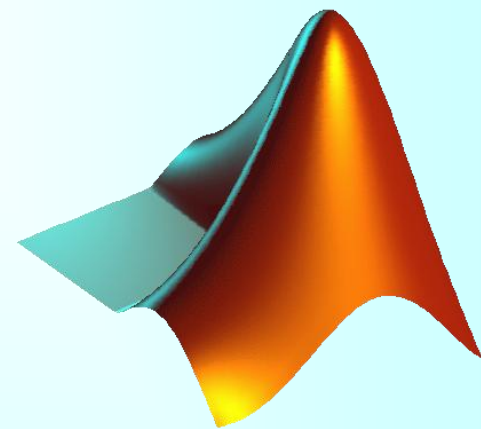
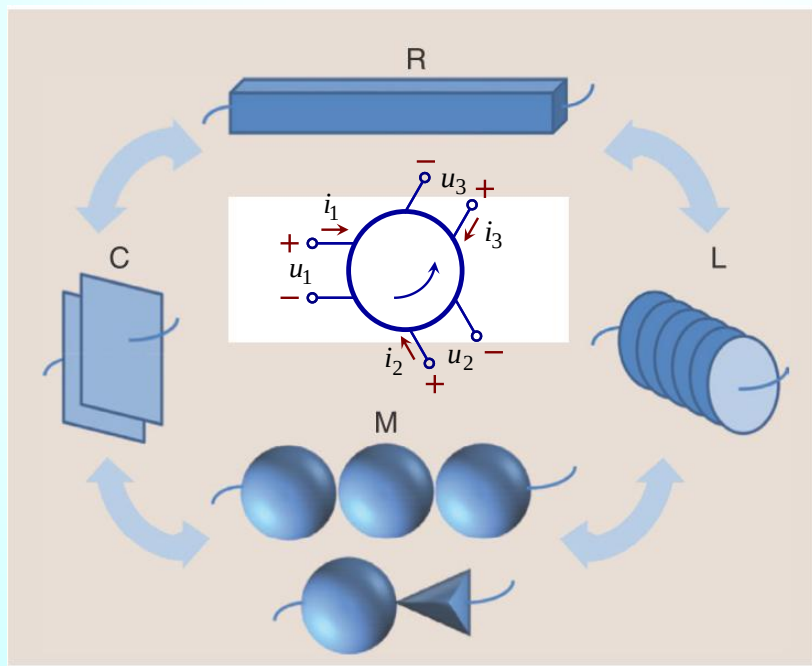


Практикум из рачунарске анализе трофазних кола



Милка Потребих

MATLAB: Simscape
Foundation Library
Utilities
Simulink

ОДРЕЂИВАЊЕ
АМПЛИТУДСКЕ & ФАЗНЕ
КАРАКТЕРИСТИКЕ

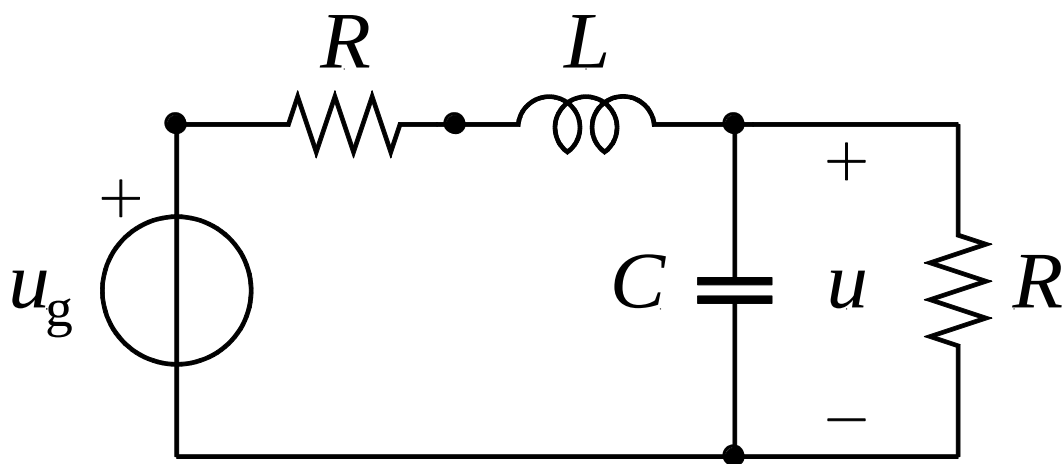
Филтар пропусник ниских учестаности

Вредности елемената електричног кола са слике су познате и постоји веза $L = R^2 C$.

(а) Одредити трансфер функцију (уопштену комплексну преносну функцију електричног кола, трансмитансу напона) $\underline{H}(s) = \frac{\underline{U}(s)}{\underline{U}_g(s)}$.

(б) Нацртати амплитудску карактеристику.

(в) Одредити пропусни опсег 3 dB.



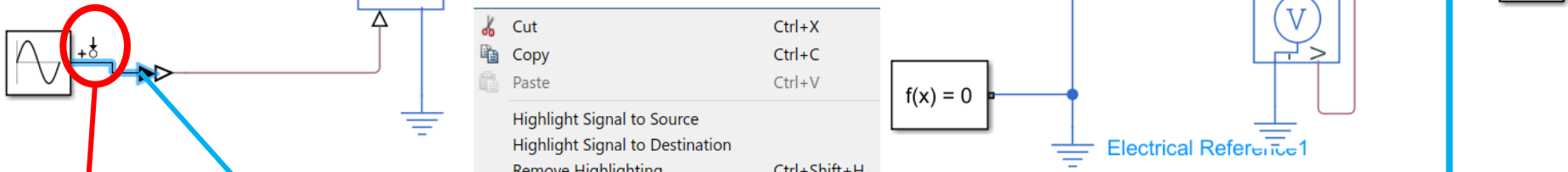
$$u_g = \sqrt{2}U_g \cos(\omega t + \theta_g)$$

Simulink, Simscape, Foundation Library, Utilities

$$R_1 = R_2 = 1\text{k}\Omega$$

$$L = 1\text{mH}$$

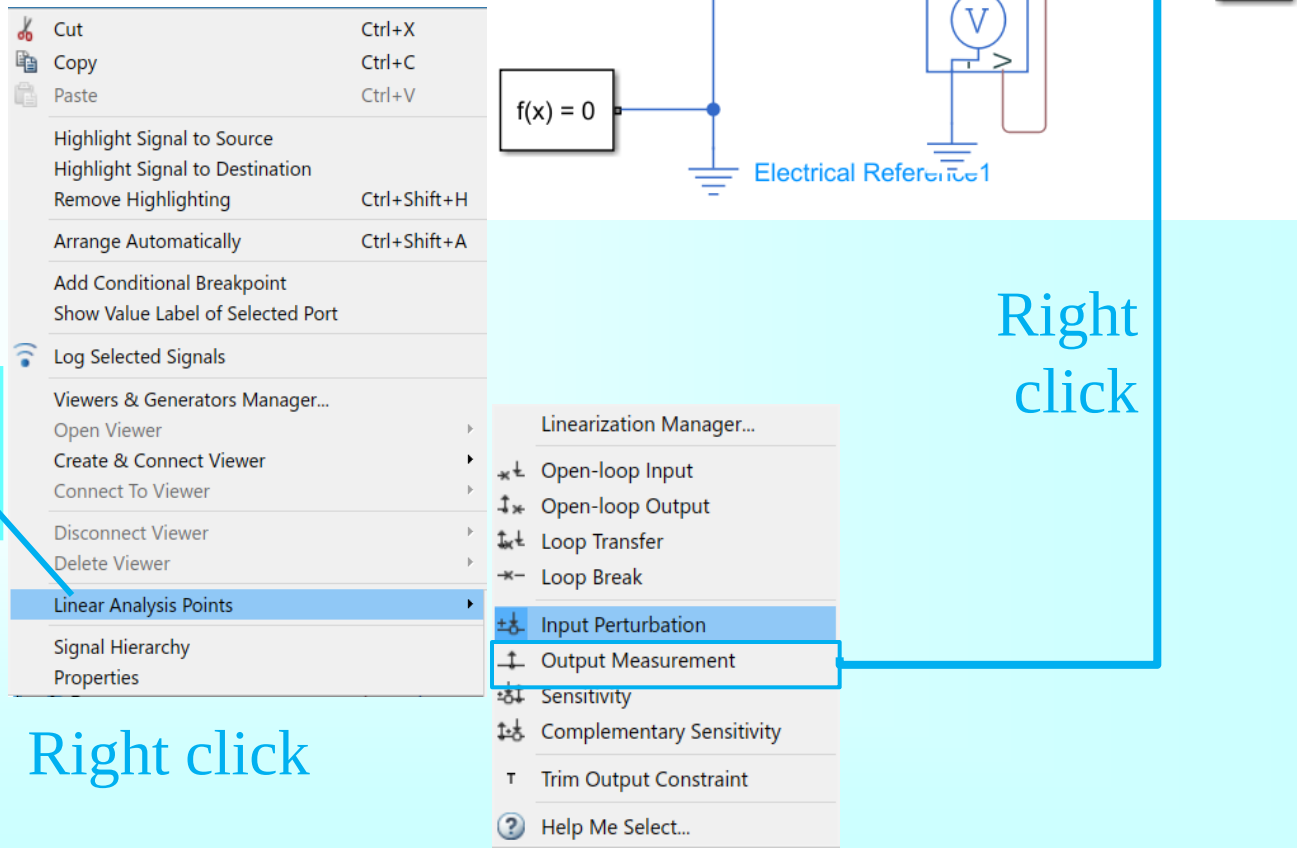
$$C = 1\mu\text{F}$$



Input Perturbation

AC Voltage Source

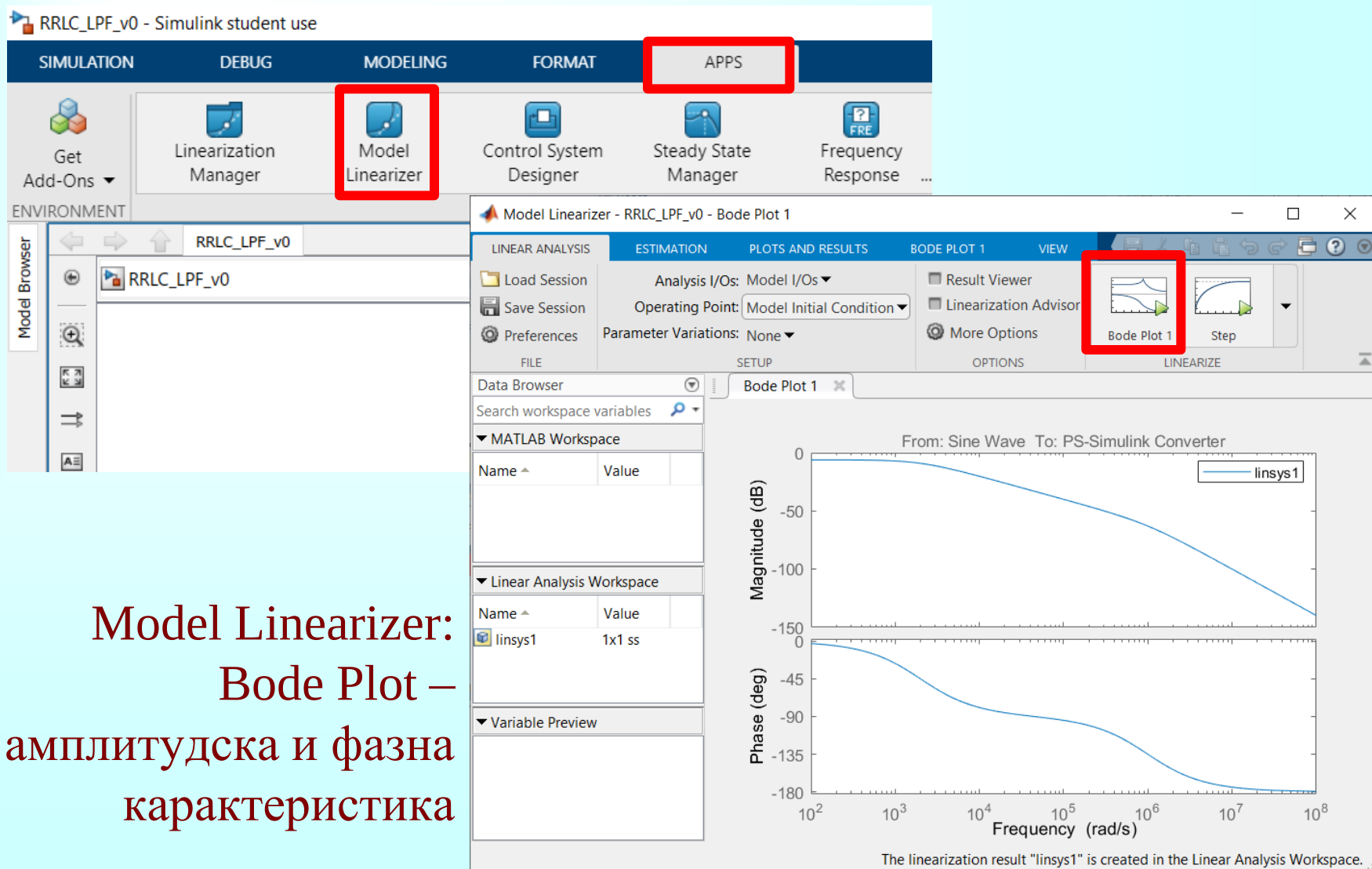
$$u_g = \sqrt{2} \underbrace{U_g}_{230\text{ V}} \sin\left(\underbrace{\omega}_{2\pi \underbrace{f}_{50\text{ Hz}}} t + \underbrace{\theta_g}_{\pi/2}\right)$$



