Mechatronic Systems Identification

Lab 6 - Non-parametric identification based on experimental data

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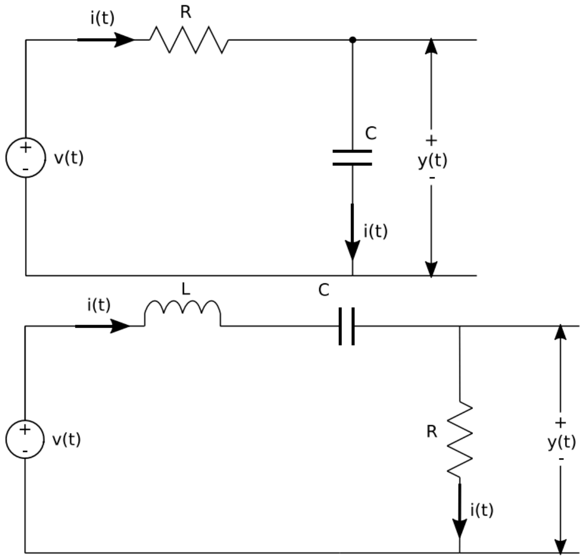
Description

The aim of this laboratory is for us to learn the non-parametric system identification methods based on the experimental data provided. To this end, we were given two filters: a 1st order RC filter and a 2nd order RLC filter. Through each of them, we have passed a chirp and noise signals for further analysis.

Task 1

This task aims to prepare theoretical models of the two filters by utilizing their transmittance, and then compare them with the experimental data excited by the chirp noise.



$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{1}{R_1C_1}}{s + \frac{1}{R_1C_1}}$$

$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{R_2}{L_2}s}{s^2 + \frac{R_2}{L_2}s + \frac{1}{C_2L_2}}$$

fig 1: RC and RLC filters and their transmittance equations

Task 1.1

To this end, we were provided with the following parameters, which are the nominal values of the components used in the circuits, as well as the transmittance models of the systems.

```
%RC filter parameters
R1 = 47; %ohm
C1 = 2.2*10^-6; %farad
%RLC filter parameters
R2 = 220; %ohm
C2 = 4.7*10^-9; %farad
L2 = 1*10^-3; %henry
```

Next, the provided experimental signals were loaded, and prepared for further operations by removing NaN and infinite values from them

```
%RC excitation signals
y11 = load("20210305-RC_Chirp40v150kHz_T2s.mat");
%cleaning the data
A11 = y11.A;
B11 = y11.B;
A11(isnan(A11)) = 0;
B11(isnan(B11)) = 0;
A11(isinf(A11)) = 0;
B11(isinf(B11)) = 0;
```

The process was repeated for each signal.
Finally, the theoretical models were calculated, and bode plots corresponding to them were plotted.

```
%RC filter
Y1=[1/(R1*C1)];
V1=[1 1/(R1*C1)];
sys1=tf(Y1,V1);
%RLC filter
Y2=[R2/L2 0];
V2=[1 R2/L2 1/(C2*L2)];
sys2=tf(Y2,V2);
%bode plot of the RC system
[mag1,phase1,w1]=bode(sys1);
mag1=squeeze(mag1);
phase1=squeeze(phase1);
bode(sys1), grid on
%bode plot of the RLC system
[mag2,phase2,w2]=bode(sys2);
bode(sys2), grid on
mag2=squeeze(mag2);
phase2=squeeze(phase2);
```

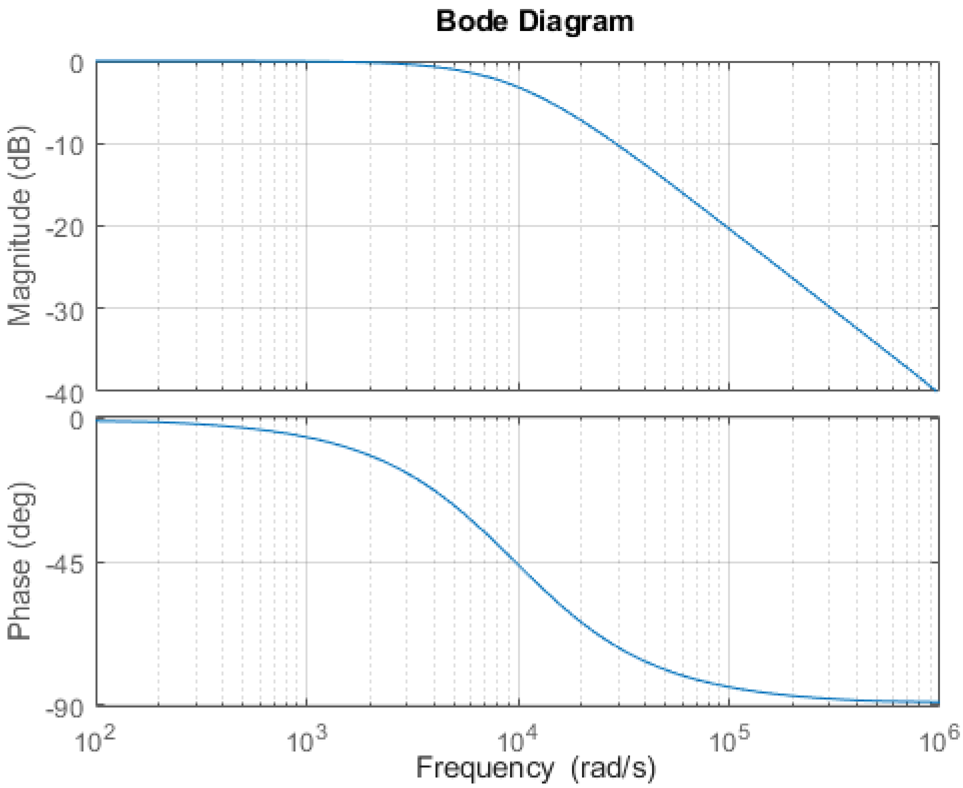


fig 2: Bode plot of the theoretical model of the RC filter (1st order).

