin
- Separate the real and the imaginary parts
- calculate Cm (imaginary part is zero at resonance freq.)
- calculate Lm

3.2 Analysis of the low-pass filter 2nd order

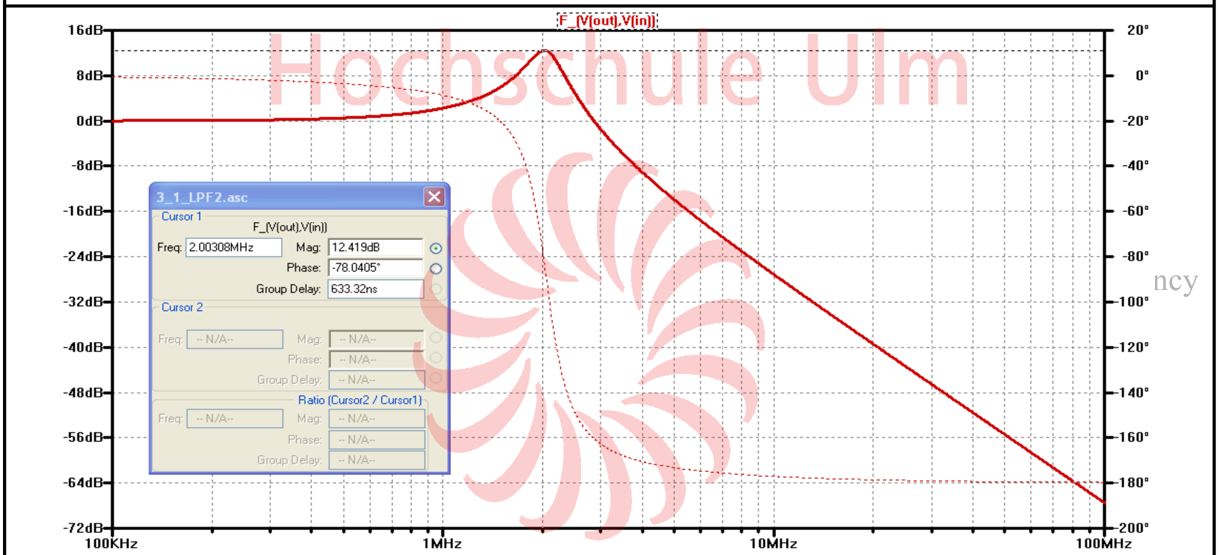
Please set up a simulation command for an AC-analysis from 10Hz to 100MegHz with 1001 points/decade and document the result for the input impedance of the filter in Bode-diagram.

Fig. 3.2: Bode Diagram showing the input impedance of the filter with magnitude / phase



In addition document the transfer function of the matching filter in the frequency range from 100kHz to 100MHz.

Fig. 3.3: Bode Diagram showing the filters transfer function in dB and its phase.



Please measure the amplification by cursor at the **crystals resonance frequency**.

Cursor-measured Value: F |{ f = MHz} = dB ≡

Please note the input impedance resonance frequency by cursor from Fig. 3.2 for the **crystals resonance frequency** with magnitude and phase.

Cursor-measured Value: $\underline{Z}_{in}$ |{ f_s = MHz} = $|\underline{Z}_{in}| * e^{j\varphi \underline{Zin}}$ = Ω * e^{j} °

4 Preamplifier and matching to the sensor for f ~ 2MHz

4.1 Drawing of electrical circuit

For Transistor Q1 we want to use a "**BFQ67**" for which there is no model available in the LTspice standard libraries. Therefore you have to add a file with the model description to the folder where your schematic is located (*source: ..\Labor\Introd_Ultrasound/BFQ67.mod*) Then place a "NPN" transistor, change its value to "BFQ67" and add a SPICE directive to include the new model. (.include BFQ67.mod)

Label interesting lines by net-names "in", "out", "base" and "filter..." for better orientation. Note that the values of the component models for Crystal and Filter are still the ones figured out by previous examinations.

Please check your circuit by running a first operating-point simulation. Modify the value of R_v to get a V_{out} of about $V_{cc}/2$. Use a "**preferred number**" from the "**E12 series**" please !