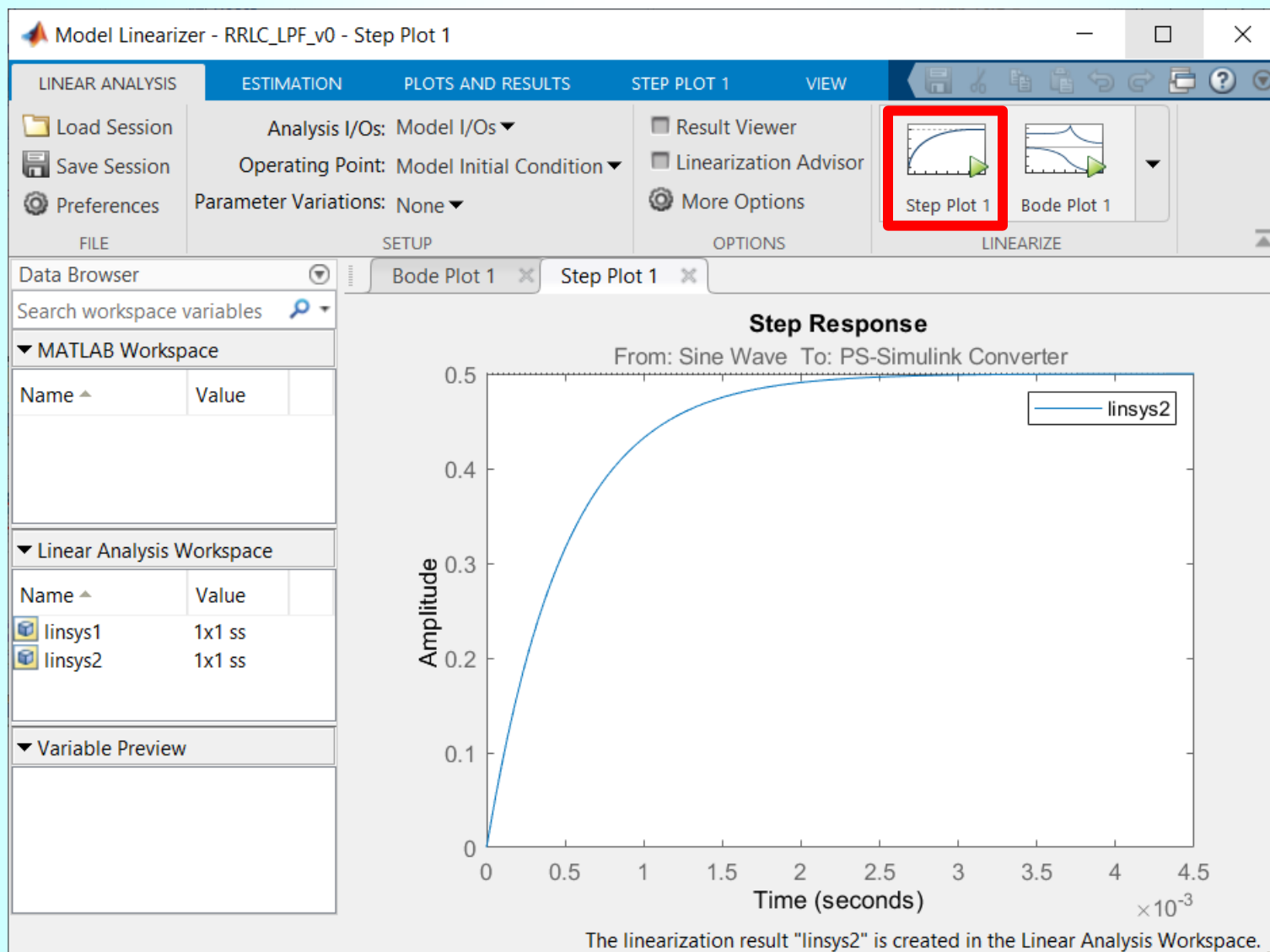
Right click

Right
click

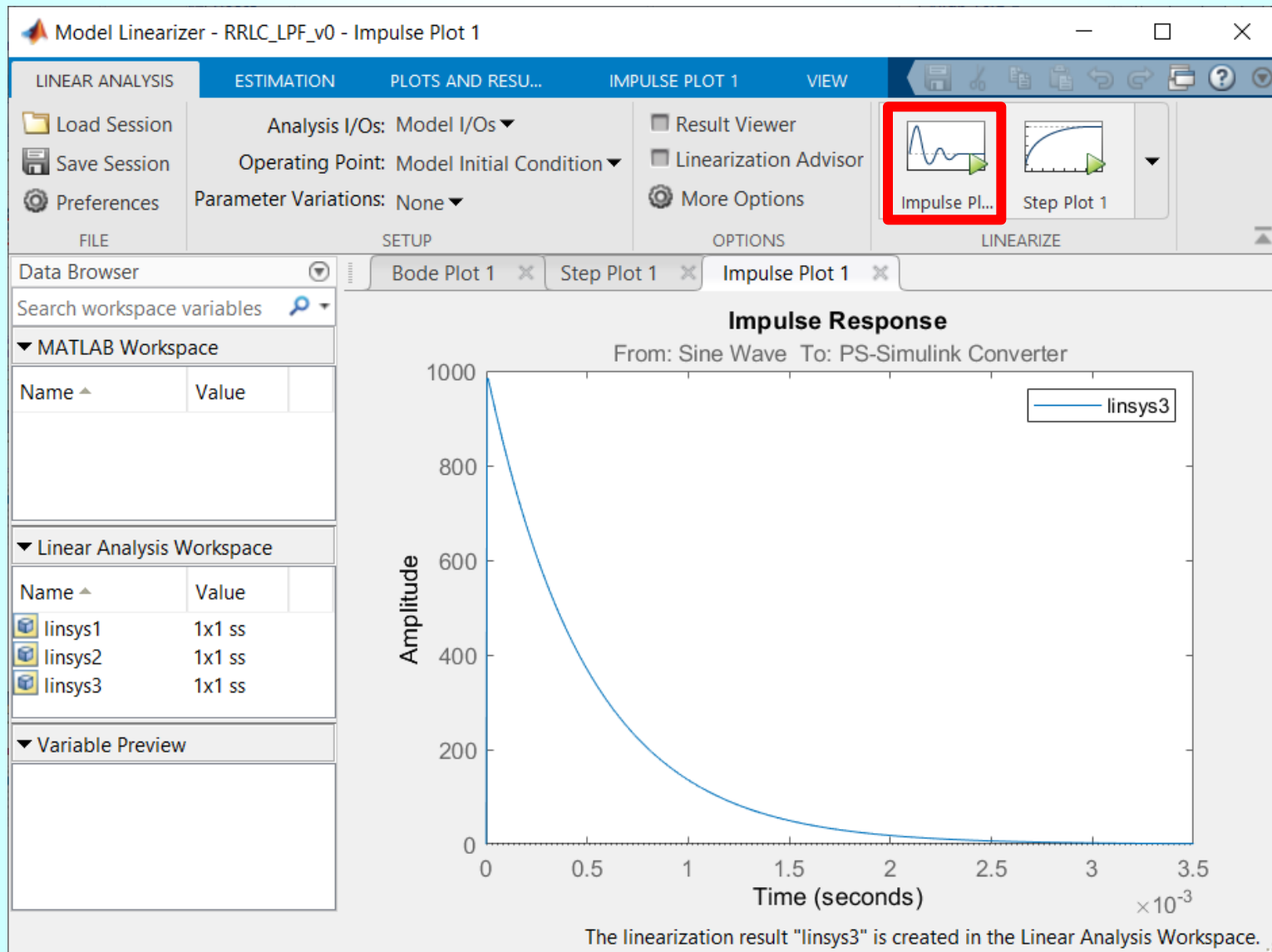
Simulink: Apps -> Model Linearizer



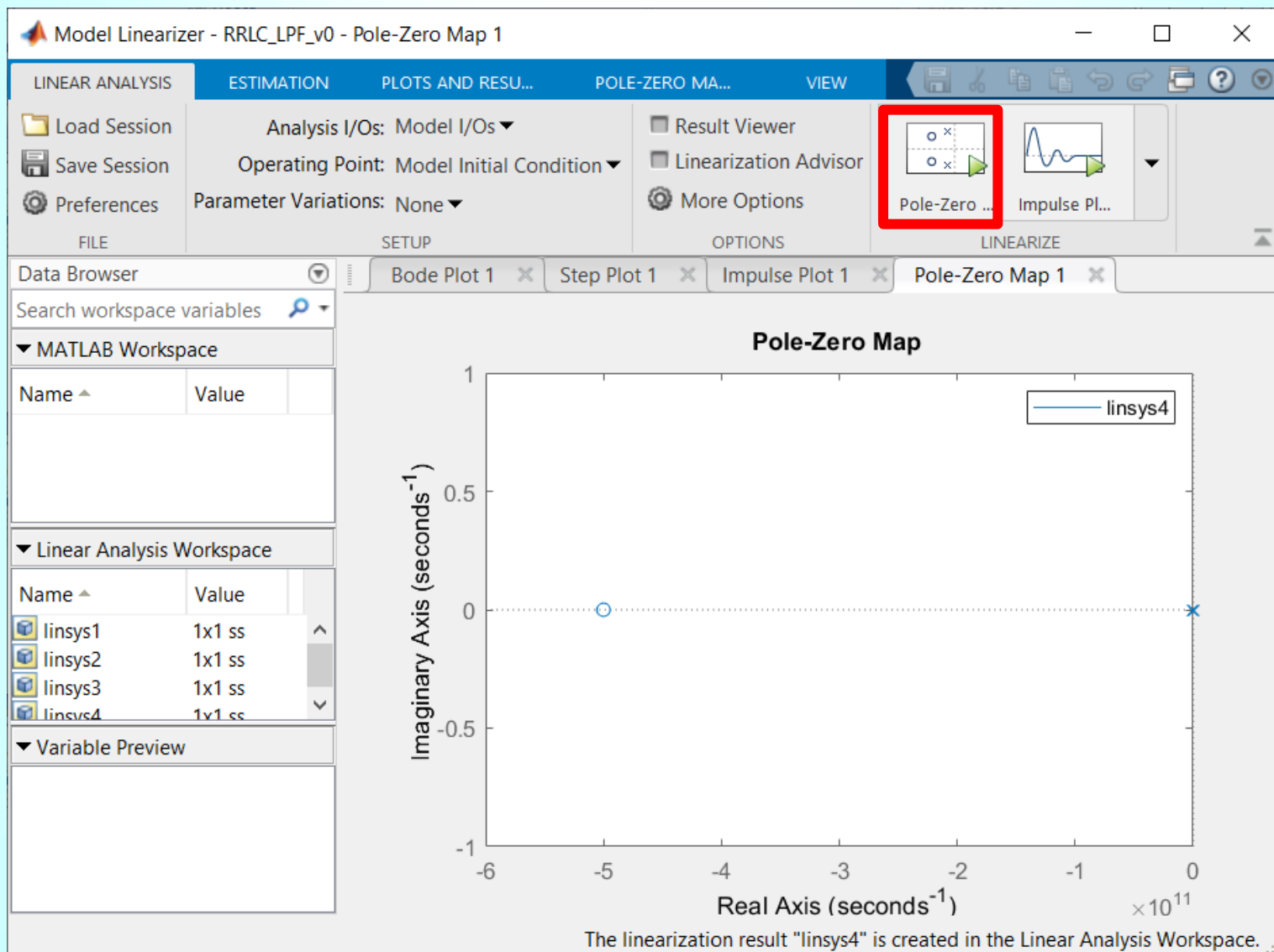
Одскочни одзив – Step Plot

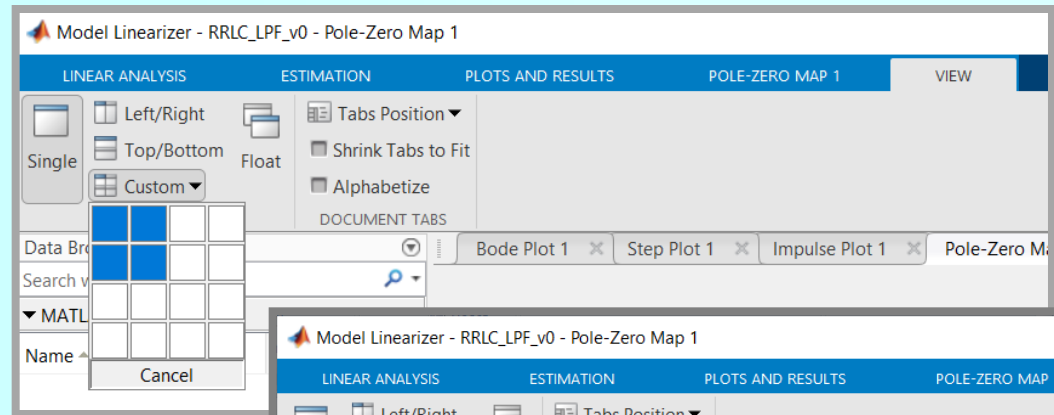


Импулсни одзив – Impulse Plot

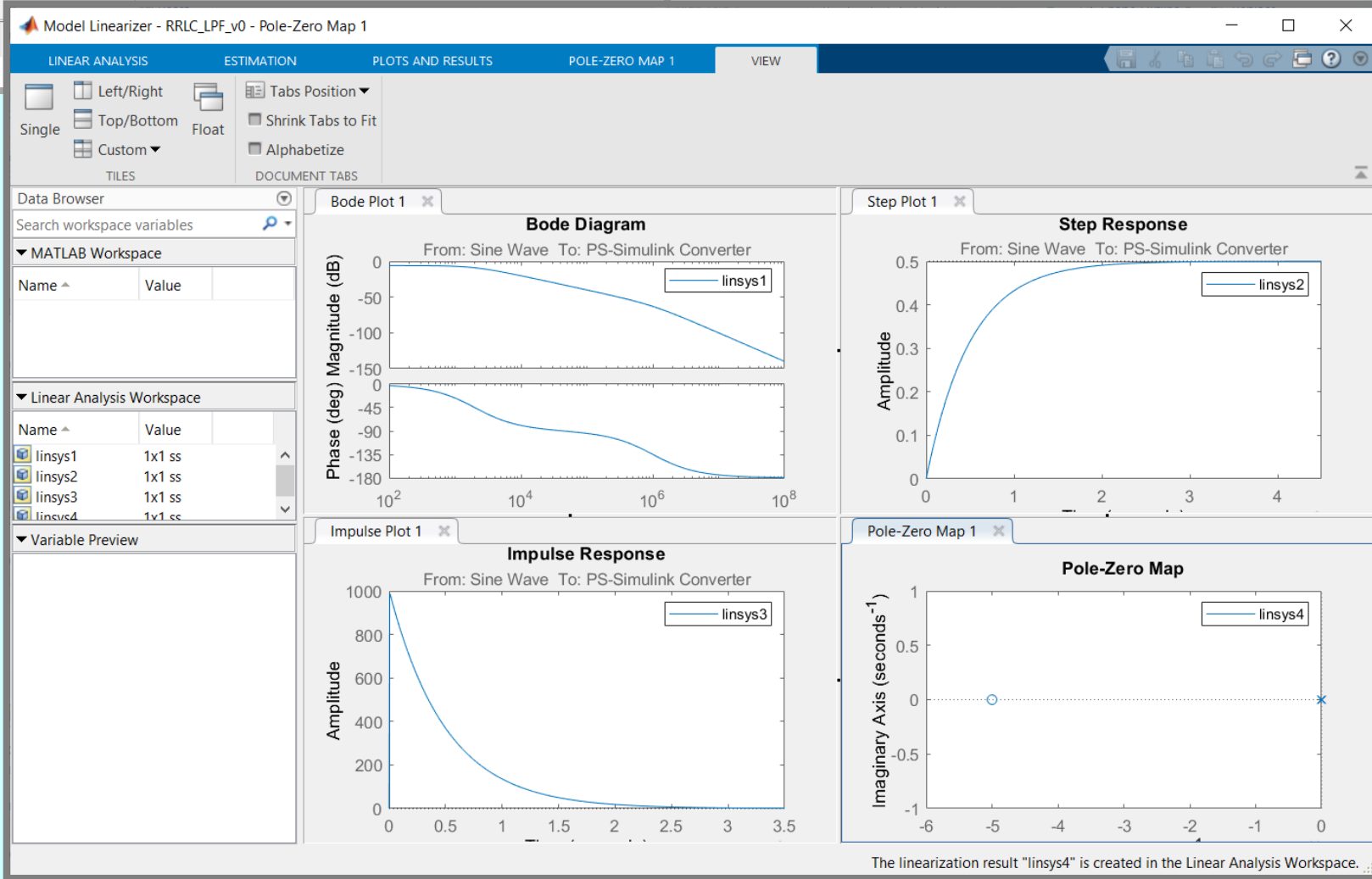


Полови и нуле трансфер функције – Pole Zero Plot





View > Custom>2x2



ФРЕКВЕНЦИЈСКИ ОДЗИВ

Оdređivanje uopštene kompleksne funkcije

```
clear variables
syms w C L R
assume(0 < R & 0 < C & 0 < L )

zamena = L == C*R^2
```

```
zamena = L = C R^2
```

```
vrednosti = [C == 1, R == 1]
vrednosti = (C = 1 R = 1)
```

```
syms s
Z1 = R + s*L
```

```
Z1 = R + L s
```

```
Z2 = 1/(s*C + 1/R)
```

```
Z2 =
1
C s + 1/R
```

```
syms H(s)
H(s) = subs(Z2/(Z1 + Z2), lhs(zamena), rhs(zamena))
```

```
H(s) =
1
(C s + 1/R) (R + 1/(C s + 1/R) + C R^2 s)
```

```
simplify(H(s))
```

```
ans =
1
C^2 R^2 s^2 + 2 C R s + 2
```

ТРАНСФЕР ФУНКЦИЈА

Amplitudska i fazna karakteristika

```
syms Hjw(w)
Hjw(w) = simplify(subs(H(s), s, 1i*w))
```

```
Hjw(w) =
-C^2 R^2 w^2 + 2 C R w i - 2
C^4 R^4 w^4 + 4
```

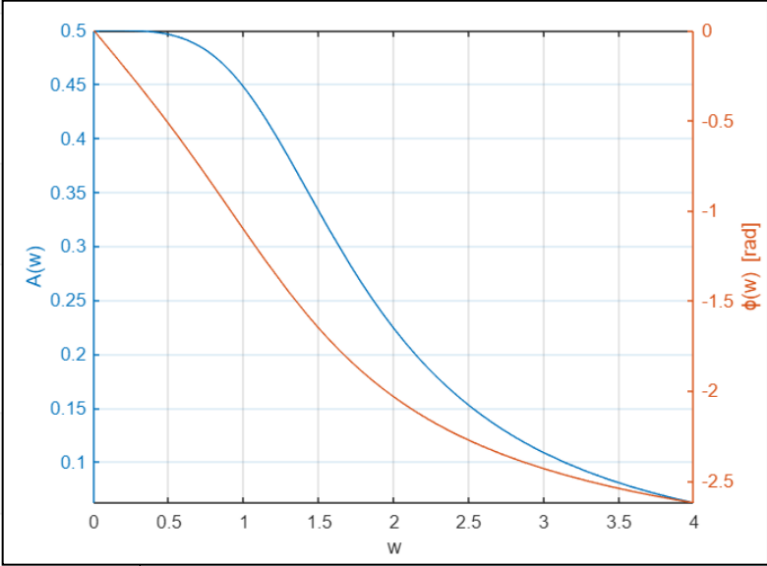
```
syms Aw(w)
Aw(w) = simplify(abs(Hjw(w)))
```

```
Aw(w) =
|C^2 R^2 w^2 + 2 C R w i - 2|
|C^4 R^4 w^4 + 4|
```

```
syms phi(w)
phi(w) = expand(angle(Hjw(w)))
```

```
phi(w) =
atan2(-2 C R w / (C^4 R^4 w^4 + 4), (2 / (C^4 R^4 w^4 + 4) - C^2 R^2 w^2 / (C^4 R^4 w^4 + 4)))
```

АМПЛИТУДСКА И