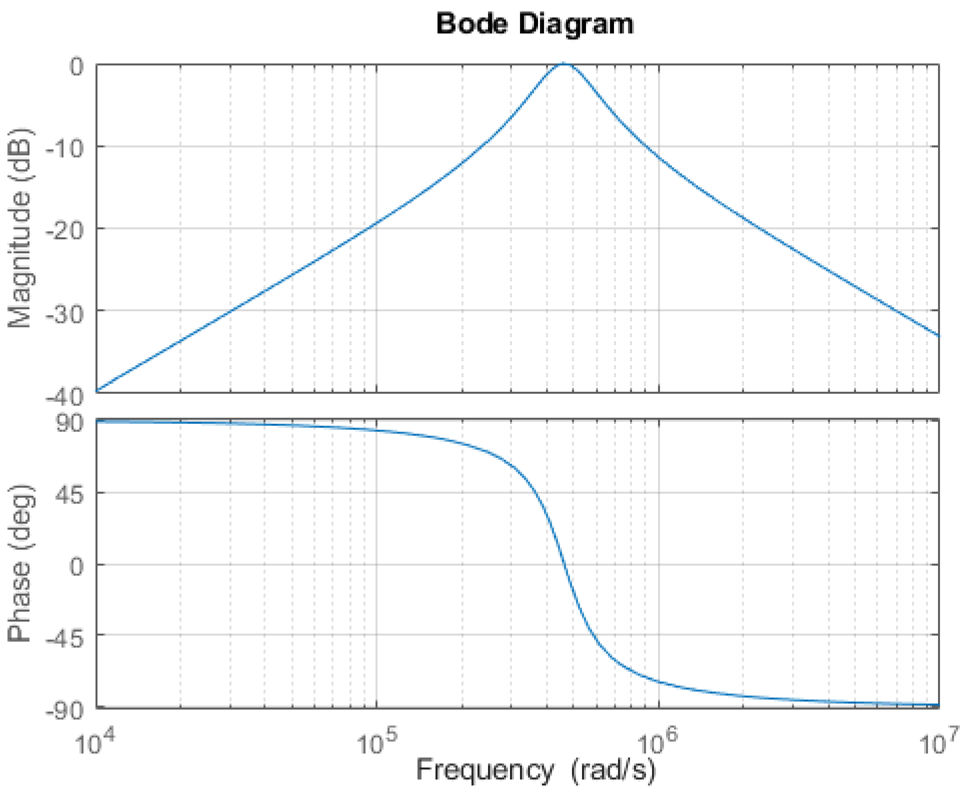
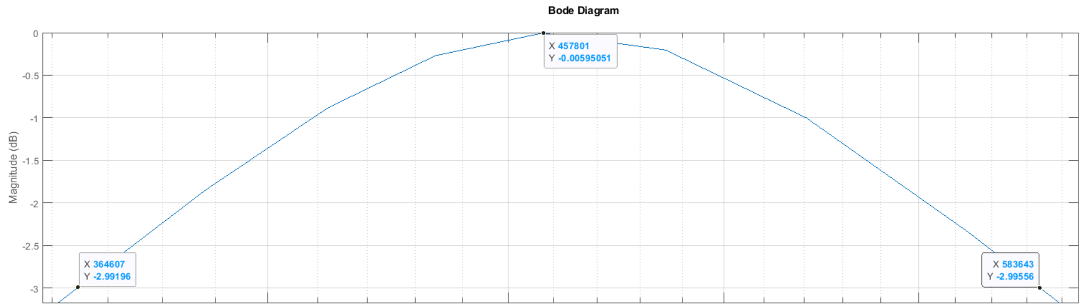


fig 3: Bode plot of the theoretical model of the RLC filter (2nd order).

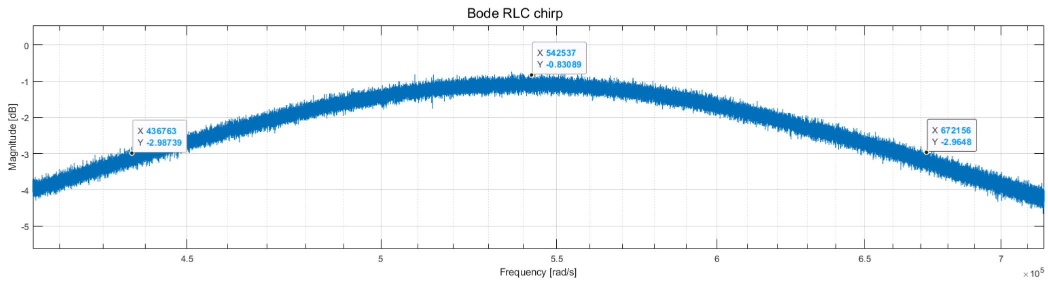
From the plot of the RLC filter, we can determine the damping coefficient of the system. We are unable to do so for the RC filter since the half-power method is not applicable to the 1st order systems.




```
omega1 = 364607;
omega2 = 583643;
omegar = 457801;
damping = (omega2-omega1)/(2*omegar)
```

```
damping = 0.2392
```

fig 4: Damping of the theoretical RLC filter (2nd order).




```
omega12 = 436763;
omega22 = 542537;
omegar2 = 672156;
damping2 = (omega22-omega12)/(2*omegar2)
```

```
damping2 = 0.0787
```

fig 5: Damping of the experimental chirp RLC filter (2nd order).

Next, we can compare the responses of the theoretical models with the responses of the experimental data.

```
figure()
subplot(2,1,1);
semilogx(f11,20*log10(mag_sys11)), grid on, hold on
semilogx(w1, 20*log10(mag1)), hold off
xlim([10^2 10^6])
xlabel('Frequency [rad/s]')
```

```
ylabel('Magnitude [dB]')
subplot(2,1,2);
semilogx(f11,phase_deg11), grid on, hold on
semilogx(w1,phase1)
xlim([10^2 10^6])
xlabel('Frequency [rad/s]')
ylabel('Phase [deg]')
sgtitle('Bode RC chirp vs RC base')
```

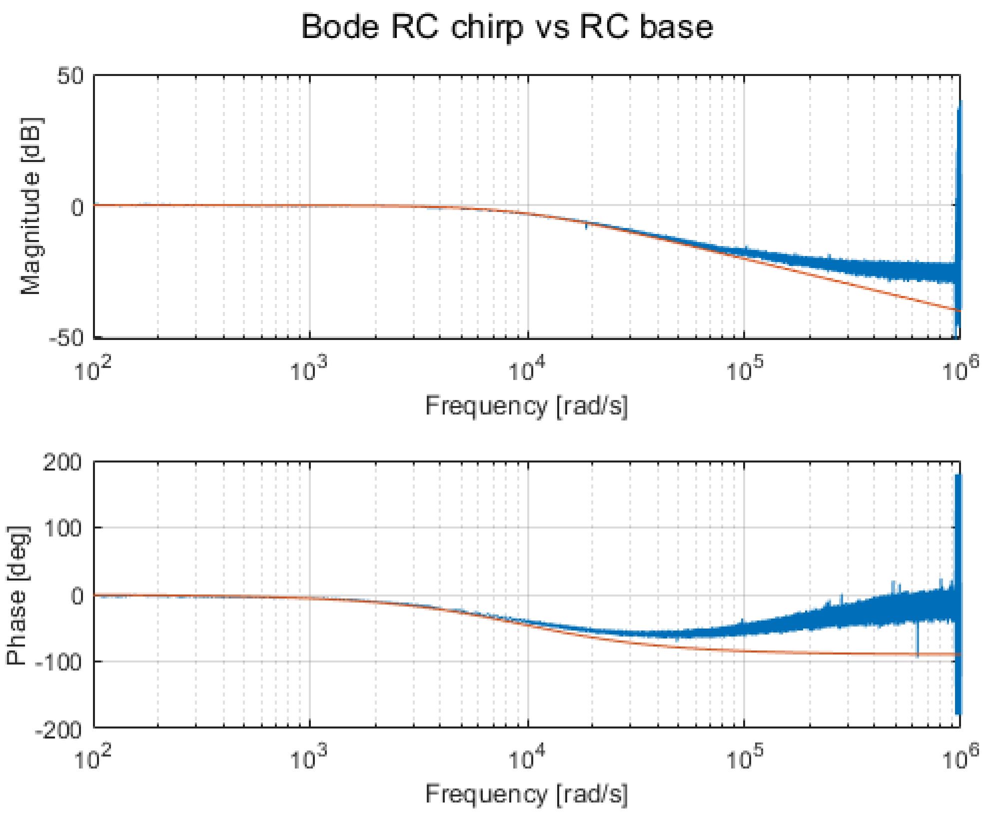


fig 6: Comparaison of the responses of the 1st order system.

```
figure()
subplot(2,1,1);
semilogx(f21,20*log10(mag_sys21)), grid on, hold on
semilogx(w2, 20*log10(mag2)), hold off
xlim([10^4 10^6])
xlabel('Frequency [rad/s]')
ylabel('Magnitude [dB]')
subplot(2,1,2);
semilogx(f21,phase_deg21), grid on, hold on
```

```
semilogx(w2, phase2), hold off
xlim([10^4 10^6])
xlabel('Frequency [rad/s]')
ylabel('Phase [deg]')
sgtitle('Bode RLC chirp vs RLC base')
```

