Experimental drawing of Nyquist and Bode diagrams

1 Theoretical aspects

Frequency response i.e. $H(j\omega) = |H(j\omega)|\angle H(j\omega)]$, can be plotted in several ways; two of them are (1) as a polar plot, where the phasor length is the magnitude and the phasor angle is the phase known as Nyquist plot; and (2) as a function of frequency, with separate magnitude and phase plots, called Bode plots. [Nice]

Nyquist diagram is a complete theoretical and graphical tool, especially used in stability analysis, being less intuitive than other methods studied previously like root locus. Bode plots seem particularly familiar because of their common use for representing frequency response data for such consumer items as audio systems. [Westphal]

2 Measurement setup

Two ways are recommended in this lab to evaluate and make experimental investigation of the magnitude and phase frequency response of OpAmp based circuits.

2.1 Practical measurements

In figure 1 and 2, a real test setup is presented. Special attention must be paid to the use of ELAB-080. The TI board ASLkit offers the possibility of implementing simple analog circuits (figure 2). This part presumes as known the use of:

- Signal generators
- TL082 general purpose Op Amps
- Oscilloscopes

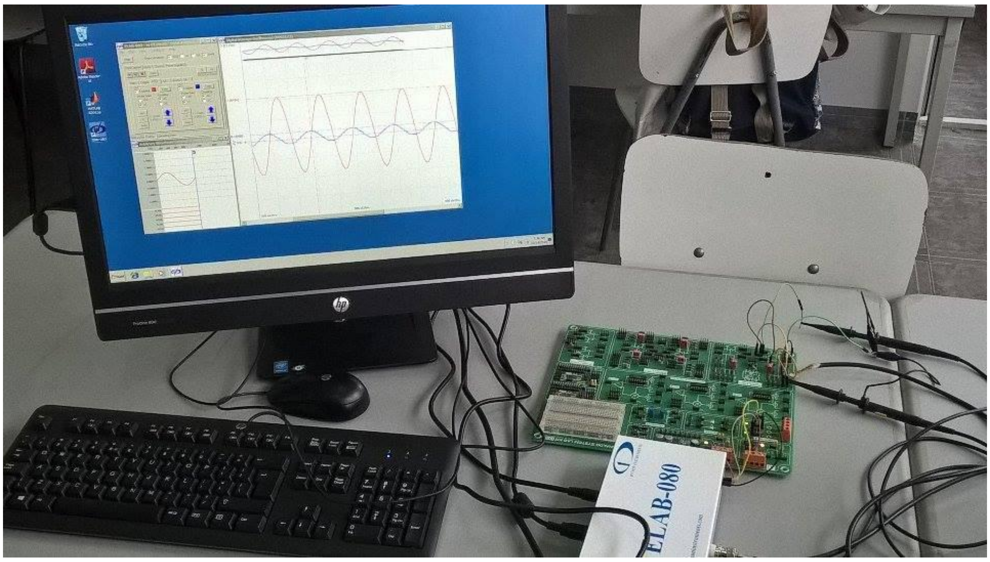

Figure 1 Experiment setup (Signal generator, circuit, oscilloscope) for frequency response measurements

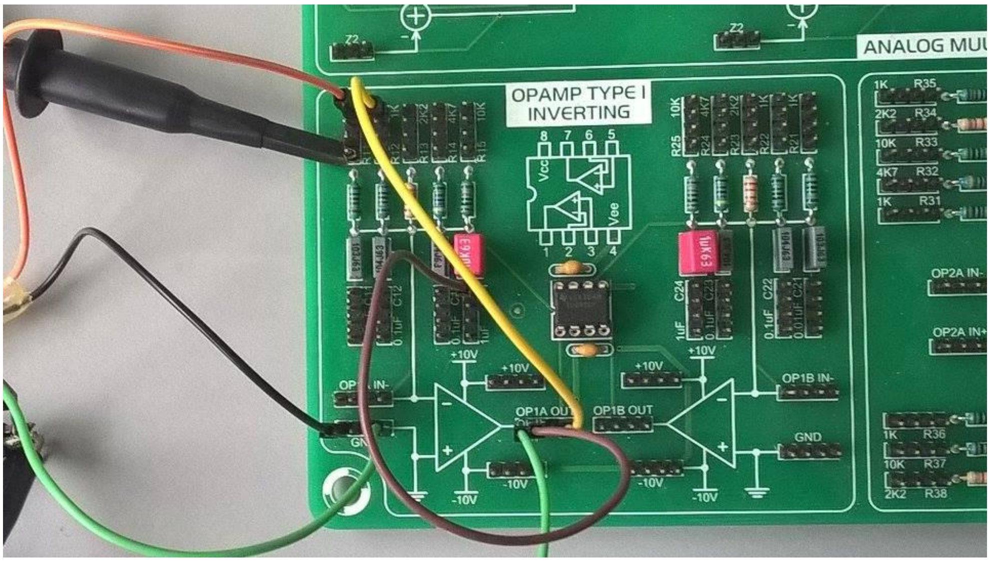

Figure 2 A simple first order element on the ASL Kit (Texas Instruments)