ФАЗНА
КАРАКТЕРИСТИКА



```
figure
yyaxis left
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('A(w)')
yyaxis right
fplot(w, subs(phi(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('\phi(w) [rad]')
```

```
xlabel('w')
grid on
```

Одређивање пропусног опсега

$$A_{ref} = A_w(0)$$

$$A_{ref} =$$

$$\frac{1}{2}$$

$$\text{assume}(0 < w)$$

$$w_{3dB} = \text{solve}(A_w(w) == A_{ref}/\sqrt{2}, w)$$

$$w_{3dB} =$$

$$\frac{\sqrt{2}}{C R}$$

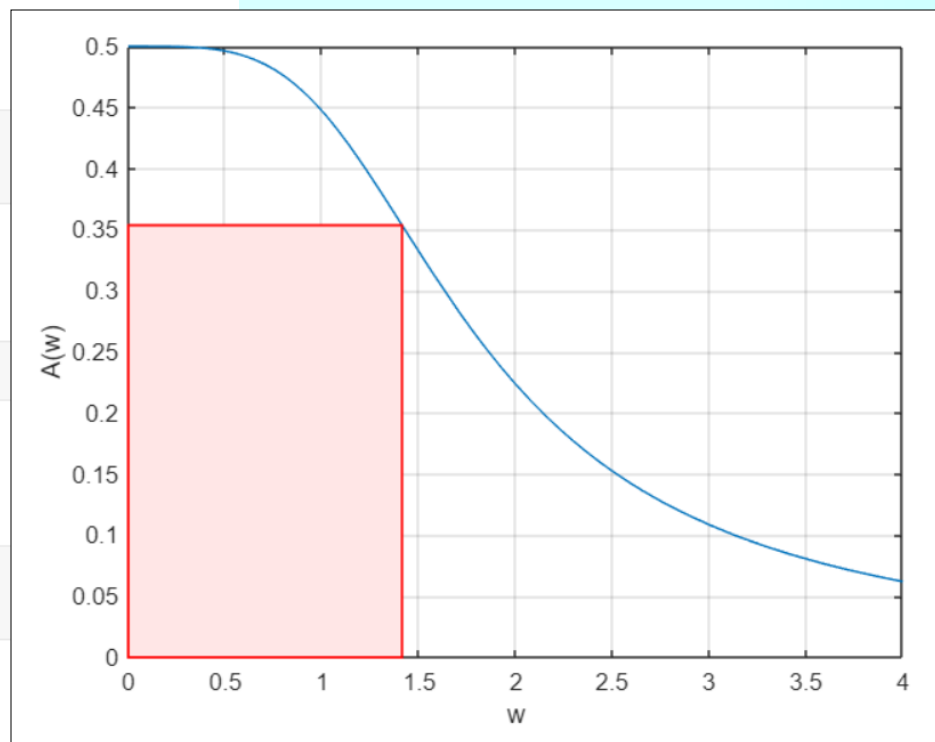
$$\text{BandPass3dB} = [0, w_{3dB}]$$

$$\text{BandPass3dB} =$$

$$\left(0 \quad \frac{\sqrt{2}}{C R}\right)$$

$$wg1 = \text{subs}(w_{3dB}(1), \text{lhs}(\text{vrednosti}), \text{rhs}(\text{vrednosti}))$$

$$wg1 = \sqrt{2}$$



Означавање пропусног опсега у графику

```
figure
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
hold on
rectangle('Position',[0, 0, double(wg1), double(Aref/sqrt(2))],...
          'EdgeColor','r',...
          'FaceColor',[1 0.9 0.9],...
          'LineWidth',1)
hold off
ylabel('A(w)')
xlabel('w')
grid on
```

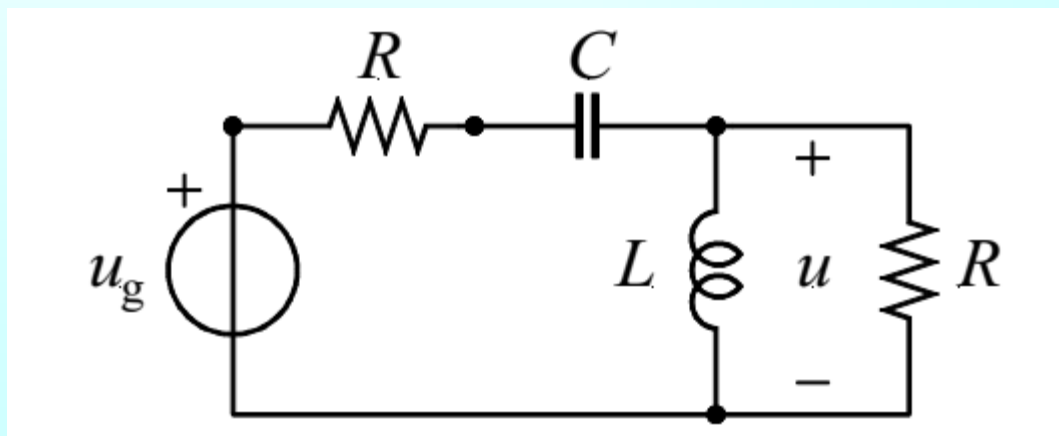
Филтар пропусник високих учестаности

Вредности елемената електричног кола са слике су познате и постоји веза $L = R^2 C$.

(а) Одредити трансфер функцију (уопштену комплексну преносну функцију електричног кола, трансмитансу напона) $\underline{H}(s) = \frac{\underline{U}(s)}{\underline{U}_g(s)}$.

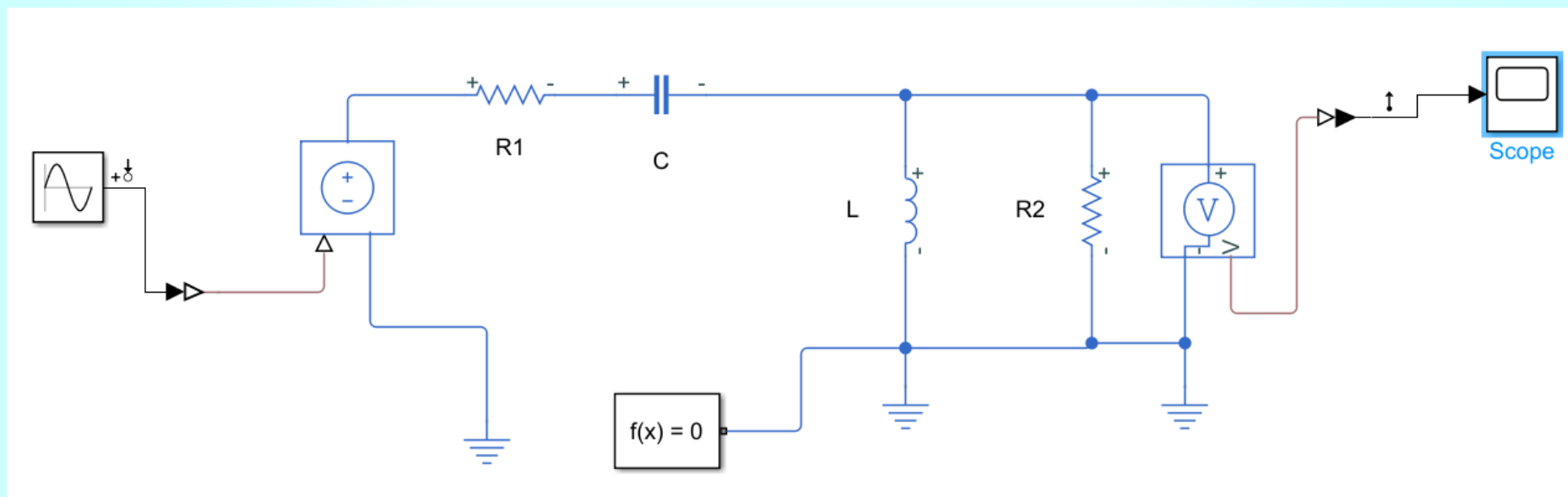
(б) Нацртати амплитудску карактеристику.