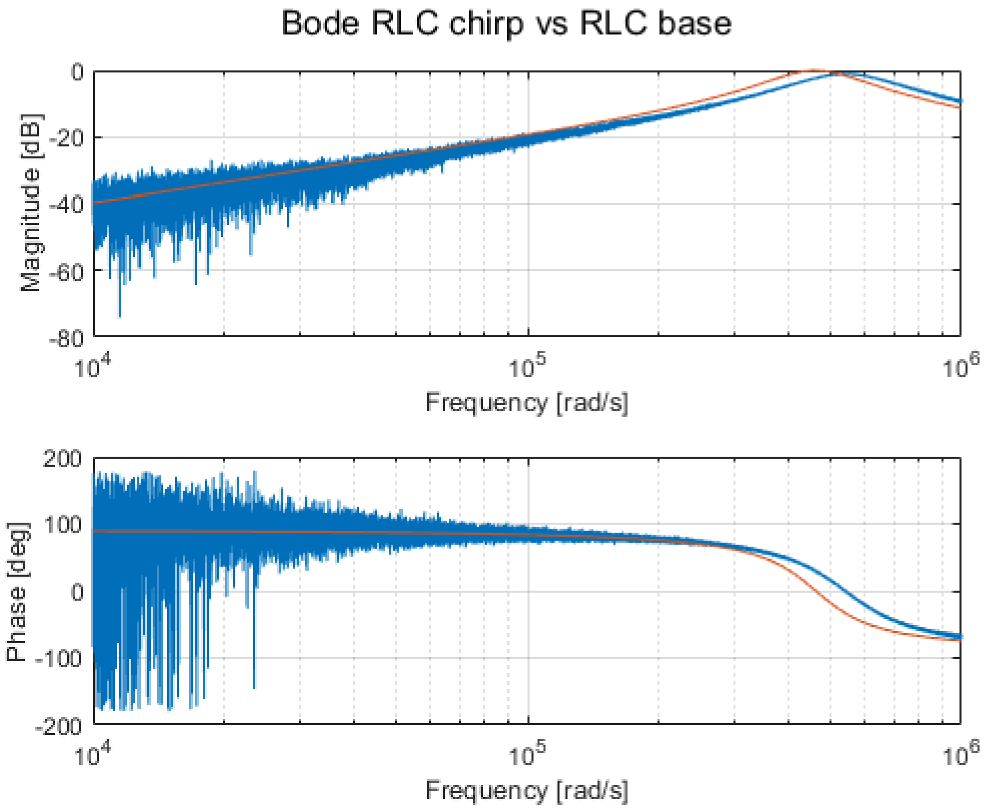


fig 7: Comparison of the responses of the 2nd order system.

Conclusions:

The use of chirp signals, which cover a broad frequency range, proved effective in identifying the frequency response characteristics of both the RC and RLC filters. This method is beneficial because it allows for the rapid assessment of a system's response across a continuum of frequencies, making it highly suitable for diagnostic applications and filter performance evaluation.

When trying to evaluate the damping from the theoretical model and the chirp we notice that there is a big discrepancy when it comes to the damping ratio and that is because of the utilization of nominal values of the RLC, as well as the oversimplified values of the components.

Bode plots generated from experimental data were compared with theoretical plots derived from the system's transmittance functions. This comparison is crucial as it highlights the discrepancies that were shown due to practical limitations such as component tolerances, non-ideal components, and measurement noise. The experimental plots generally followed the trend of the theoretical predictions but exhibited deviations that can be attributed to the real-world imperfections in the filter components.

Task 1.2

As stated above, the results of the previous comparison were fairly inaccurate due to the utilization of the nominal values of the electrical components within the filters, the limitations of the mathematical models applied, and the noise within the experimental signal.
In this task, we will once again plot the bode plot of the RLC filter, but this time using a more advanced model.

$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{R_2}{L_2}s}{s^2 + \frac{(R_2 + R_{2L})}{L_2}s + \frac{1}{C_2 L_2}}$$

fig 8: New transmittance model of the 2nd order system.

The aim of the task is to determine an actual set of parameters describing the electrical components within the system to account for the producer's tolerances such that the responses are as similar as possible. After some testing, the obtained parameters were:

```
%creating the corrected system
R2=217;
C2=4.1*10^-9;
L2=0.83*10^-3;
R2L=25;
Ind=15.4;
%corrected RLC filter
Y2=[R2/L2 0];
V2=[1 (R2+R2L)/L2 1/(C2*L2)];
sys3=tf(Y2,V2);
%bode plot of the corrected RLC system
[mag3,phase3,w3]=bode(sys3);
```

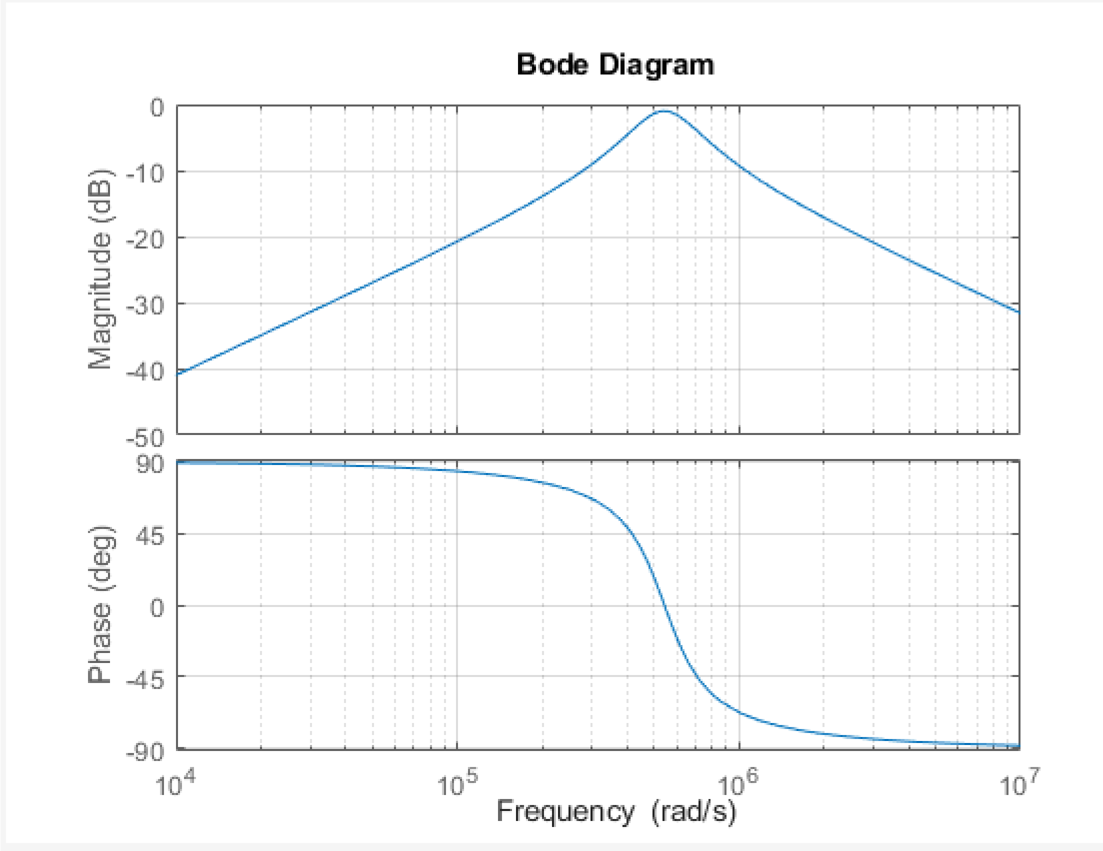


fig 9: Bode plot of the new 2nd order system.