Fig. 4.1: Electrical circuit for simulating preamplifier based on the transistor

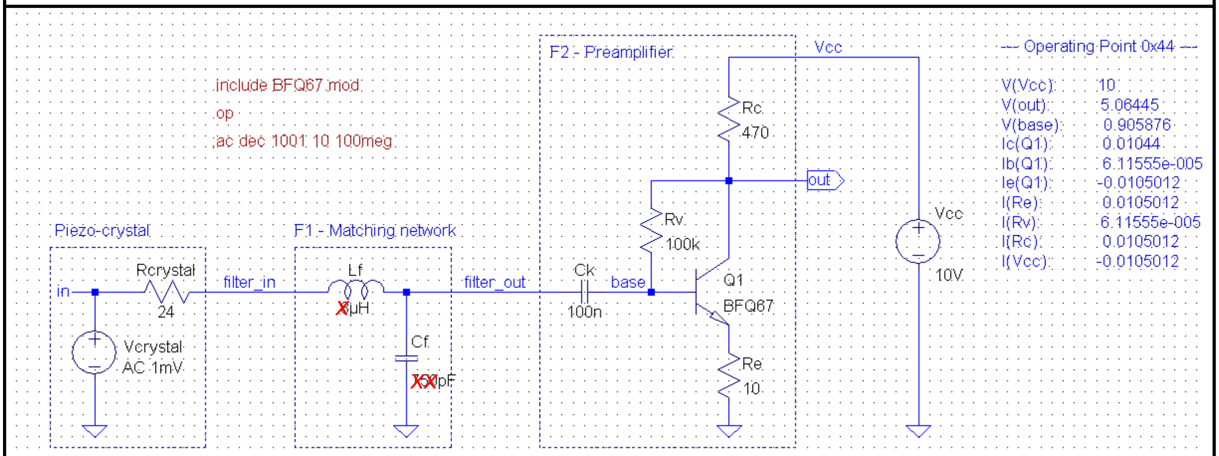
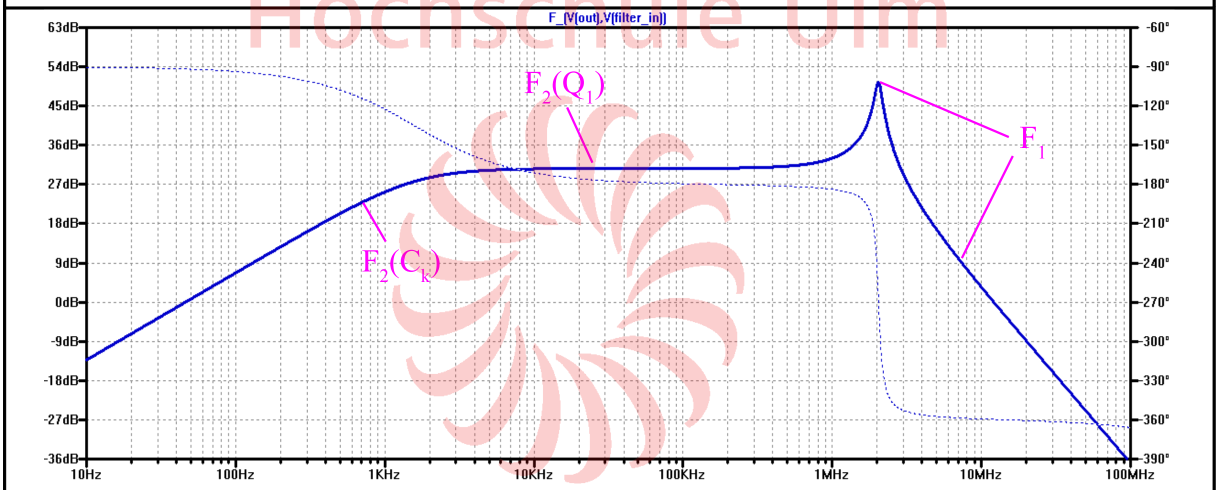


Fig. 4.2: Bode Diagram of the different stages (F1,F2) of the measuring chain.



As an overview to frequency response create the transfer function of both modules in the measuring chain. Module **F1** is the matching filter and module **F2** corresponds to the transistor amplifier. Set up an AC-analysis from 10Hz to 100MegHz with 1001 points/decade.

At the resonance frequency fr ≈ 2MHz :

- The matching filter F1 approximately amplifies the signal for dB
- and the transistor stage F2 by the value of dB

Please calculate from the dB – values to normal factors:

$F_1|_{dB} =$ dB $\equiv$ $F_1 =$

$F_2|_{dB} =$ dB $\equiv$ $F_2 =$

4.2 Analysis of the measuring chain at frequency f=2MHz using time domain analysis

Based on the documented results (Bode Diagram) of chapter 4.2 these values have to be checked by applying time domain signals (sinusoidal **2MHz**-signal with amplitude **1mV**).