(в) Одредити пропусни опсег 3 dB.



$$u_g = \sqrt{2}U_g \cos(\omega t + \theta_g)$$

Simulink, Simscape, Foundation Library, Utilities



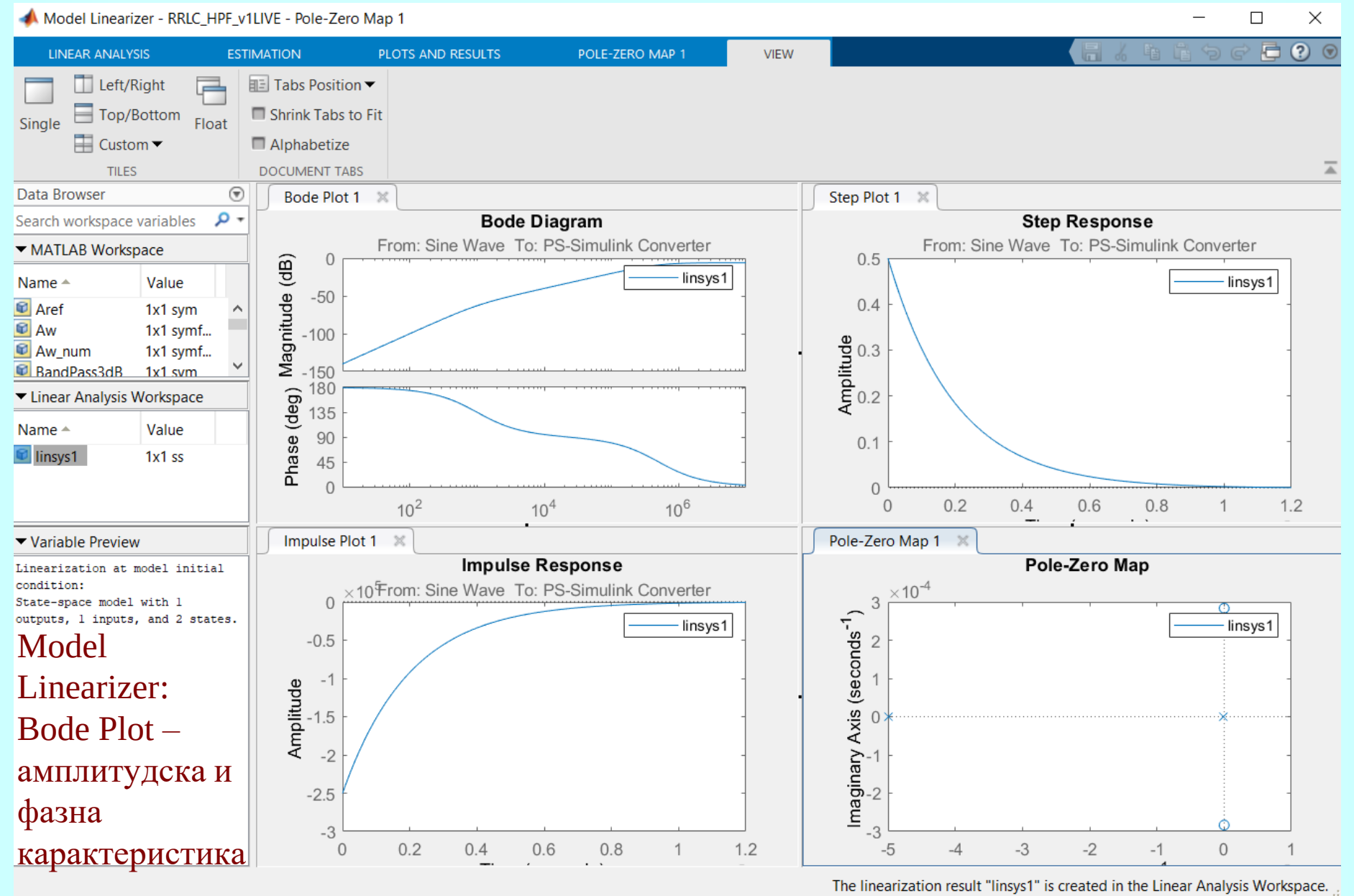
AC Voltage Source

$$u_g = \sqrt{2} \underbrace{U_g}_{230\text{ V}} \sin\left(\underbrace{\omega}_{2\pi \underbrace{f}_{50\text{ Hz}}} t + \underbrace{\theta_g}_{\pi/2}\right)$$

$$R_1 = R_2 = 1\text{ k}\Omega$$

$$L = 1\text{ mH}$$

$$C = 1\text{ }\mu\text{F}$$



Одређивање уопштене комплексне функције

```
clear variables
syms w C L R
assume(0 < R & 0 < C & 0 < L )
```

```
zamena = L == C*R^2
```

```
zamena = L = C R^2
```

```
vrednosti = [C == 1, R == 1]
```

```
vrednosti = (C = 1 R = 1)
```

```
syms s
Z1 = R + 1/(s*C)
```

```
Z1 =
R + 1/C s
```

```
Z2 = 1/(1/(s*L) + 1/R)
```

```
Z2 =
1
1/R + 1/L s
```

```
syms H(s)
H(s) = subs(Z2/(Z1 + Z2), lhs(zamena), rhs(zamena))
```

```
H(s) =
```

$$\frac{1}{\left(\frac{1}{R} + \frac{1}{C R^2 s}\right) \left(R + \frac{1}{C s} + \frac{1}{\frac{1}{R} + \frac{1}{C R^2 s}}\right)}$$

```
simplify(H(s))
```

```
ans =
```

$$\frac{C^2 R^2 s^2}{2 C^2 R^2 s^2 + 2 C R s + 1}$$

Амплитудска и фазна карактеристика

```
syms Hjw(w)
Hjw(w) = subs(simplify(H(s)), s, 1i*w)
```

$$Hjw(w) = \frac{C^2 R^2 w^2}{-2 C^2 R^2 w^2 + 2 C R w i + 1}$$

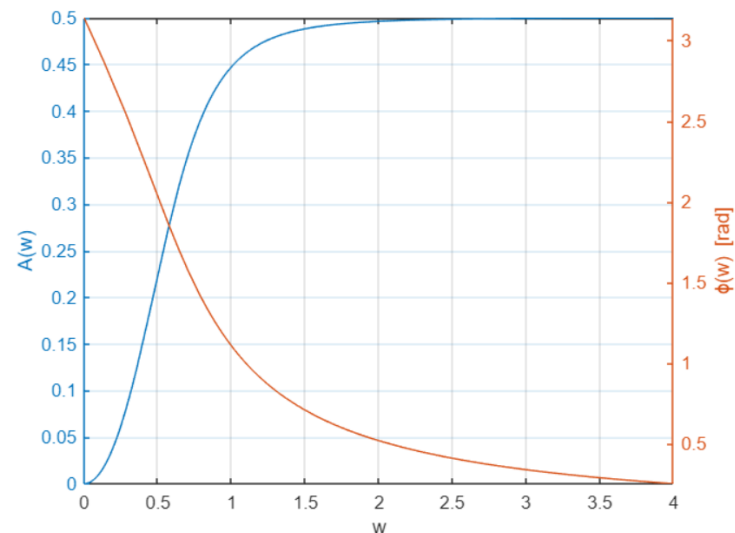
```
syms Aw(w)
Aw(w) = simplify(abs(Hjw(w)))
```

$$Aw(w) = \frac{C^2 R^2 |w|^2}{|-2 C^2 R^2 w^2 + 2 C R w i + 1|}$$

```
syms phi(w)
phi(w) = expand(angle(Hjw(w)))
```

$$\phi(w) = \text{angle}\left(-\frac{w^2}{-2 C^2 R^2 w^2 + 2 C R w i + 1}\right)$$

MATLAB: Symbolic Toolbox



Цртање амплитудске и фазне карактеристике

```
figure
yyaxis left
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('A(w)')
yyaxis right
fplot(w, subs(phi(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('\phi(w) [rad]')
xlabel('w')
grid on
```

Određivanje propusnog opsega

```
Aref = limit(Aw(w), w, Inf)
```

```
Aref =  
 $\frac{1}{2}$ 
```

```
assume(0 < w)  
w3dB = solve(Aw(w) == Aref/sqrt(2), w)
```

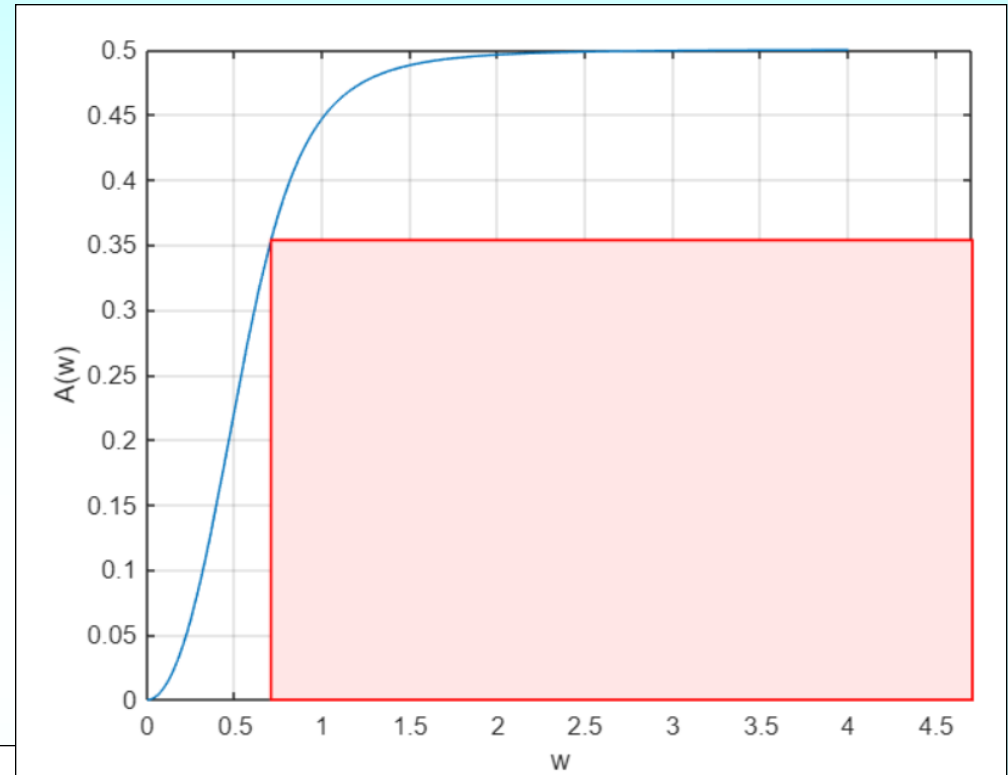
```
w3dB =  
 $\frac{\sqrt{2}}{2 C R}$ 
```

```
BandPass3dB = [ w3dB, Inf]
```

```
BandPass3dB =  
 $\left( \frac{\sqrt{2}}{2 C R} \quad \infty \right)$ 
```

```
wg1 = subs(w3dB(1), lhs(vrednosti), rhs(vrednosti))
```

```
wg1 =  
 $\frac{\sqrt{2}}{2}$ 
```



Označavanje propusnog opsega u grafiku

```
figure  
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])  
hold on  
rectangle('Position',[double(wg1), 0, 4, double(Aref/sqrt(2)) ], ...  
          'EdgeColor','r',...  
          'FaceColor',[1 0.9 0.9],...  
          'LineWidth',1)  
  
hold off  
ylabel('A(w)')  
xlabel('w')  
grid on
```

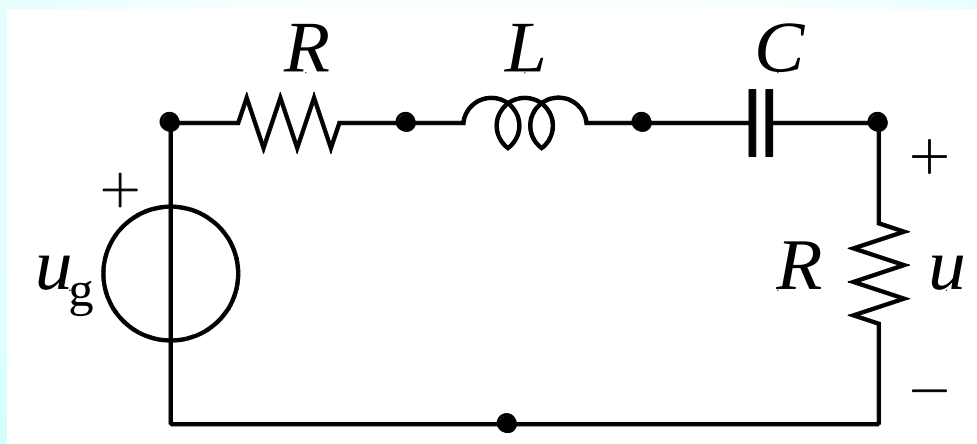

Филтар пропусник опсега учестаности

Вредности елемената електричног кола са слике су познате и постоји веза $L = R^2 C$.

(а) Одредити трансфер функцију (уопштену комплексну преносну функцију електричног кола, трансмитансу напона) $\underline{H}(\underline{s}) = \frac{\underline{U}(\underline{s})}{\underline{U}_g(\underline{s})}$.

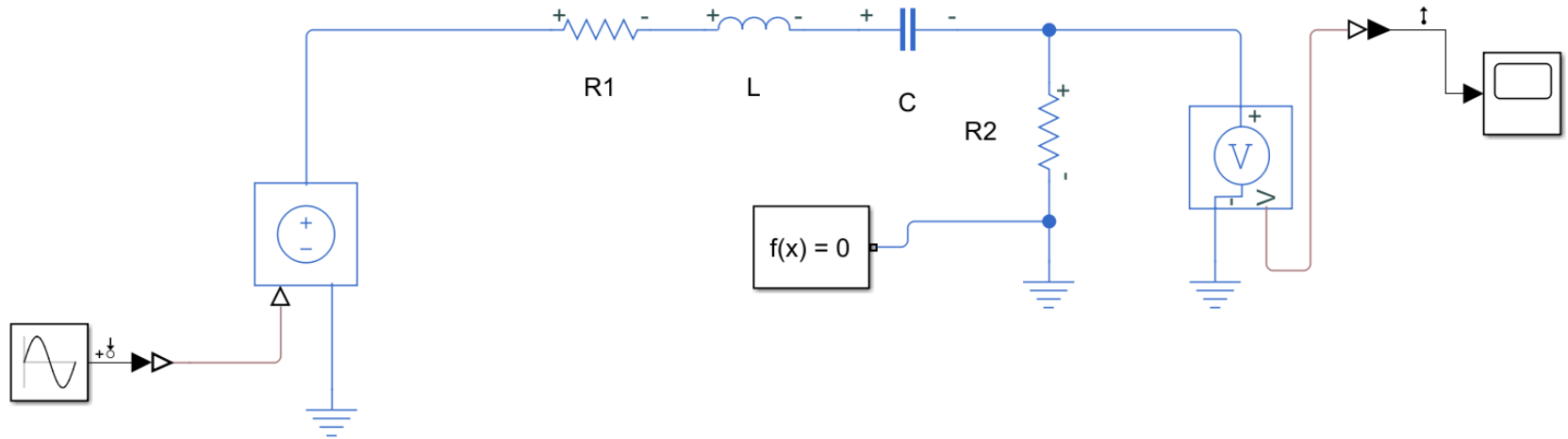
(б) Нацртати амплитудску карактеристику.