Once again we plot the comparison between the new theoretical model and the obtained experimental data.

```
%comparing with the chirp
figure()
subplot(2,1,1);
semilogx(f21,20*log10(mag_sys21)), grid on, hold on
semilogx(w3, 20*log10(mag3)), hold off
xlim([10^4 10^6])
xlabel('Frequency [rad/s]')
ylabel('Magnitude [dB]')
subplot(2,1,2);
semilogx(f21,phase_deg21), grid on, hold on
semilogx(w3, phase3), hold off
xlim([10^4 10^6])
xlabel('Frequency [rad/s]')
ylabel('Phase [deg]')
sgtitle('Bode RLC chirp vs RLC corrected base')
```

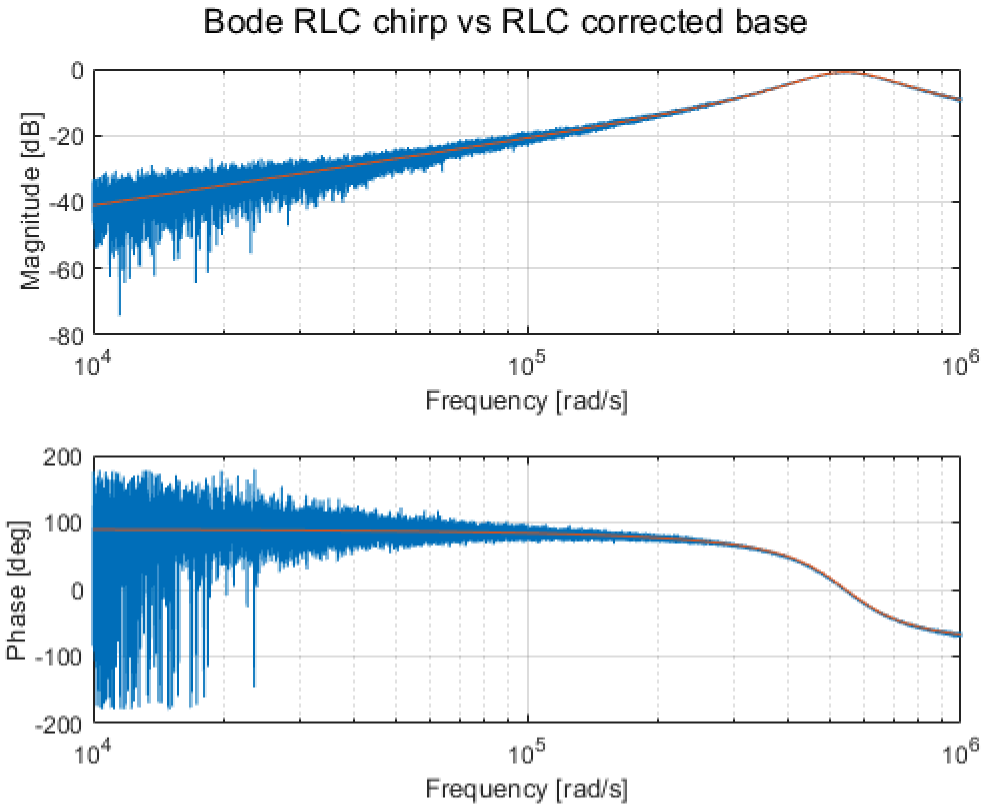


fig 10: Comparison of the responses of the 2nd ordered corrected system.

Conclusions:

As shown in fig. 10, the delay in the phase shift and magnitude drop present in the original system (fig.7) was corrected by utilizing the more advanced mathematical model, as well as determining the true value of the electrical components present within the filter.

Task 2

This task aims at the utilization of the estimation methods in order to determine the transition function, mainly *tfestimate()* is to be used in the following determination. This method should smoothen the noisy signals because it splits the signal into windows, calculates bode, and averages the results with some overlap (in our case 50%)

```
df = 1;
dt=y22.Tinterval; %timestep given in the data
fs=1/dt;
window = round(fs/df); %from df=fs/N
overlap = round(window / 2); %50% means half of the window
nfft = window;
[H3,F] = tfestimate(B22,A22,window,overlap,nfft,fs,'twosided');
F=F';
N3=length(H3);
f3=2*pi*1/y22.Tinterval*(0:(N3-1))/N3;
mag_sys3=abs(H3);
phase_deg3=rad2deg(angle(H3));
figure()
subplot(2,1,1);
semilogx(f3,20*log10(mag_sys3)), grid on, hold on
semilogx(w3, 20*log10(mag3)), hold off
xlabel('Frequency [rad/s]')
ylabel('Magnitude [dB]')
subplot(2,1,2);
semilogx(f3,phase_deg3), grid on, hold on
semilogx(w3, phase3), hold off
xlabel('Frequency [rad/s]')
ylabel('Phase [deg]')
sgtitle('Bode RLC Noise using tfestimate vs RLC corrected base')
```

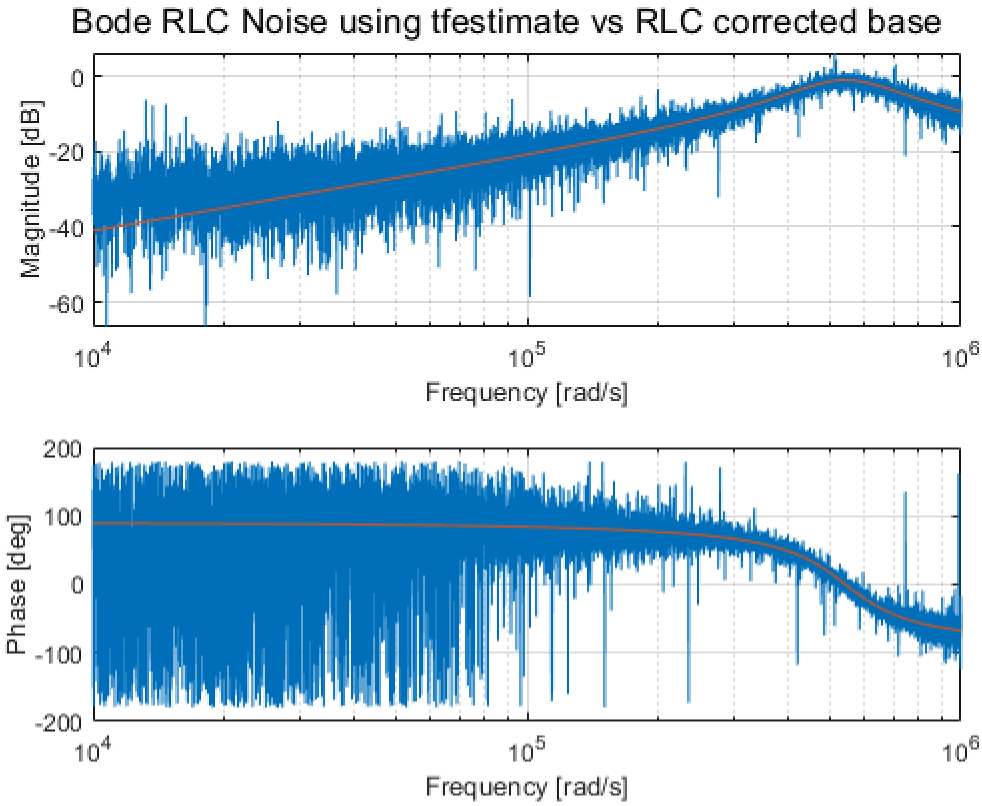


fig 11: Comparison of the responses of the 2nd ordered corrected system.