2.2 Numerical experiments

Using the Matlab/ Simulink/ Simscape simulator, the frequency response measuremet can be accomplished if using the Simulink model in figure 3.

This part involves good knowledges on how to configure the entire workspace in Matlab.

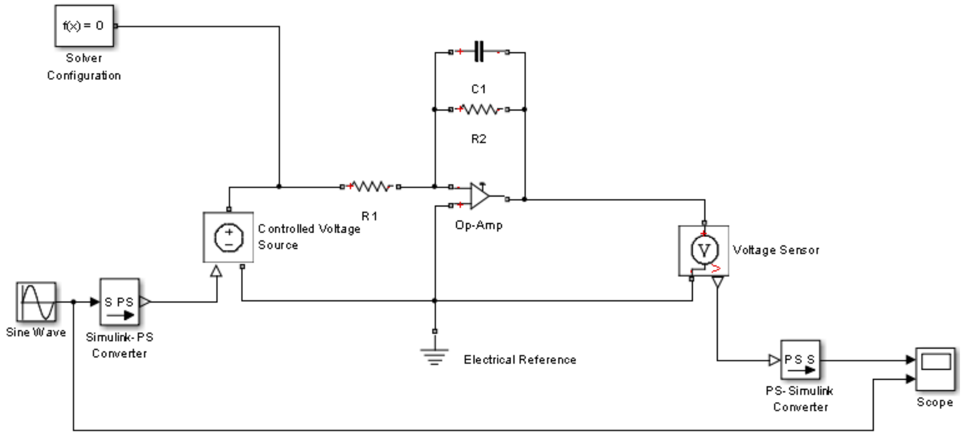

Figure 3 OpAmp based circuit performed in Matlab/Simulink, Simscape

3 Solved problem

3.1 Drawing Nyquist diagram from data

For the circuit in figure 1, the next steps are required to complete a short report on how obtain the Nyquist diagram:

1. Open the Matlab environment with current folder on “…/desktop/Lab3”
2. Open the file “circuit1.slx” and sketch the circuit on your notebook (maintain only the electronic components: Op-Amp, R and C) indicating the input and the output signals by u and y.
3. Open the companion file “script_circuit1.m” and briefly comment each command (in case one function is unknown, open the Matlab help).