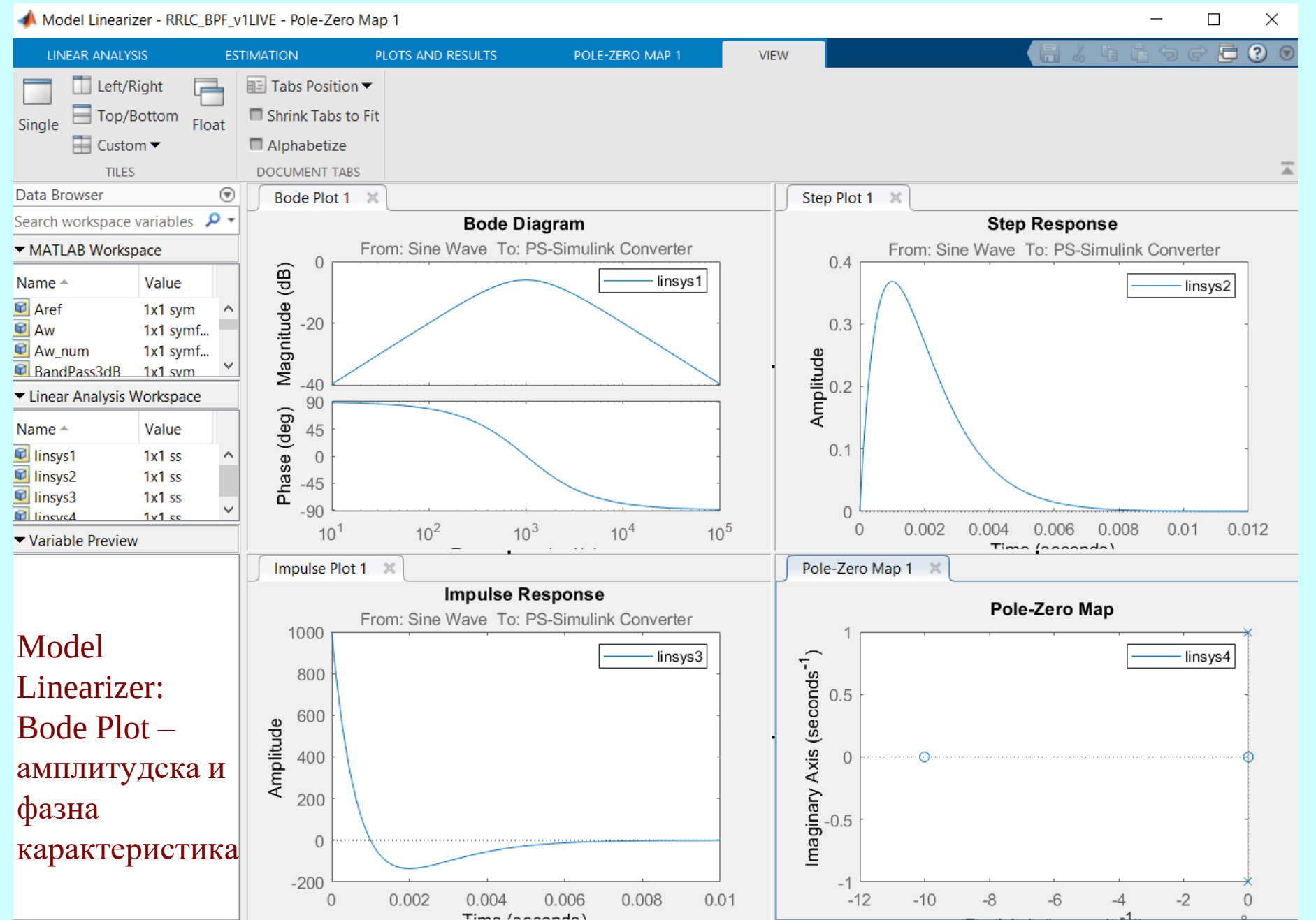
(в) Одредити пропусни опсег 3 dB.



$$u_g = \sqrt{2}U_g \cos(\omega t + \theta_g)$$

Simulink Simscape Foundation Library Utilities





Model
Linearizer:
Bode Plot –
амплитудска и
фазна
карактеристика

Одређивање уопштене комплексне функције

```
clear variables
syms w C L R
assume(0 < R & 0 < C & 0 < L )

zamena = L == C*R^2

zamena = L = C R^2

vrednosti = [C == 1, R == 1]

vrednosti = (C = 1 R = 1)

syms s H(s)
H(s) = simplify(subs(R/(R + s*L + 1/(s*C) + R), lhs(zamena), rhs(zamena)))

H(s) =
    
$$\frac{C R s}{(C R s + 1)^2}$$

```

MATLAB: Symbolic Toolbox

Amplitudska i fazna karakteristika

```
syms Hjw(w)
Hjw(w) = simplify(subs(H(s), s, 1i*w))

Hjw(w) =
    
$$\frac{C R w i}{(1 + C R w i)^2}$$


syms Aw(w)
assume(0 < w)
Aw(w) = simplify(abs(Hjw(w)))

Aw(w) =
    
$$\frac{C R w}{|1 + C R w i|^2}$$


syms phi(w)
phi(w) = angle(Hjw(w))

phi(w) =
    
$$\text{angle}\left(\frac{w i}{(1 + C R w i)^2}\right)$$

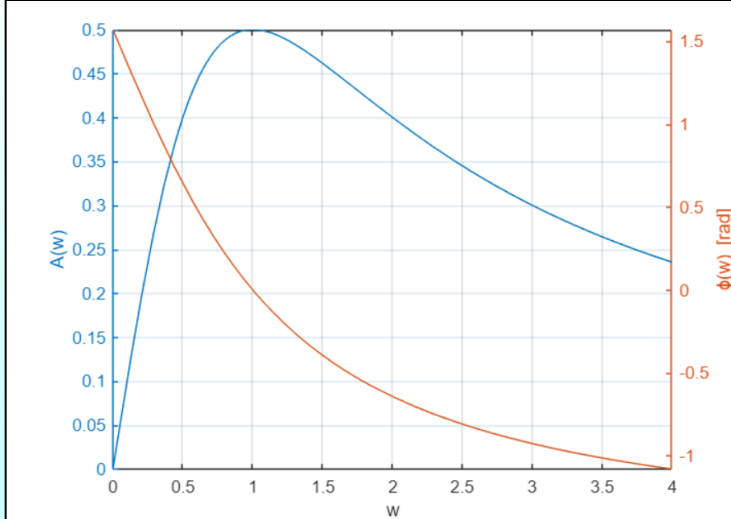
```

Crtaње amplitudske i fazne karakteristike

```
figure

yyaxis left
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('A(w)')

yyaxis right
fplot(w, subs(phi(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('\phi(w) [rad]')
xlabel('w')
grid on
```



Одређивање пропусног опсега

```
syms Aw_num(w)
assume(0 < w)
Aw_num(w) = subs(Aw, lhs(vrednosti), rhs(vrednosti))
```

$$Aw_num(w) = \frac{w}{w^2 + 1}$$

```
wg = solve(diff(Aw_num,w) == sym(0), w, 'Real', true)
```

$$wg = 1$$

```
Aref = subs(Aw_num(wg))
```

$$Aref = \frac{1}{2}$$

```
w3dB = simplify(solve(Aw(w) == Aref/sqrt(2)))
```

$$w3dB = \left(\frac{\sqrt{2}-1}{C R} \right) \left(\frac{\sqrt{2}+1}{C R} \right)$$

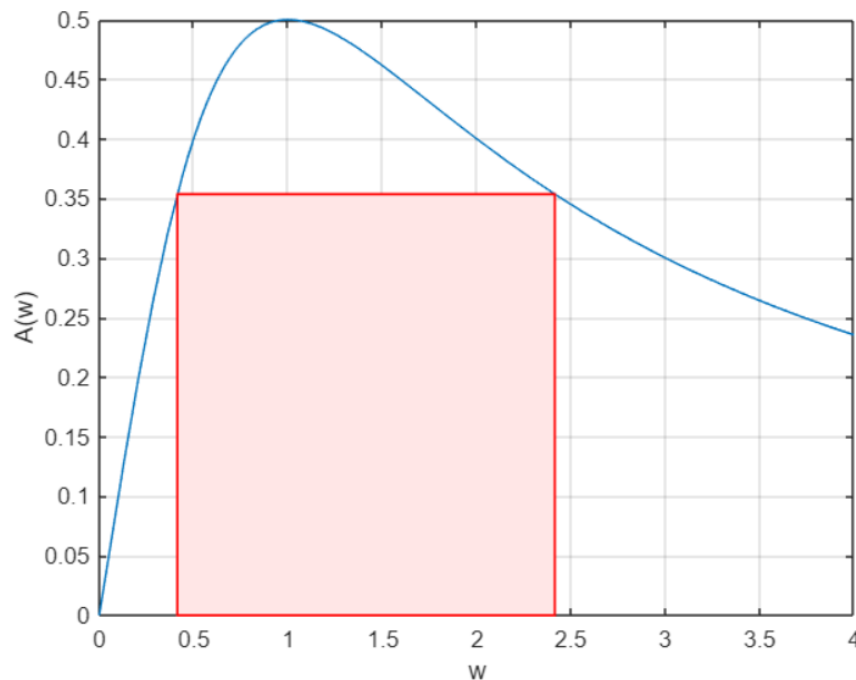
```
BandPass3dB = w3dB.'
```

$$BandPass3dB = \left(\frac{\sqrt{2}-1}{C R} \right) \left(\frac{\sqrt{2}+1}{C R} \right)$$

```
wg1 = subs(w3dB(1), lhs(vrednosti), rhs(vrednosti))
```

$$wg1 = \sqrt{2} - 1$$

```
wg2 = subs(w3dB(2), lhs(vrednosti), rhs(vrednosti))
```



Означавање пропусног опсега у графiku

```
figure
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
hold on
rectangle('Position',[double(wg1), 0, double(wg2-wg1), double(Aref/sqrt(2))],...
          'EdgeColor','r',...
          'FaceColor',[1 0.9 0.9],...
          'LineWidth',1)
hold off
ylabel('A(w)')
xlabel('w')
grid on
```

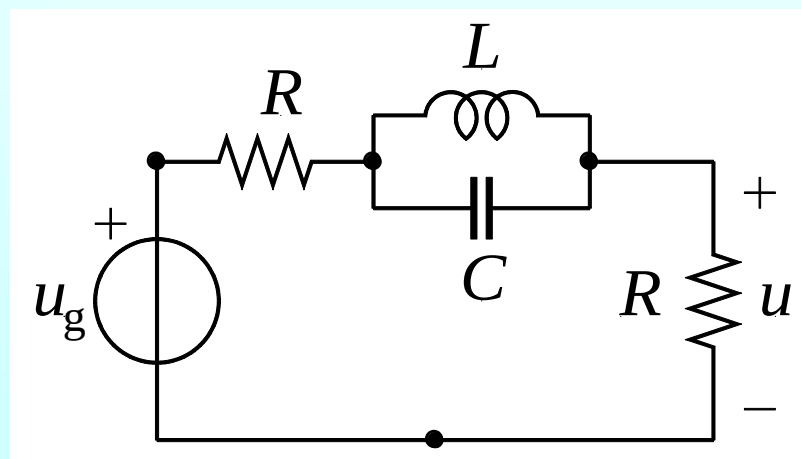
Филтар непропусник опсега учестаности

Вредности елемената електричног кола са слике су познате и постоји веза $L = R^2 C$.

(а) Одредити трансфер функцију (уопштену комплексну преносну функцију електричног кола, трансмитансу напона) $\underline{H}(s) = \frac{\underline{U}(s)}{\underline{U}_g(s)}$.