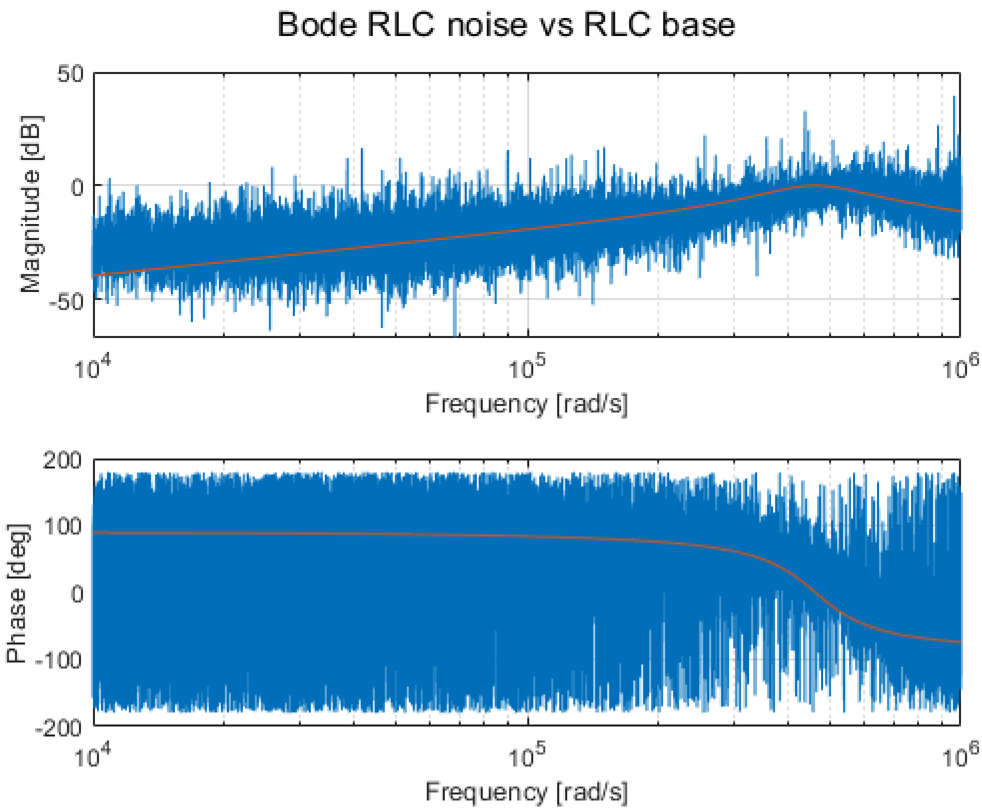


fig 12: Comparison of the responses of the 2nd ordered base system.

Conclusions:

The utilization of the *tfestimate()* has proved efficient in reducing the noise and showing the filter characteristics more clearly and in a better way. The function provides a more accurate depiction of the filter's frequency response. For linear systems, this means a better visualization and understanding of the gain and phase shift introduced by the filter at different frequencies. This is crucial for tasks like filter design and system diagnostics, where understanding the precise behavior of the filter across its operational bandwidth is essential.

Regarding the window, it was calculated based on the following reasoning; for a given *df* and *dt* (time interval) we calculated the sampling frequency (*fs*), and then from the formula $df = fs/N$, we know that the window size is *fs/df*. Furthermore, the overlap ratio is 50% so we take half the window.

Task 3

This task aims at observing the behavior of our system under the influence of different frequency resolutions df.

Task 3.1

This task aims at observing the behavior of the systems in the noisy environment. To this end we have plotted the comparisons of the theoretical response with the noisy response to observe how much of the original behavior is preserved.

```
figure()

subplot(2,1,1);

semilogx(f12,20*log10(mag_sys12)), grid on, hold on

semilogx(w1, 20*log10(mag1)), hold off

xlim([10^2 10^6])

xlabel('Frequency [rad/s]')

ylabel('Magnitude [dB]')

subplot(2,1,2);

semilogx(f12,phase_deg12), grid on, hold on

semilogx(w1,phase1)

xlim([10^2 10^6])

xlabel('Frequency [rad/s]')

ylabel('Phase [deg]')

sgtitle('Bode RC noise vs RC base')
```

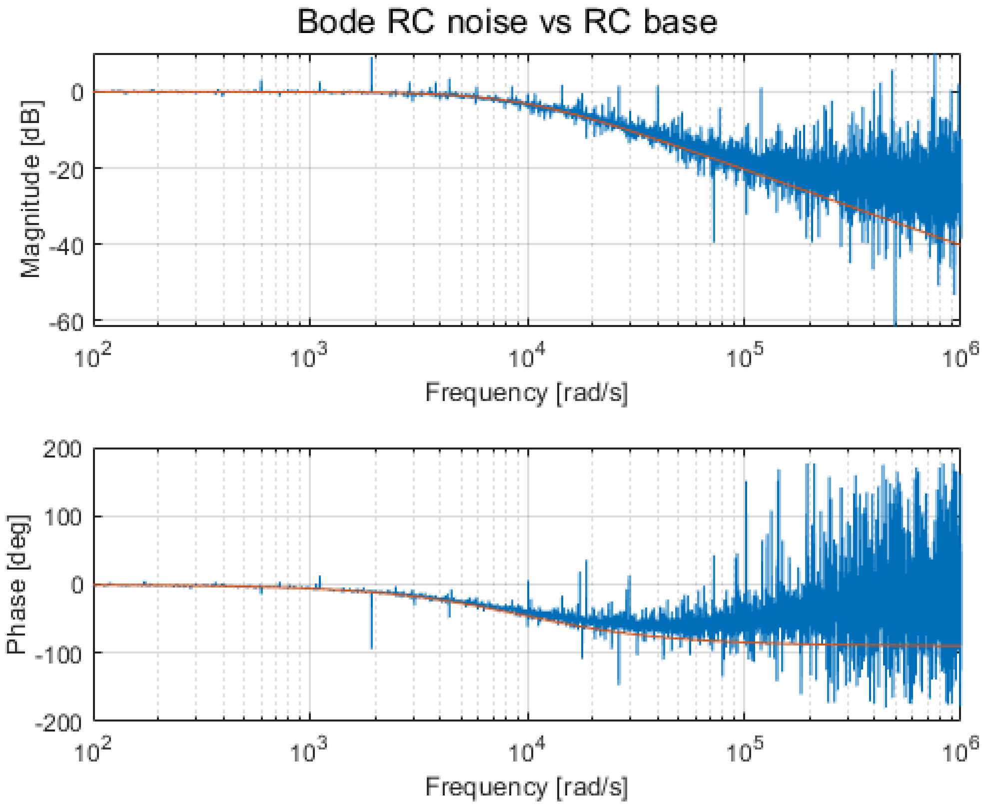


fig 13: Comparison of the bode of RC noise and RC base.

```
figure()

subplot(2,1,1);

semilogx(f3,20*log10(mag_sys3)), grid on, hold on

semilogx(w3, 20*log10(mag3)), hold off

xlim([10^4 10^7])

xlabel('Frequency [rad/s]')

ylabel('Magnitude [dB]')

subplot(2,1,2);

semilogx(f3,phase_deg3), grid on, hold on

semilogx(w3, phase3), hold off

xlim([10^4 10^7])

xlabel('Frequency [rad/s]')

ylabel('Phase [deg]')

sgtitle('Bode RLC noise using tfestimate vs RLC base corrected')
```