Further on the matching of the filter has to be approved.

Therefore please create a simulation command for time domain-analysis (Transient) for about 10 periods of the resonance frequency. Take care not to forget of the signal settings for the signal source "$V_{crystal}$".

Fig. 4.3: Time domain signals at the nodes ***in***, ***filter_in***, ***filter_out***, and ***out***.

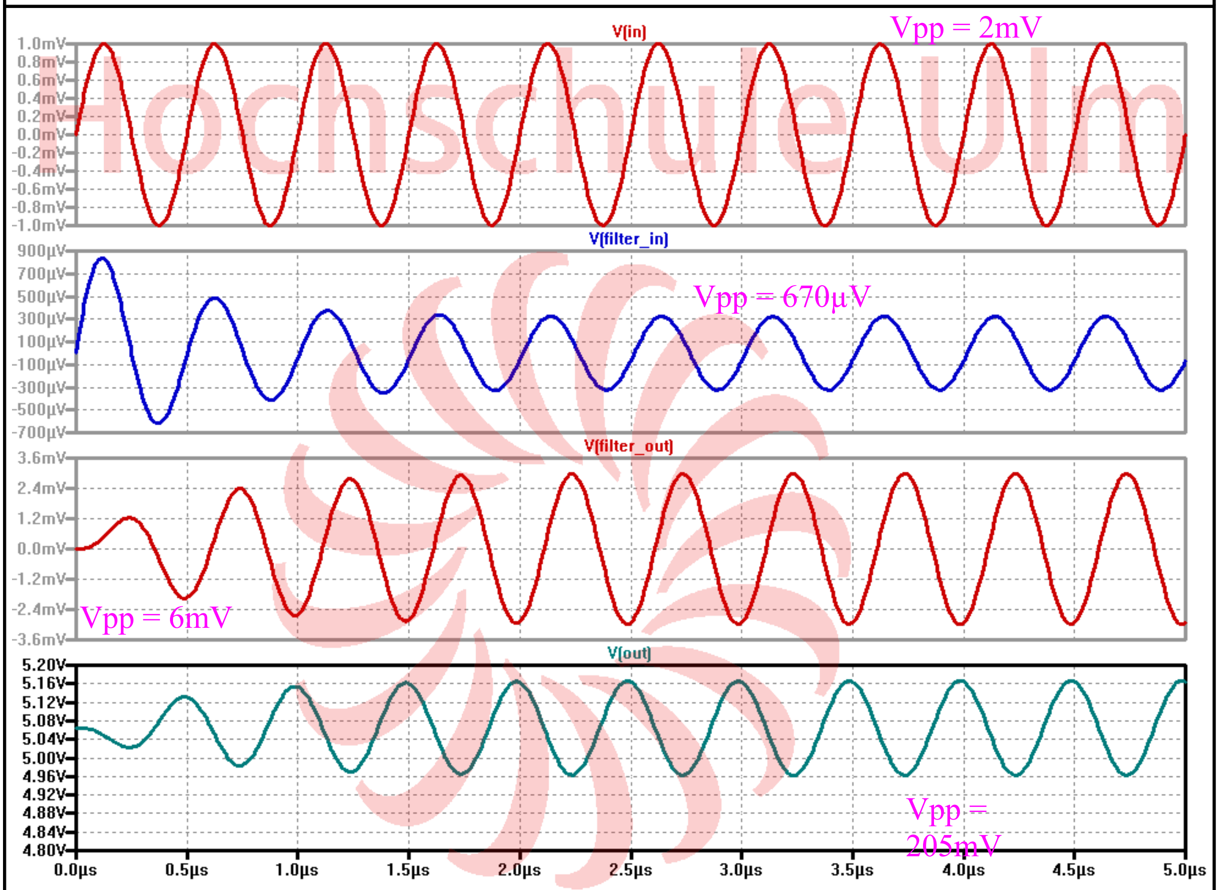


Fig. 4.3 shows the results of several time signals at the different nodes "in", "filter", and "out". By measuring the ratio of the different signal amplitudes the amplification factor of the modules F1 and F2 can be calculated.