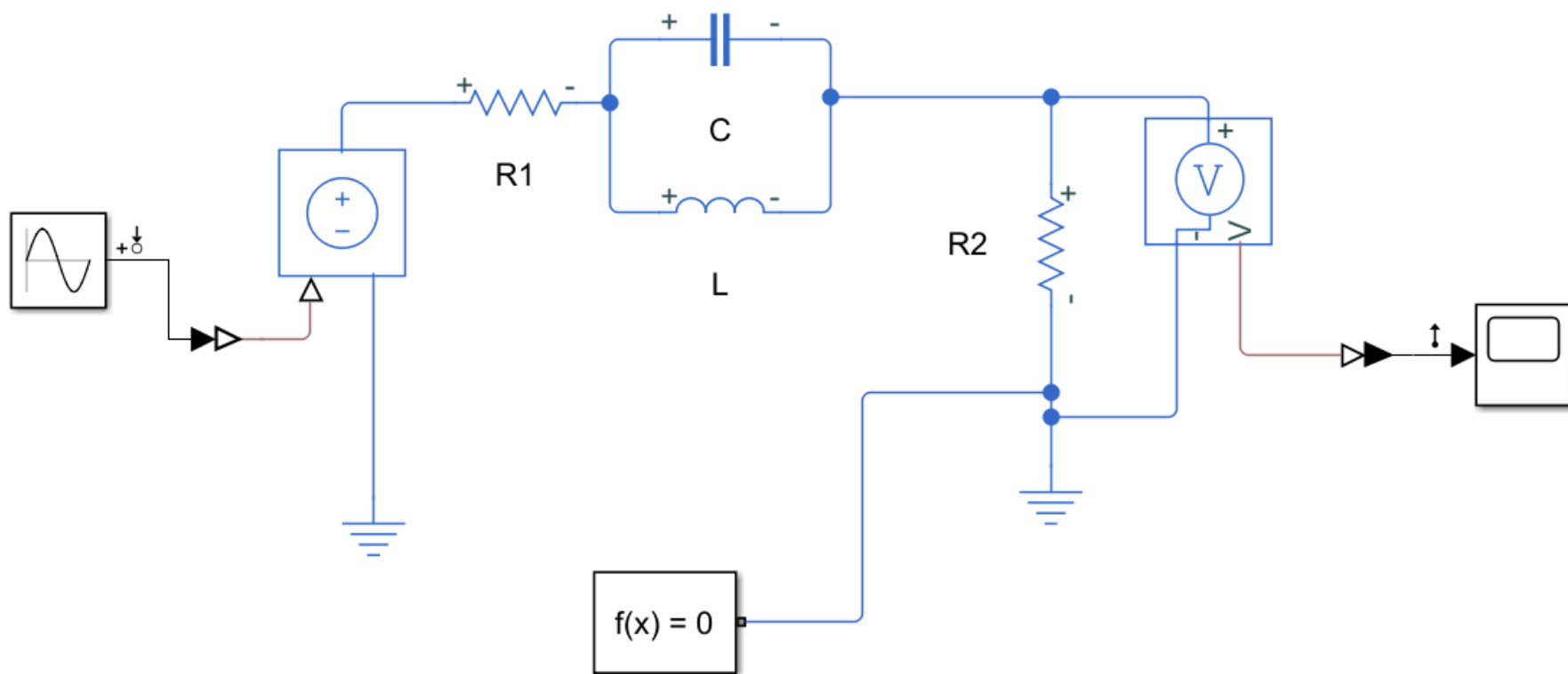
(б) Нацртати амплитудску карактеристику.

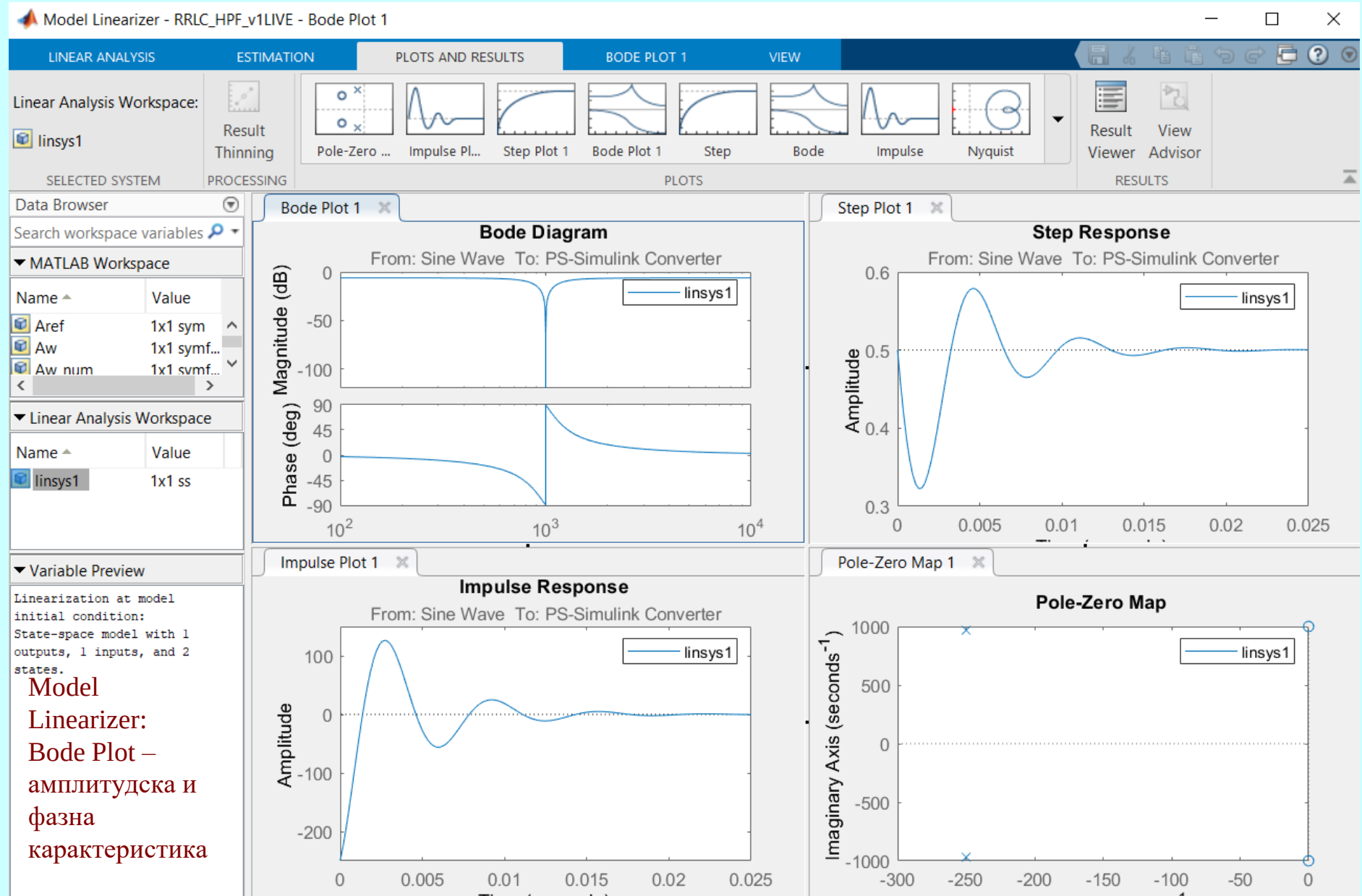
(в) Одредити пропусни опсег 3 dB.



$$u_g = \sqrt{2}U_g \cos(\omega t + \theta_g)$$

Simulink Simscape Foundation Library Utilities





The linearization result "linsys1" is created in the Linear Analysis Workspace.

Одређивање уопштене комплексне функције

```
clear variables
syms w C L R
assume(0 < R & 0 < C & 0 < L )
```

```
zamena = L == C*R^2
```

```
zamena = L = C R^2
```

```
vrednosti = [C == 1, R == 1]
```

```
vrednosti = (C = 1 R = 1)
```

```
syms s H(s)
H(s) = simplify(subs(R/(R + 1/(1/(s*L) + s*C) + R), lhs(zamena), rhs(zamen
```

$$H(s) = \frac{C^2 R^2 s^2 + 1}{2 C^2 R^2 s^2 + C R s + 2}$$

MATLAB: Symbolic Toolbox

Амплитудска и фазна карактеристика

```
syms Hjw(w)
Hjw(w) = simplify(subs(H(s), s, 1i*w))
```

$$Hjw(w) = \frac{C^2 R^2 w^2 - 1}{-2 C^2 R^2 w^2 + C R w i + 2}$$

```
syms Aw(w)
assume(0 < w)
Aw(w) = simplify(abs(Hjw(w)))
```

$$Aw(w) = \frac{|C^2 R^2 w^2 - 1|}{|-2 C^2 R^2 w^2 + C R w i + 2|}$$

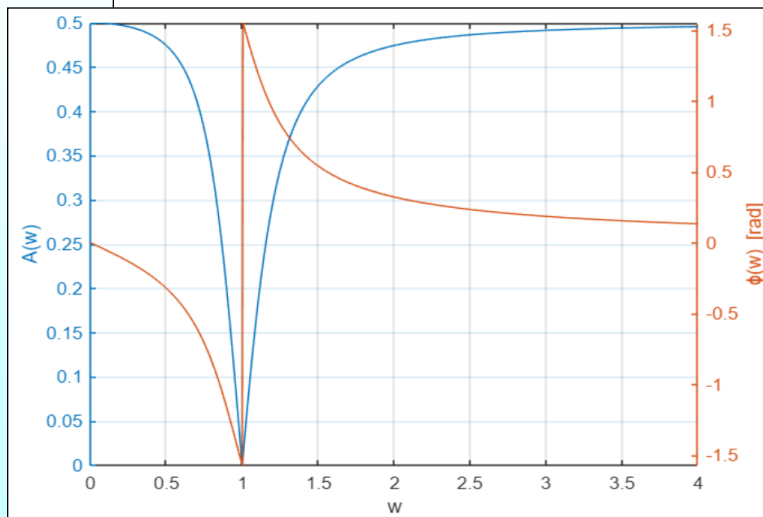
```
syms phi(w)
phi(w) = angle(Hjw(w))
```

$$\phi(w) = \angle \left(-\frac{C^2 R^2 w^2 - 1}{-2 C^2 R^2 w^2 + C R w i + 2} \right)$$

Цртање амплитудске и фазне карактеристике

```
figure
yyaxis left
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('A(w)')

yyaxis right
fplot(w, subs(phi(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
ylabel('\phi(w) [rad]')
xlabel('w')
grid on
```



Одређивање пропусног опсега

```
syms Aw_num(w)
Aref = Aw(0)
```

$$Aref = \frac{1}{2}$$

```
assume(w>0)
w3dB = expand(solve(Aw(w) == Aref/sqrt(2), w))
```

$$w3dB = \left(\frac{\sqrt{\frac{9}{2} - \frac{\sqrt{17}}{2}}}{2 C R}, \frac{\sqrt{\frac{\sqrt{17}}{2} + \frac{9}{2}}}{2 C R} \right)$$

```
Aw_num(w) = subs(Aw, lhs(vrednosti), rhs(vrednosti))
```

$$Aw_num(w) = \frac{|w^2 - 1|}{\sqrt{w^2 + (2w^2 - 2)^2}}$$

```
wg1 = subs(w3dB(1), lhs(vrednosti), rhs(vrednosti))
```

$$wg1 = \frac{\sqrt{\frac{9}{2} - \frac{\sqrt{17}}{2}}}{2}$$

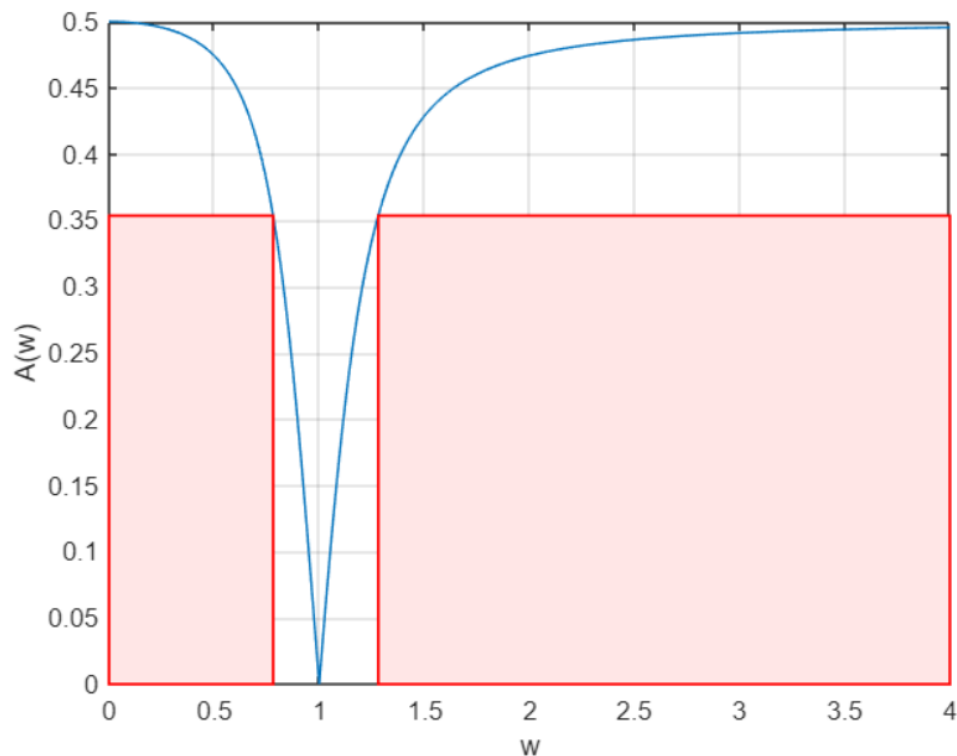
```
wg2 = subs(w3dB(2), lhs(vrednosti), rhs(vrednosti))
```

$$wg2 = \frac{\sqrt{\frac{\sqrt{17}}{2} + \frac{9}{2}}}{2}$$

Означавање пропусног опсега у графiku

```
figure
fplot(w, subs(Aw(w), lhs(vrednosti), rhs(vrednosti)), [0,4])
hold on
rectangle('Position',[0, 0, double(wg1), double(Aref/sqrt(2))],...
          'EdgeColor','r',...
          'FaceColor',[1 0.9 0.9],...
          'LineWidth',1)
rectangle('Position',[double(wg2), 0, double(4-wg2), double(Aref/sqrt(2))],...
          'EdgeColor','r',...
          'FaceColor',[1 0.9 0.9],...
          'LineWidth',1)
hold off
ylabel('A(w)')
xlabel('w')
grid on
```

MATLAB: Symbolic Toolbox



Устаљен сложенепериодичан одзив

Електрично коло са слике има познате вредности елемената:

$$L_1 = L, L_2 = 2L,$$

$$C_1 = C, C_2 = 2C,$$

$$R_1 = R_2 = R.$$

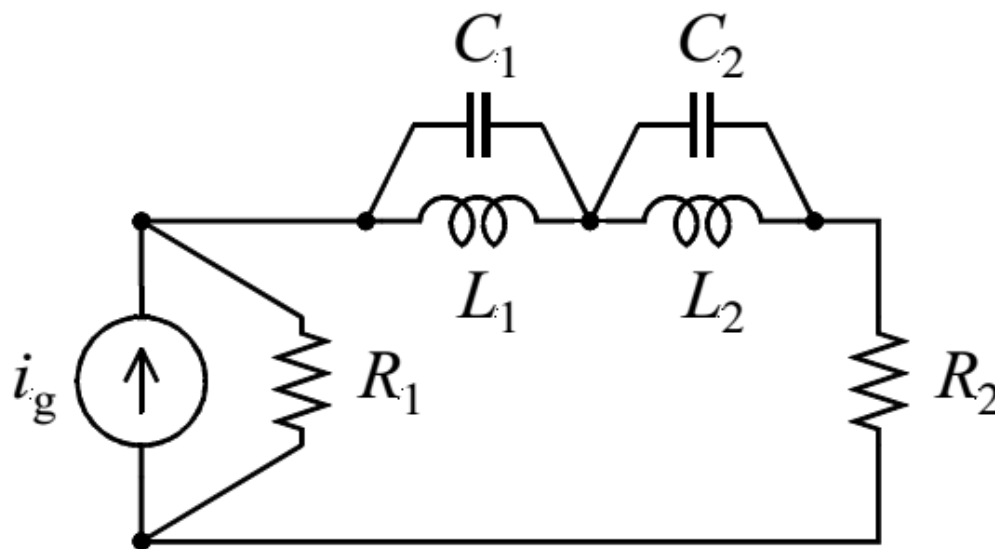
Побуда (екситација) је $i_g(t) = I_m + I_m \cos\left(\frac{1}{2\sqrt{CL}}t\right) + I_m \sin\left(\frac{1}{\sqrt{CL}}t\right)$