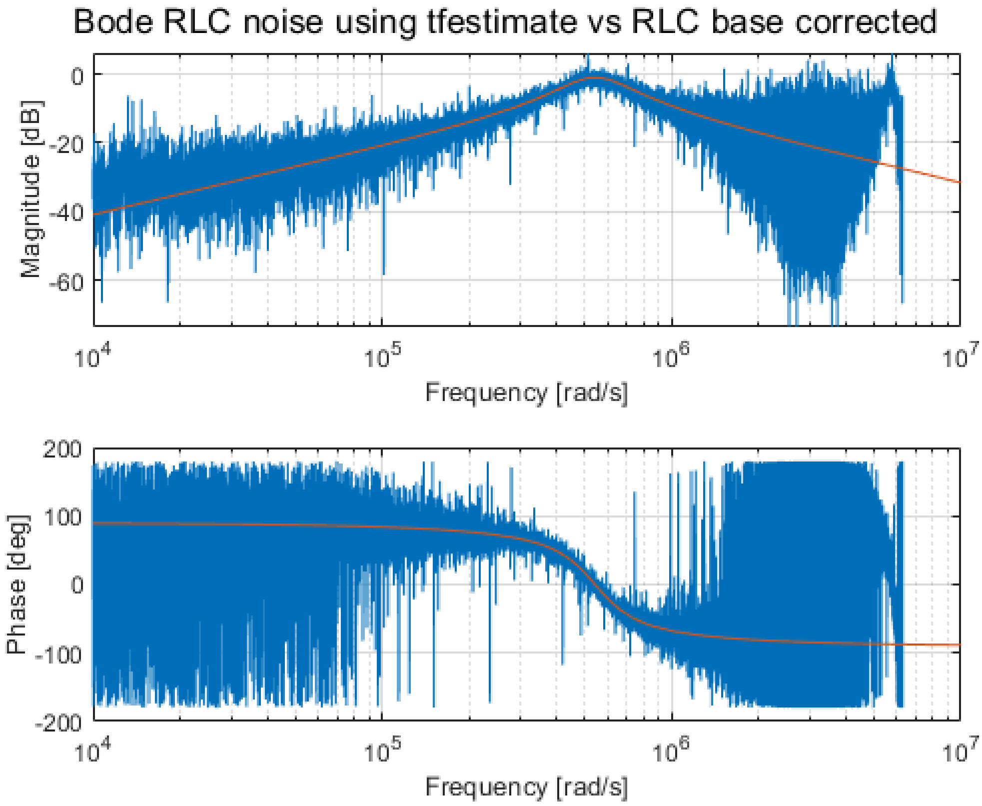


fig 14: Comparison of the bode of RLC using tfestimate and the corrected RLC base.

```
figure()

subplot(2,1,1);

semilogx(f3,20*log10(mag_sys3)), grid on, hold on

semilogx(w2, 20*log10(mag2)), hold off

xlim([10^4 10^7])

xlabel('Frequency [rad/s]')

ylabel('Magnitude [dB]')

subplot(2,1,2);

semilogx(f3,phase_deg3), grid on, hold on

semilogx(w2, phase2), hold off

xlim([10^4 10^7])

xlabel('Frequency [rad/s]')

ylabel('Phase [deg]')

sgtitle('Bode RLC noise vs RLC base')
```

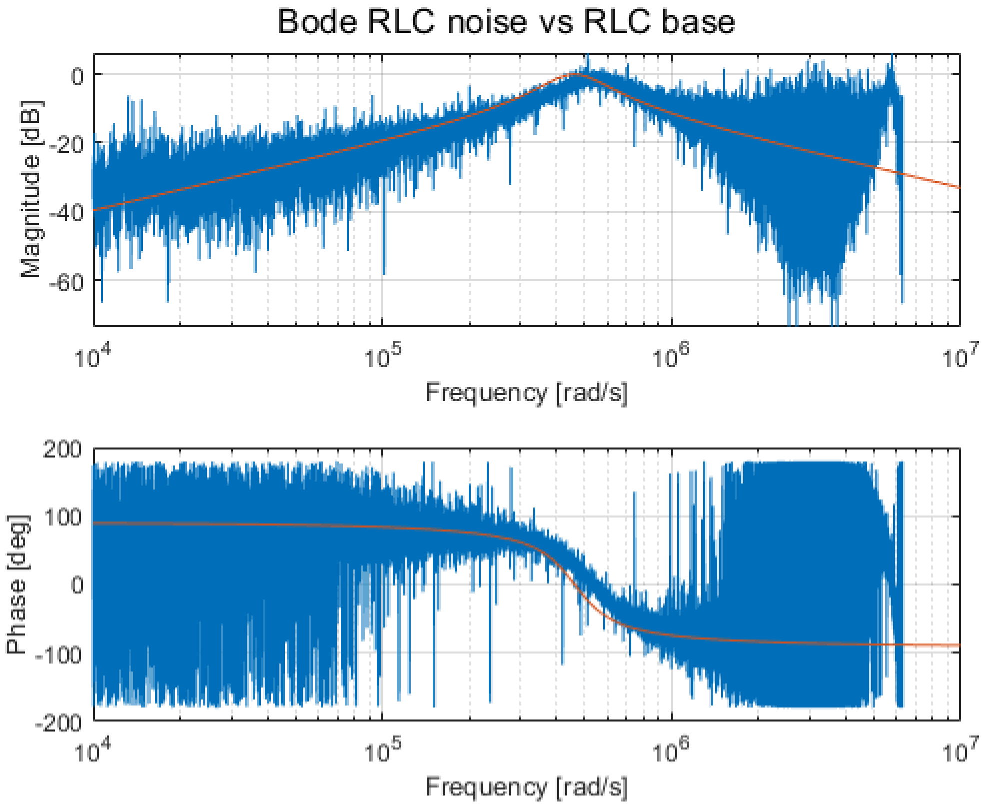


fig 15: Comparison of the bode of RLC noise and RLC base.

Conclusions:

The results show us that the general behavior of the filters is preserved within the noisy environment, but the disturbances have to be reduced by smoothening the function in order to be readable. Additionally, without correcting the RLC filter, the phase and magnitude transitions are delayed.

Task 3.2

In this task, we want to observe how our system response estimation changes with the increase of the df. To this end, we will be plotting the comparison for each system for three different values of df showcased below.

```
df = [1 10 100];
```

fig 16: different frequency resolutions for which we will be preparing the bode plot.