For the determining the peak-to-peak values of the voltage signals, you may use the method to quickly measure differences with the mouse cursor.
If you drag the mouse as if you were going to zoom, the size of box is displayed on the status bar. You can measure differences in this manner without performing the zoom by either pressing the ***[Esc]*** key or right mouse button before releasing the left mouse button.

Please add the measured peak to peak values to your diagram above (Fig. 4.4)

$F_1 = U_{filter\_out} / U_{filter\_in}$ = ___ / ___ = ___ ≡ $F1|dB$ = ___ dB

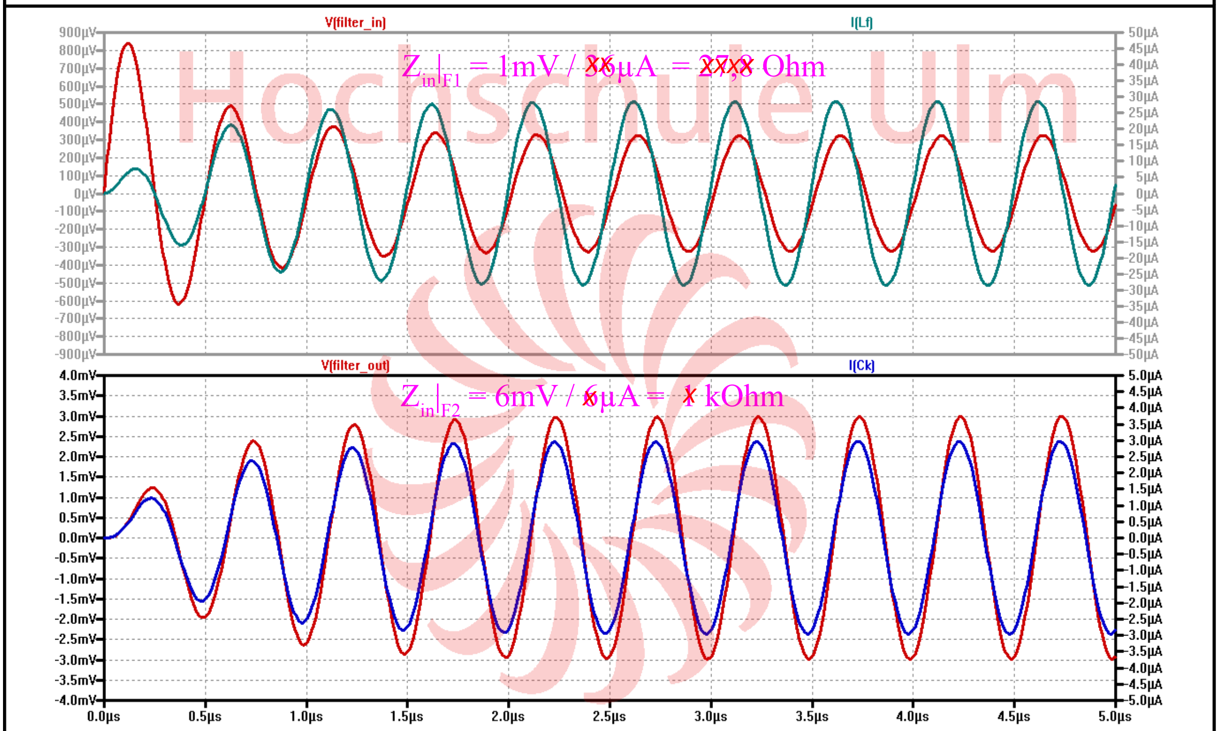
$F_2 = U_{out} / U_{filter\_out}$ = ___ / ___ = ___ ≡ $F_2|_{dB}$ = ___ dB

4.3 Analysis of the matching status / improvements by variation of Re

Based on the above documented results in time domain at the frequency f_r 2MHz the situation of correct matching of the sensor can be checked.

Using the signals shown below, please calculate the input-impedance of the matching filter and the load of the matching filter (input-impedance of the transistor amplifier).
Is there a mismatching ?

Fig. 4.5: Voltage and current trace for calc. of impedance values to check matching grade



Please try to evaluate a optimized value for R_e for closer matching. *(use preferred value -E12)*
To speed up this process you may switch to a parametric (*".step ..."*) AC-analysis.

optimized Values: R_e = ___ Ω $Z_{in}|_{F1}$ = ___ $\Omega * e^{j\ \ \circ}$