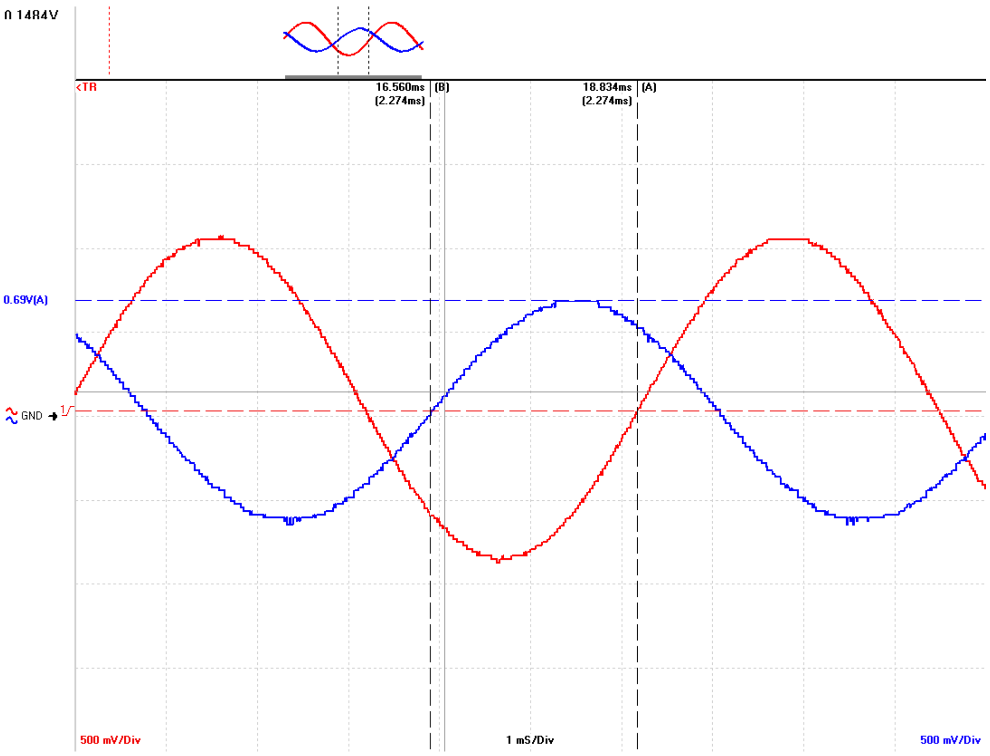

Figure 4 Oscilloscope capture with the circuit response to an input frequency of 159 Hz [channel A (red) – input sinewave, channel B(blue)- the steady state response]

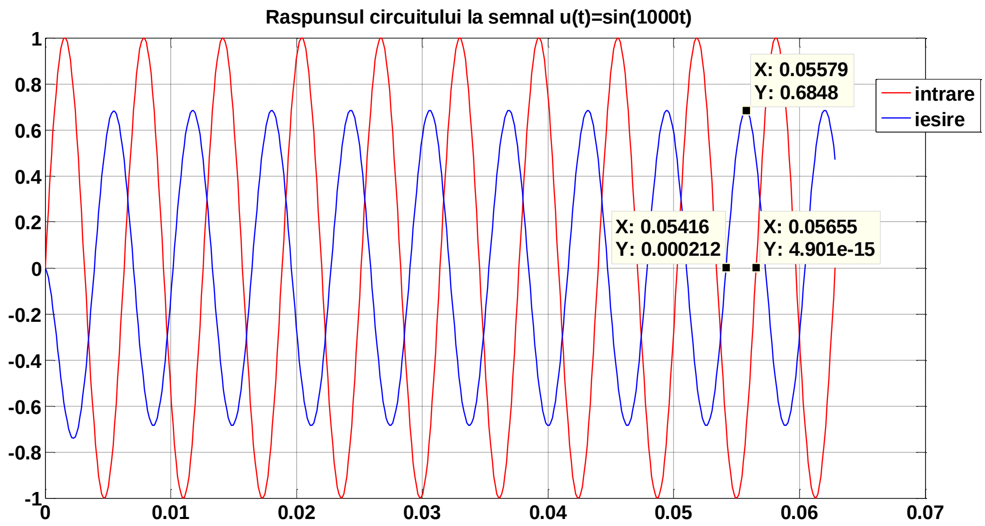

Figure 5 Matlab Simulation

4. Fill in the next table for a given range of frequencies around the inverse of circuit time constant ($\omega_c = 1/(R_2 C_1)$)
    a. Measure (evaluate) the amplitude of the output signal in steady state A_{ss} (in figure 4, the output amplitude is 0.69 V),(in figure 5, the amplitude results more accurately, in 0.6848 V);
    b. The phase shift is measured in seconds underlining once again that the interest is over the steady state, φ_{ss} (in figure 4, 18.834ms-16.560ms=2.274ms),(in figure 5, 0.05655-0.05416=0.00239 seconds);
    c. If using numerical simulations, than use the next structure for the table you have to fill in:

No.	frequency (rad/sec)	frequency (Hz)	A_{ss}	tu (sec.)	ty (sec)	$\varphi_{ss}\,(sec.)$ [tu-ty]	$\varphi_{ss}\,(grade)$
...							
6	1000	159.2	0.6848	0.05655	0.05416	0.00239	129.1447
...							

d. The values for amplitude and phase shift (in sec.) are recorded in the table from your notebooks and manually typed in a new section in the current script.

e. The rest of computations (like transforming the phase shift into radians) are strongly recommended to be made using Matlab.

No.	frequency (rad/sec)	frequency (Hz)	A_{ss}	$\varphi_{ss}\,(sec.)$	$\varphi_{ss}\,(grade)$
1	100	15.9	1	31.778 ms	182.0745
2	143	22.7	0.97	20.457 ms	167.4428
3	200	31.8	0.96	14.49 ms	166.0432
4	250	39.8	0.95	11.221 ms	160.7290
5	500	79.6	0.88	5.114 ms	146.5053
6	1000 (ω_c)	159.2	0.69	2.274 ms	129.1447
7	2000	318.3	0.44	973.188 us	111.5191
8	4000	636.6	0.22	456.8 us	104.6908
9	5000	795.8	0.18	347.567 us	99.5706
10	7000	1114.1	0.13	243.297 us	97.5792
11	10000	1591.5	0.12	152.92 us	87.6167