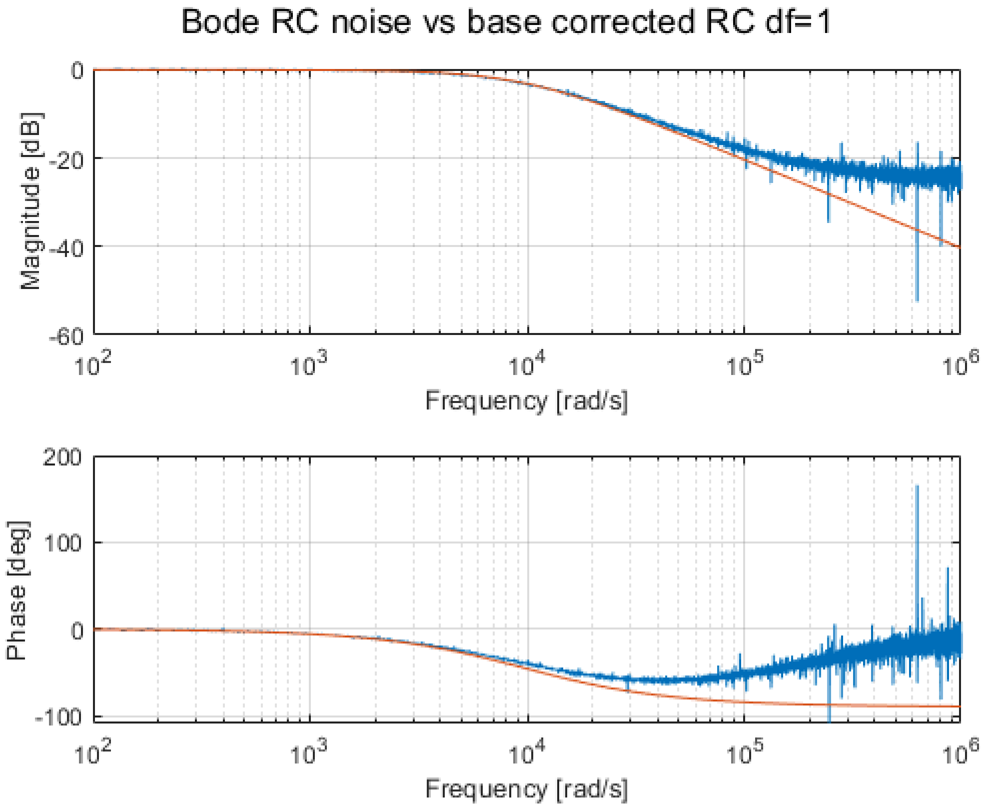


fig 17: Comparison of the bode of RC noise and RC base for df=1.

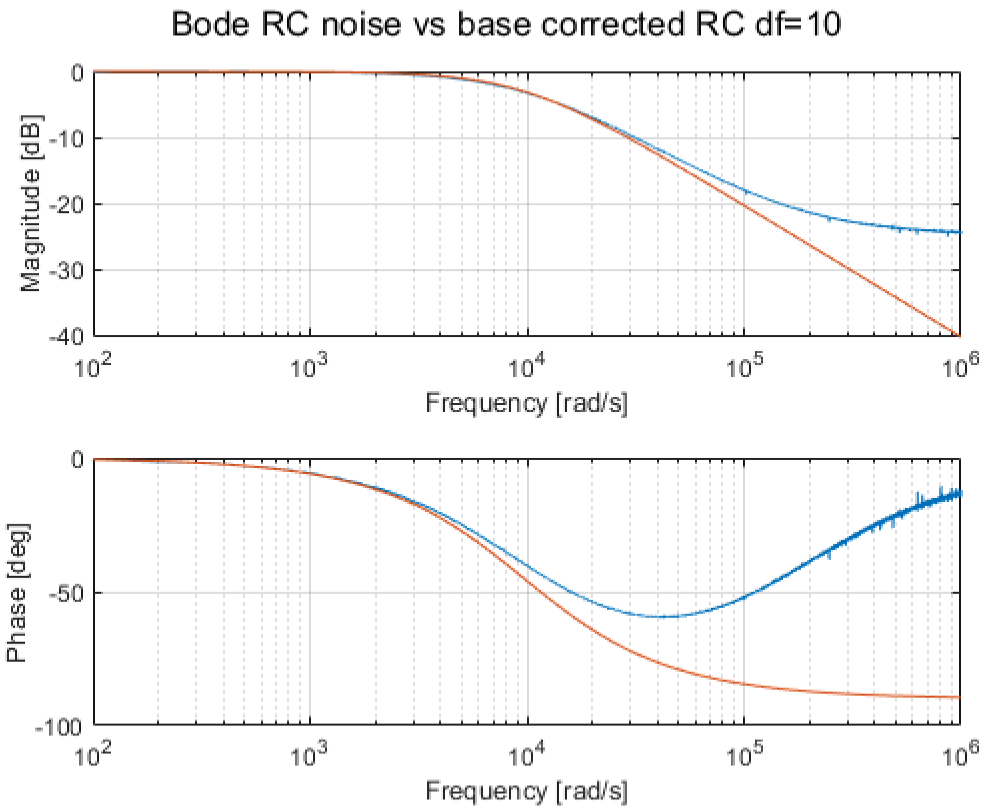


fig 18: Comparison of the bode of RC noise and RC base for df=10.

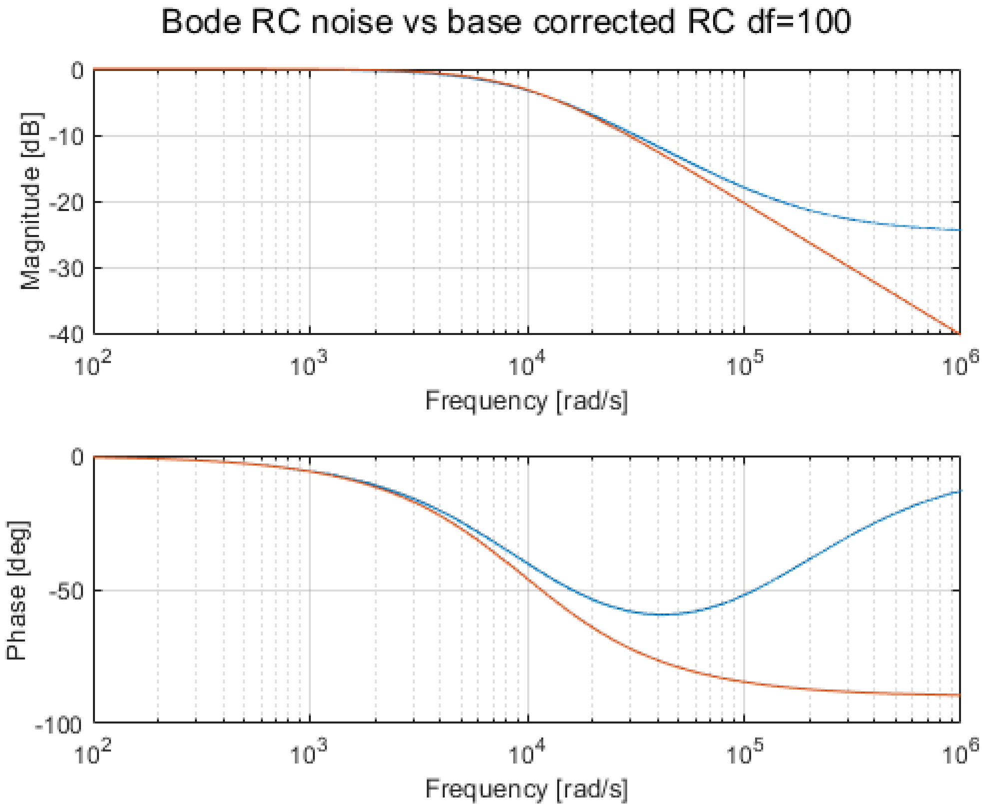


fig 19: Comparison of the bode of RC noise and RC base for df=100.