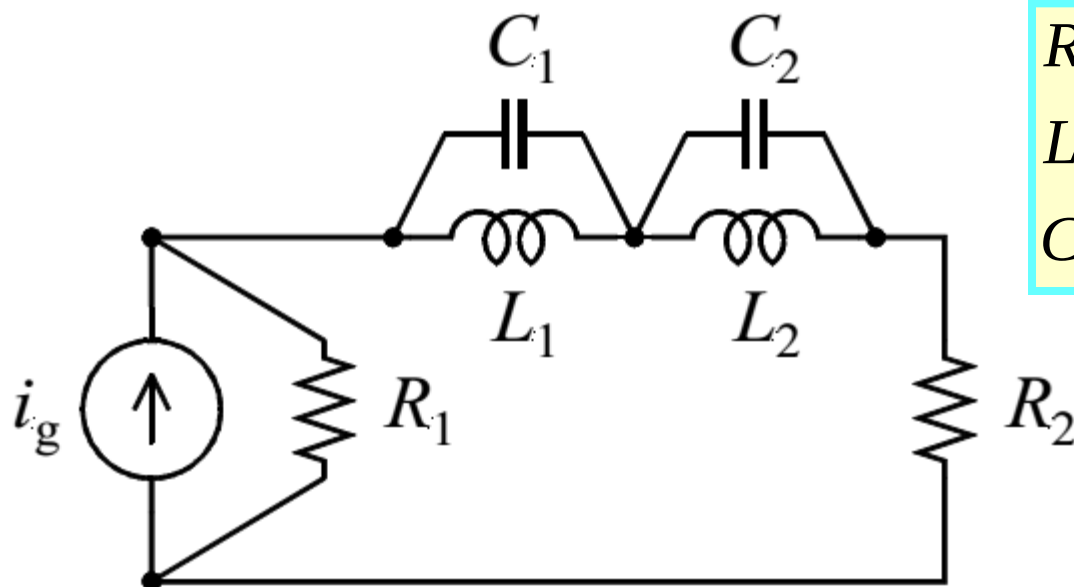
Одзив је устаљен.

(а) Одредити напон отпорника R_2 .

(б) Одредити напон струјног извора (струјног генератора).

(б) Ког реда је ово коло?





$$R_1 = R_2 = 1\text{k}\Omega$$

$$L_1 = L, L_2 = 2L, L = 0.5\text{mH}$$

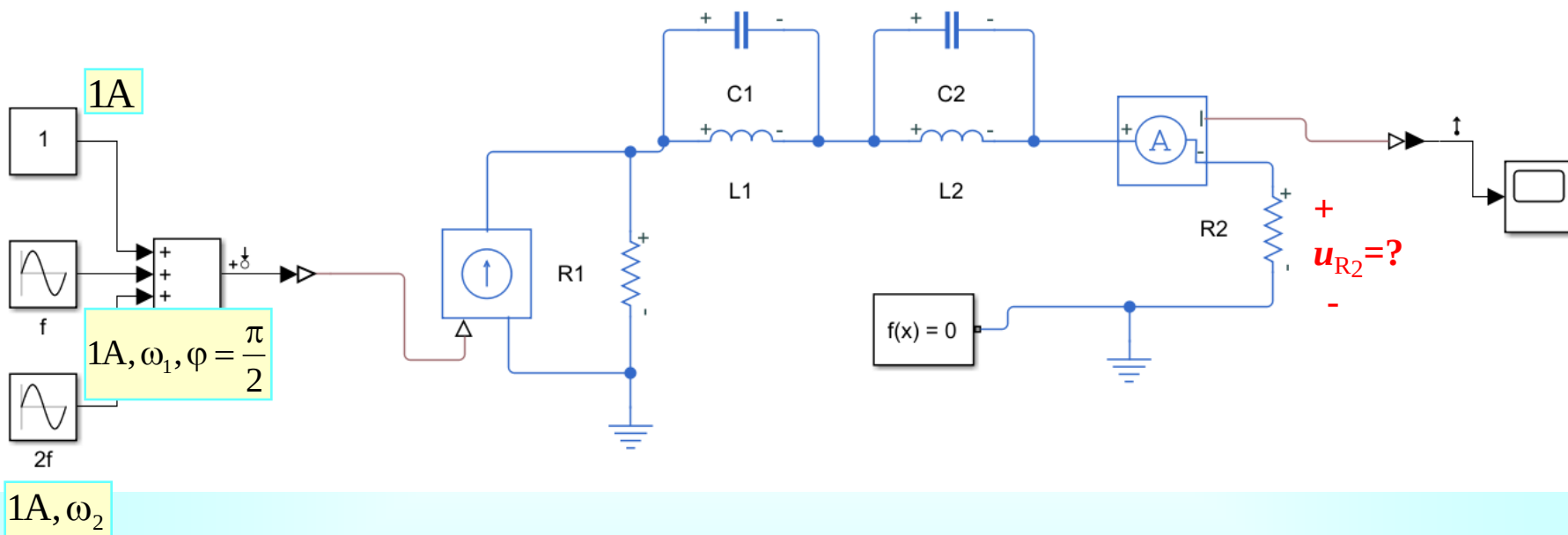
$$C_1 = C, C_2 = 2C, C = 5\mu\text{F}$$

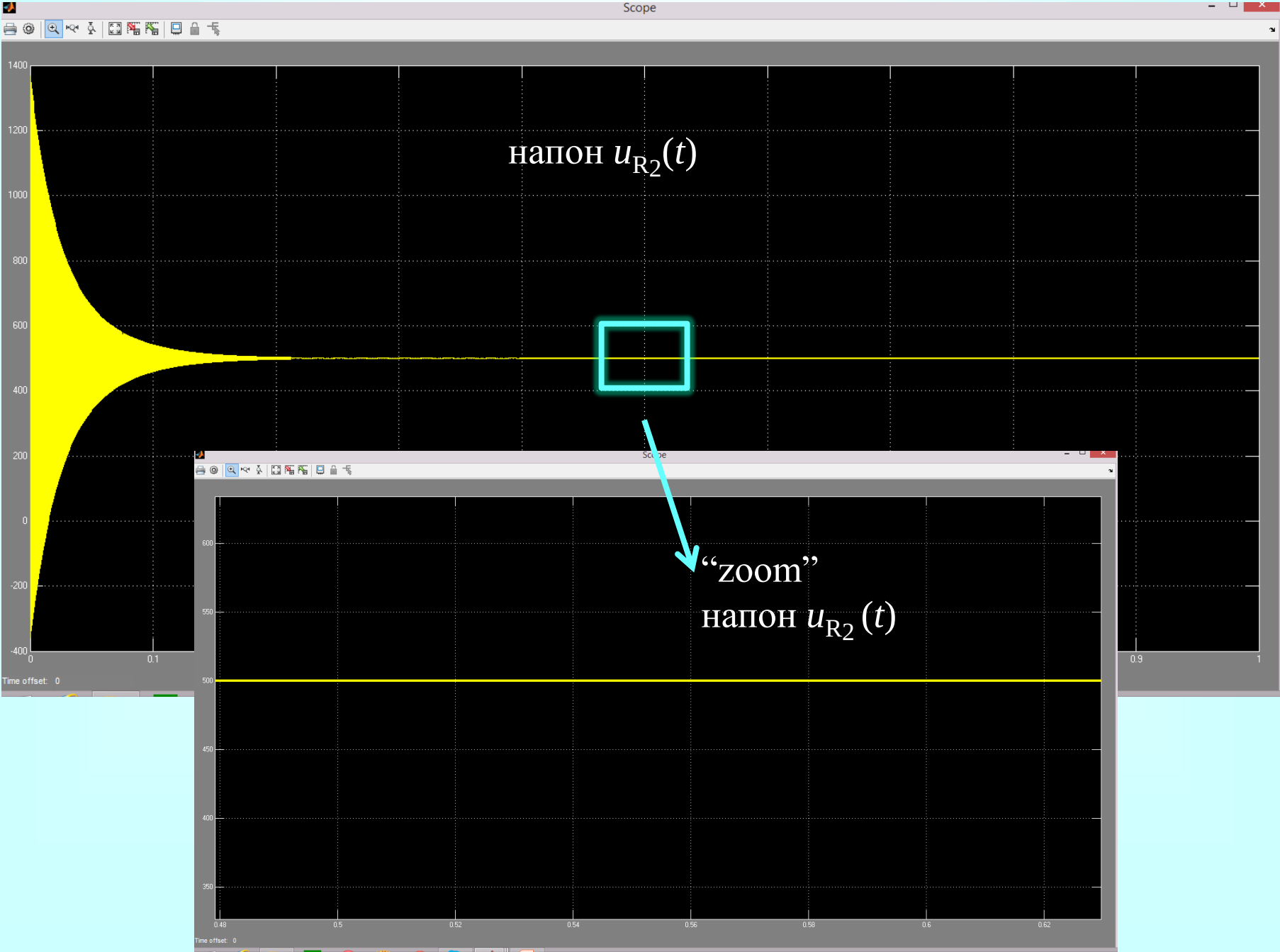
$$i_g(t) = \underbrace{I_m}_{1\text{A}} + I_m \cos(\omega_1 t) + I_m \sin(\omega_2 t)$$

$$\omega_1 = \frac{1}{\sqrt{L_2 C_2}} = \frac{1}{2\sqrt{LC}} = 10^4 \text{ rad/s}$$

$$\omega_2 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{LC}} = 2 \cdot 10^4 \text{ rad/s}$$

Simulink Simscape > Foundation Library, Utilities





```
clear variables
close all

syms C C1 C2 I_m L L1 L2 R R1 R2
assume(0 < L1 & 0 < L2 & 0 < C1 & 0 < C2 & 0 < R1 & 0 < R2 & 0 < L & 0 < C & 0 < R & 0 < I_m)
```

Frekvencije, pobude, zamene

```
zamene = [L1 == L, C1 == C, L2 == 2 * L, C2 == 2*C, R1 == R, R2 == R]
```

zamene = ($L_1 = L$ $C_1 = C$ $L_2 = 2 L$ $C_2 = 2 C$ $R_1 = R$ $R_2 = R$)

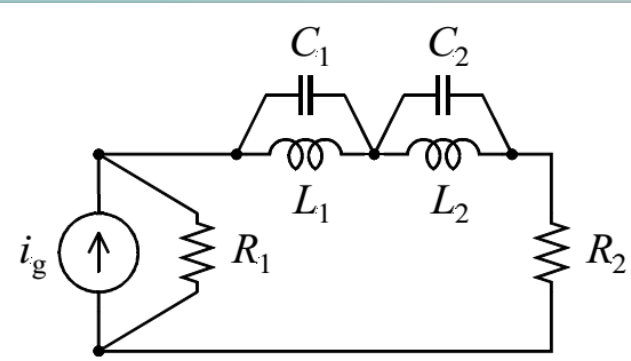
```
syms w0 w1 w2 I_g0 I_g1 I_g2
```

```
pobuda = [I_g0 == I_m, I_g1 == I_m/sqrt(2), I_g2 == I_m/sqrt(2) * exp(-1i*pi/sym(2))]
```

pobuda =
 $\left(I_{g0} = I_m \quad I_{g1} = \frac{\sqrt{2} I_m}{2} \quad I_{g2} = -\frac{\sqrt{2} I_m i}{2} \right)$

```
frekvencije = [w0 == 0, w1 == 1/(2*sqrt(L*C)), w2 == 1/sqrt(L*C)]
```

frekvencije =
 $\left(w_0 = 0 \quad w_1 = \frac{1}{2 \sqrt{C} \sqrt{L}} \quad w_2 = \frac{1}{\sqrt{C} \sqrt{L}} \right)$



Određivanje kompleksne funkcije UR2

```
syms UR2(s) I_g
UR2(s) = (R1*I_g*R2)/(R1 + 1/(s*C1 + 1/(s*L1)) + 1/(s*C2 + 1/(s*L2)) + R2)
```

UR2(s) =
$$\frac{I_g R_1 R_2}{R_1 + R_2 + \frac{1}{C_1 s + \frac{1}{L_1 s}} + \frac{1}{C_2 s + \frac{1}{L_2 s}}}$$

```
syms UR2_jw(w)
UR2_jw(w) = simplify(subs(subs(UR2(s), lhs(zamene), rhs(zamene)), s, 1i*w))
```

UR2_jw(w) =
$$\frac{I_g R^2 (4 C^2 L^2 w^4 - 5 C L w^2 + 1)}{8 R C^2 L^2 w^4 - 6 C L^2 w^3 i - 10 R C L w^2 + 3 L w i + 2 R}$$