5. Plot the 11 measured points using polar representation if considering the magnitude in A_{ss} and the argument in φ_{ss} considered in degrees. After connecting by straight lines all the eleven points, the approximation of the Nyquist diagram will result.
6. Use the next script to compare the ideal shape and the one approximated by points.

```
%% comparatie cu diagrama obtinuta in Matlab
H=tf(-R2/R1,[C1*R2 1]);
nyquist(H); hold
% click dreapta pe spatiu alb si debifati "Negative
frequencies"
A_ss=[1,0.97,0.96,0.95,0.88,0.69,0.44,0.22,0.18,0.13,0.12];
Phi_ss=[182.0745,
167.4428,166.0432,160.7290,146.5053,129.1447,111.5191,104.690
8,99.5706,97.5792,87.6167];
Phi_ss_rad=deg2rad(Phi_ss);
[re_m,im_m]=pol2cart(Phi_ss_rad,A_ss);
plot(re_m,im_m,'*r');hold;shg
legend('diagrama bazata pe model','diagrama bazata pe
masuratori')
```

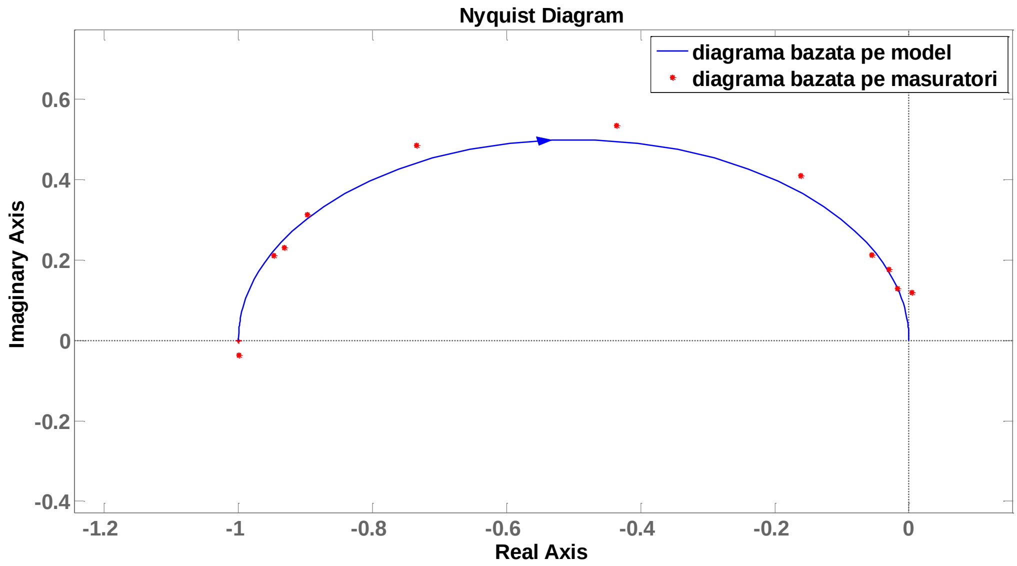

Figure 6 Nyquist diagram (approximated by measurements vs. the ideal one in Matlab)

3.1.1 Drawing Bode diagrams

7. Fill in the next tabel

Nr. măs.	Pulsaţia semnalului de intrare	20*lg(A_{ss}) [$d\beta$]	φ_{ss} [$degree$]
1	100		
2	143		
3	200		
4	250		
5	500		
6	1000 (ω_c)		
7	2000		
8	4000		
9	5000		
10	7000		
11	10000		

8. Plot in logarithmic scale the magnitude vs. the frequencies (magnitude characteristic).
9. Plot in logarithmic scale the phase shift vs. the frequencies (phase characteristic).
10. Use the next script (comment the commands in English) to make the comparison between the approximated and the ideal diagram.

```
%% diagrama Bode
 close all
 H=tf(-R2/R1,[C1*R2 1]);
 A_ss=[1,0.97,0.96,0.95,0.88,0.69,0.44,0.22,0.18,0.13,0.12];
Phi_ss=[182.0745,
167.4428,166.0432,160.7290,146.5053,129.1447,111.5191,104.690
8,99.5706,97.5792,87.6167];
% se transforma modulul in decibeli
A_ss_dB=20*log10(A_ss);
% faza ramane in grade

% vectorul cu pulsatiile
wv=[100,143,200,250,500,1000,2000,4000,5000,7000,10000];
```

```
% vor fi 2 caracteristici separate

subplot(211);title('Caracteristca de modul')
semilogx(wv,A_ss_dB,'r*-');grid;hold

subplot(212);title('Caracteristca de faza')
semilogx(wv,Phi_ss,'r*-');grid;shg

% comparatie cu caracteristica ideala
hold
wv_i=logspace(1,5,100);% generare pulsatii in scara
logaritmica
[modul_i,faza_i]=bode(H,wv_i);
modul_i=squeeze(modul_i);faza_i=squeeze(faza_i);
subplot(211);semilogx(wv_i,20*log10(modul_i));
legend('masurata','simulata');
subplot(212);semilogx(wv_i,faza_i);
legend('masurata','simulata');
hold
```