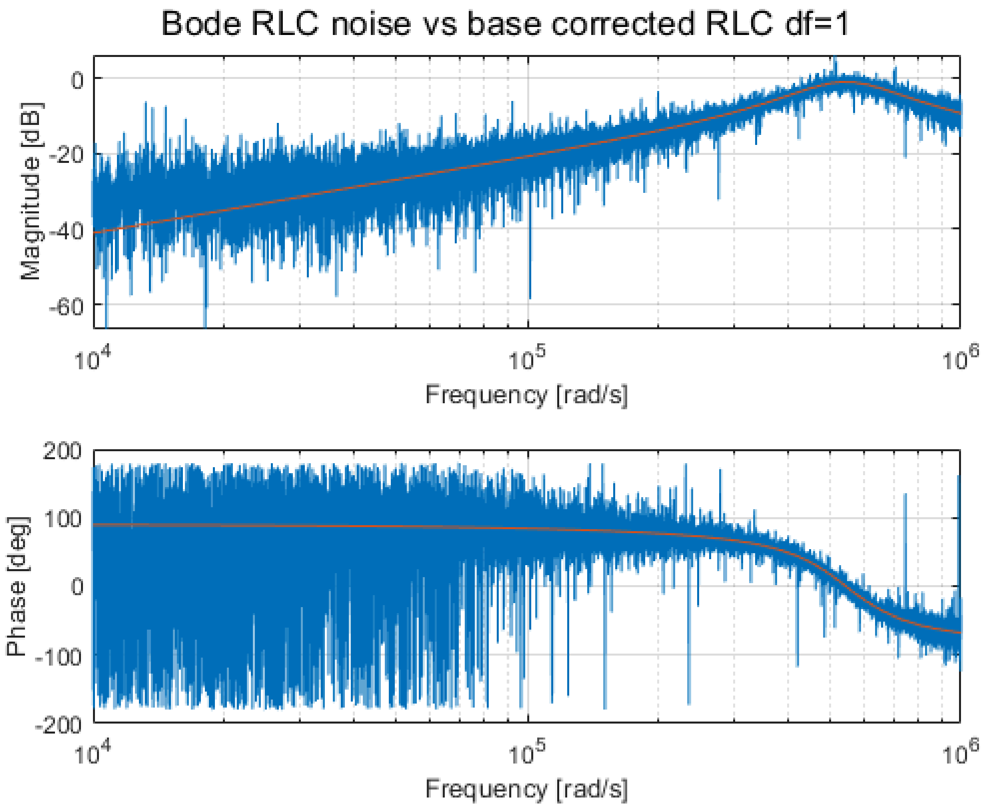


fig 20: Comparison of the bode of RLC noise and RLC base for df=1.

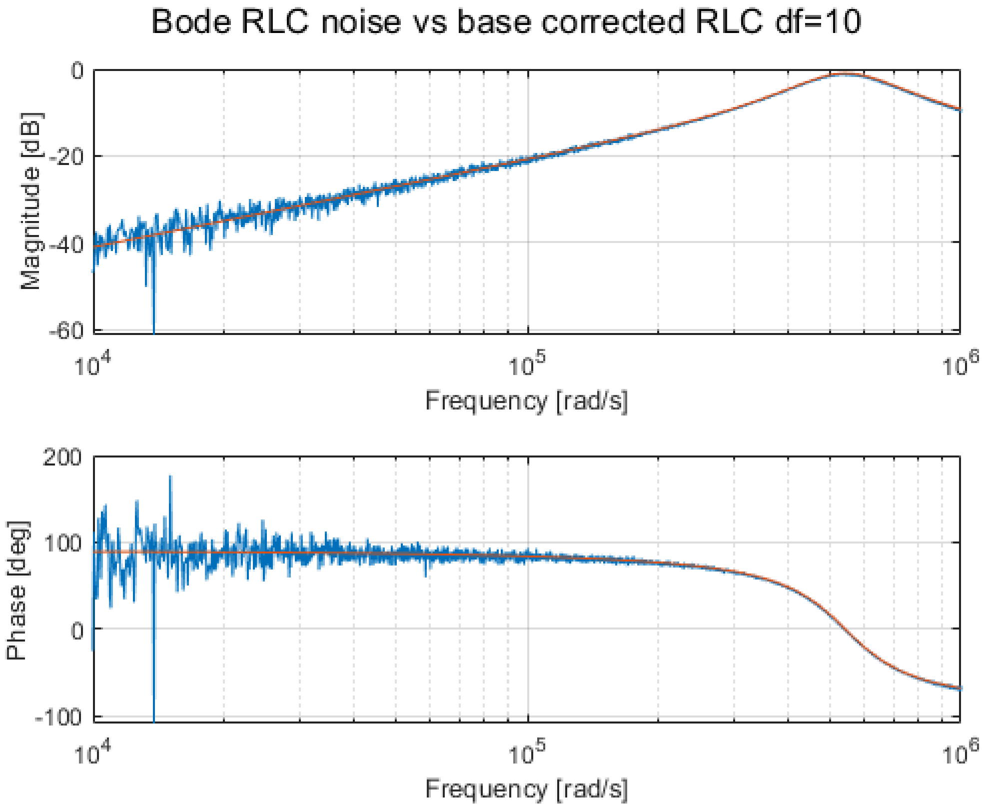


fig 21: Comparison of the bode of RLC noise and RLC base for df=10.

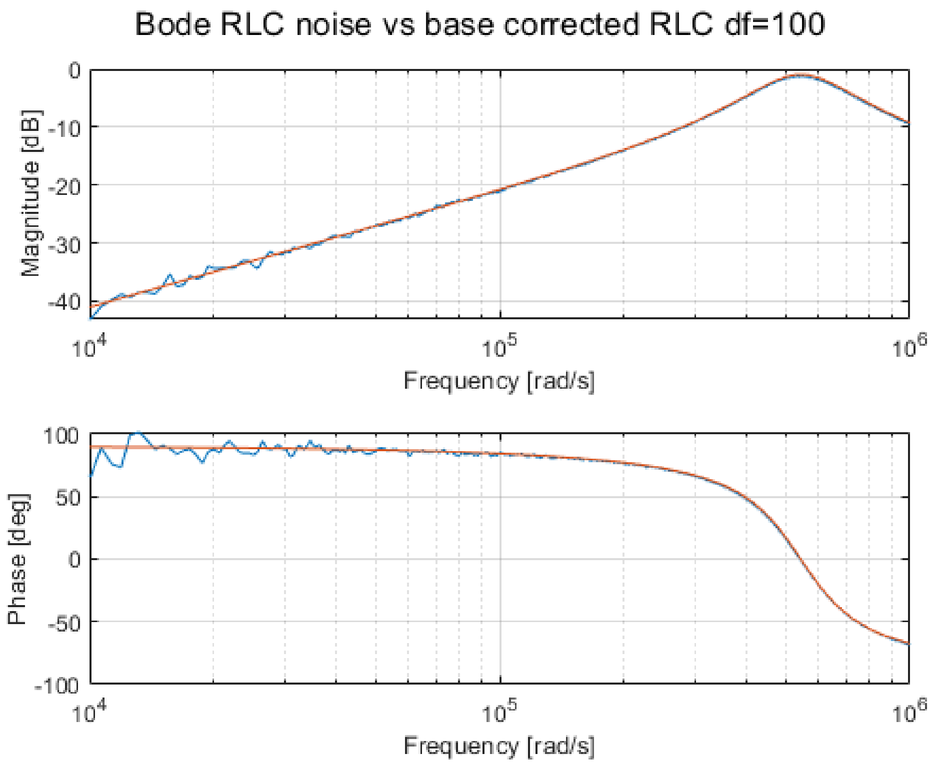


fig 22: Comparison of the bode of RLC noise and RLC base for df=100.

Conclusions: We can observe that the higher order of the df, the less noise is present in the response. This result was expected since higher df results in smaller windows, therefore the signal is more averaged due to the 50% overlap. This operation has, however a negative impact on the RC filter in which we can progressively observe bigger and bigger discrepancies as the df increases. The RLC filter on the other hand continues to improve with the higher orders of df, and the values remain consistent.