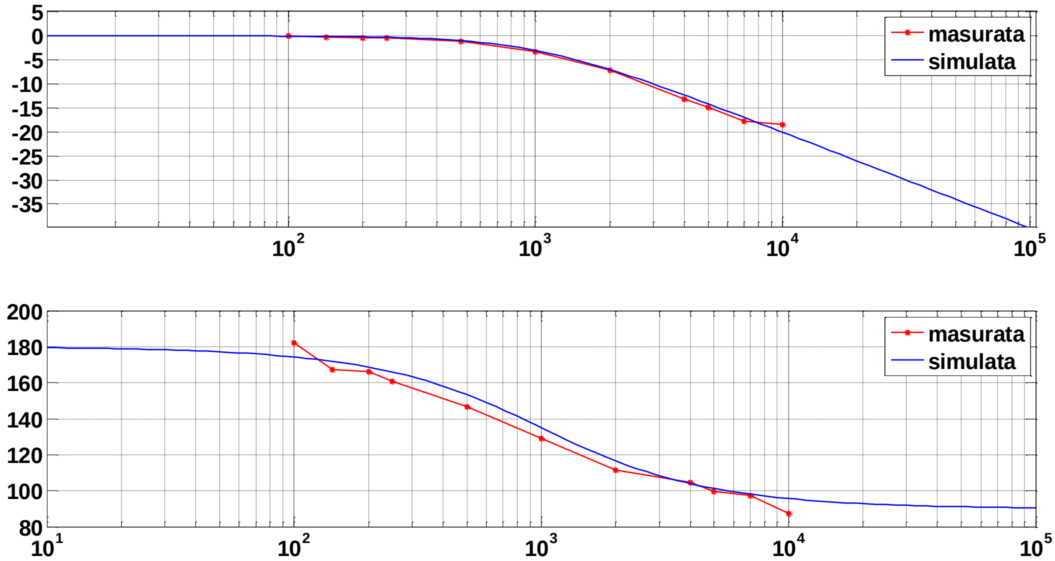

Figure 7 Bode Diagram (measured vs. the ideal based on transfer function)

3.2 Questions

1. Indicate the phase shift and the amplitude for frequencies 100 lower/higher than the cutting frequency ($\omega_c = 1/(R_2C_1)$).
2. Describe the difference between `linspace` and `logspace`.
3. Describe the difference between `plot` and `semilogx`.

4 Problems

Follow all the steps in section 3 in order to draw the experimental Nyquist and Bode diagrams for the circuit in figure 8 [R1= 1kΩ, R2= 1kΩ, R3==1kΩ, R4=2.2kΩ, R5= 1kΩ, C1= 1μF].

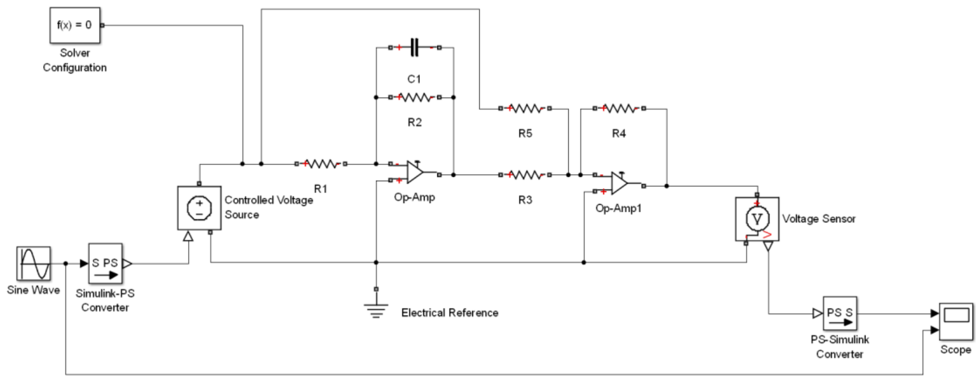

Figure 8 Analog circuit based on OpAmp