Хармоници, Временски домен

```
UR2_0 = simplify(subs(subs(subs(UR2_jw(w), [w I_g], [w0 I_g0]), lhs(frekvencije), rhs(frekvencije)), lhs(pobuda), rhs(pobuda)))
```

$$UR2_0 = \frac{I_m R}{2}$$

```
UR2_wg1 = simplify(subs(subs(subs(UR2_jw(w), [w I_g], [w1 I_g1]), lhs(frekvencije), rhs(frekvencije)), lhs(pobuda), rhs(pobuda)))
```

$$UR2_{wg1} = 0$$

```
UR2_wg2 = simplify(subs(subs(subs(UR2_jw(w), [w I_g], [w2 I_g2]), lhs(frekvencije), rhs(frekvencije)), lhs(pobuda), rhs(pobuda)))
```

$$UR2_{wg2} = 0$$

Времени домен за uR2

```
syms U0 Uwg1 Uwg2  
syms uR2(t)
```

```
uR2(t) = subs(UR2_0 + sqrt(2)*abs(UR2_wg1)*cos(w1*t + angle(UR2_wg1)) + sqrt(2)*abs(UR2_wg2)*cos(w2*t + angle(UR2_wg2)), lhs(frekvencije), rhs(frekvencije))
```

$$uR2(t) = \frac{I_m R}{2}$$

Одређивање комплексне функције UR1

```
syms Z(s)
Z(s) = simplify(1/(s * C1 + 1/(s*L1)) + 1/(s*C2 + 1/(s*L2)) + R2)
```

$Z(s) =$

$$R_2 + \frac{L_1 s}{C_1 L_1 s^2 + 1} + \frac{L_2 s}{C_2 L_2 s^2 + 1}$$

```
syms UR1(s)
UR1(s) = expand(subs( I_g*R1*Z(s)/(R1 + Z(s)), lhs(zamene), rhs(zamene) ) )
```

$UR1(s) =$

$$\frac{I_g R^2}{2 R + \frac{L s}{\sigma_1} + \sigma_2} + \frac{I_g L R s}{2 R + \frac{L s}{\sigma_1} + \sigma_2 + 2 C L R s^2 + \frac{C L^2 s^3}{\sigma_1} + \frac{2 C L^2 s^3}{\sigma_3}} + \frac{2 I_g L R s}{2 R + \frac{L s}{\sigma_1} + \sigma_2 + 8 C L R s^2 + \frac{4 C L^2 s^3}{\sigma_1} + \frac{8 C L^2 s^3}{\sigma_3}}$$

where

$$\sigma_1 = C L s^2 + 1$$

$$\sigma_2 = \frac{2 L s}{\sigma_3}$$

$$\sigma_3 = 4 C L s^2 + 1$$

```
syms UR1_jw(w)
UR1_jw(w) = simplify(subs(UR1(s), s, 1i*w))
```

$UR1_jw(w) =$

$$-\frac{(3 L w - 6 C L^2 w^3) \sigma_1 i - (8 R C^2 L^2 w^4 - 10 R C L w^2 + 2 R) \sigma_1}{64 C^4 L^4 R^2 w^8 - 160 C^3 L^3 R^2 w^6 + 36 C^2 L^4 w^6 + 132 C^2 L^2 R^2 w^4 - 36 C L^3 w^4 - 40 C L R^2 w^2 + 9 L^2 w^2 + 4 R^2}$$

where

$$\sigma_1 = 4 I_g C^2 L^2 R^2 w^4 - 6 i I_g C L^2 R w^3 - 5 I_g C L R^2 w^2 + 3 i I_g L R w + I_g R^2$$

Хармоници, Временски домен

```
UR1_0 = simplify(subs(subs(subs(UR1_jw(w), [w I_g], [w0 I_g0]), lhs(frekvencije), rhs(frekvencije)), lhs(pobuda), rhs(pobuda)))
```

UR1_0 =

$$\frac{I_m R}{2}$$

```
UR1_wg1 = simplify(subs(subs(subs(UR1_jw(w), [w I_g], [w1 I_g1]), lhs(pobuda), rhs(pobuda)), lhs(frekvencije), rhs(frekvencije)))
```

UR1_wg1 =

$$\frac{\sqrt{2} I_m R}{2}$$

```
UR1_wg2 = simplify(subs(subs(subs(UR1_jw(w), [w I_g], [w2 I_g2]), lhs(pobuda), rhs(pobuda)), lhs(frekvencije), rhs(frekvencije)))
```

UR1_wg2 =

$$-\frac{\sqrt{2} I_m R i}{2}$$

Vremenski domen za uR1

```
syms uR1(t)
uR1(t) = subs(UR1_0 + sqrt(sym(2)) * abs(UR1_wg1) * cos(w1 * t + angle(UR1_wg1)) + sqrt(sym(2)) * abs(UR1_wg2) * cos(w2 * t + angle(UR1_wg2)), lhs(frekvencije), rhs(frekvencije))
```

uR1(t) =

$$\frac{I_m R}{2} + I_m R \cos\left(\frac{t}{2 \sqrt{C} \sqrt{L}}\right) + I_m R \cos\left(\frac{\pi}{2} - \frac{t}{\sqrt{C} \sqrt{L}}\right)$$

```
simplify(uR1(t))
```

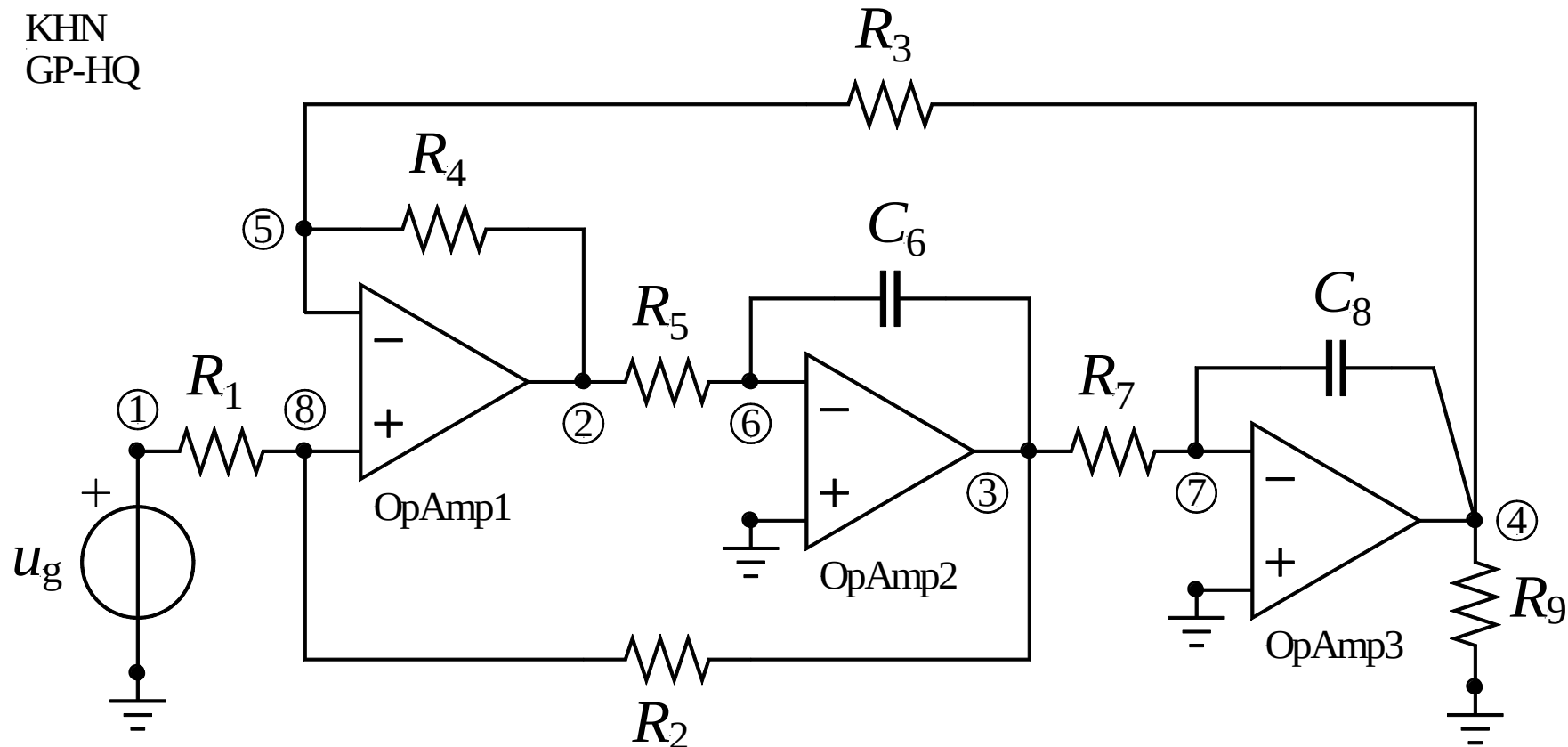
ans =

$$\frac{I_m R \left(2 \cos\left(\frac{t}{2 \sqrt{C} \sqrt{L}}\right) + 2 \sin\left(\frac{t}{\sqrt{C} \sqrt{L}}\right) + 1 \right)}{2}$$

MATLAB: Symbolic Toolbox

KHN active filter

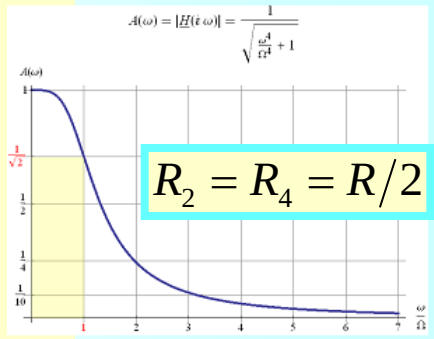
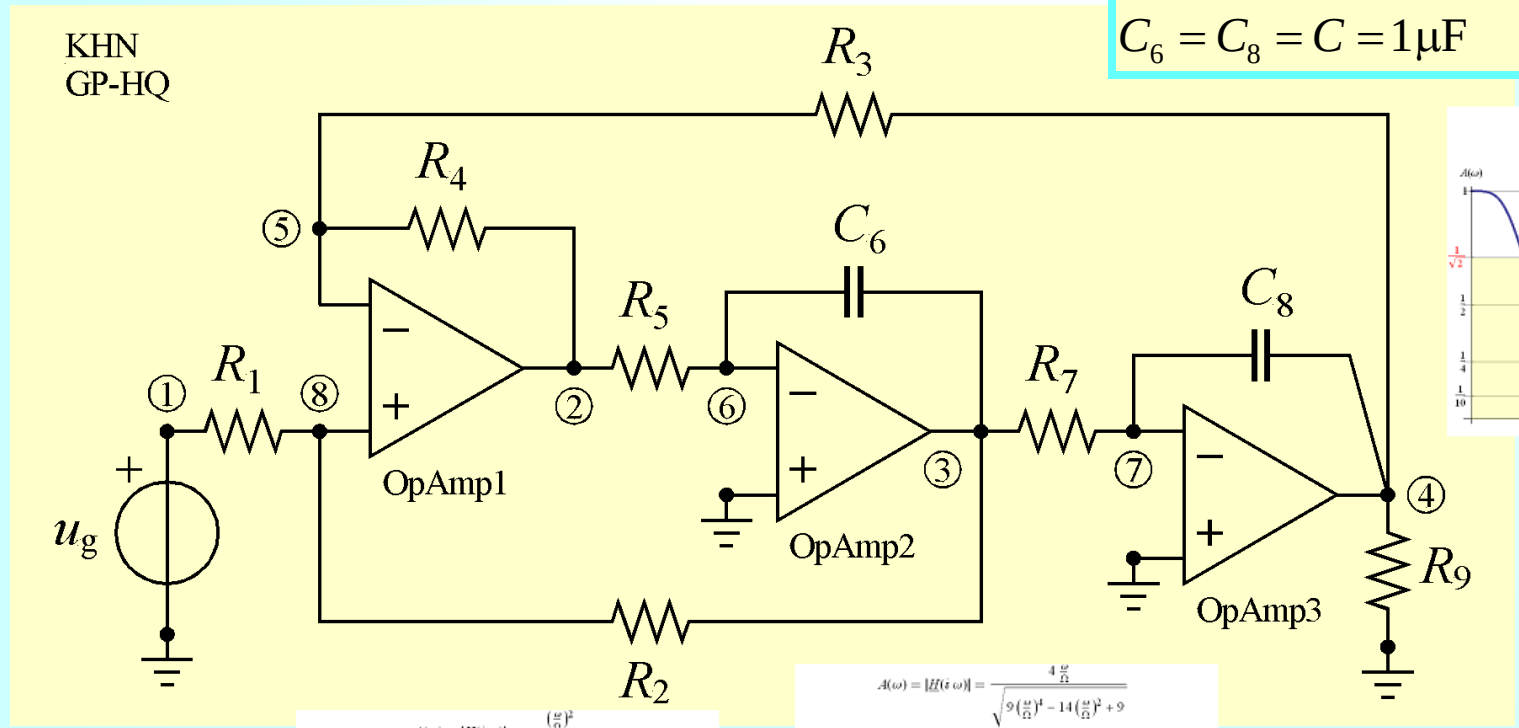
Kerwin-Huelsman-Newcomb, state-variable biquad, UAF42



Kerwin-Huelsman-Newcomb, state-variable biquad, UAF42

KHN active filter

$R_1 = R_3 = R_5 = R_7 = R_9 = R = 1\text{k}\Omega$
 $C_6 = C_8 = C = 1\mu\text{F}$

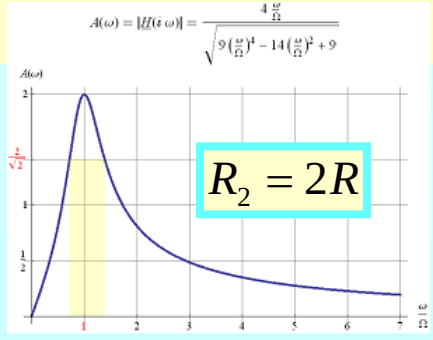
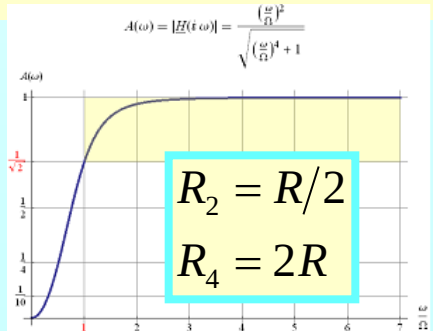


$$\underline{H}(s) = \frac{V_4(s)}{\underline{U}_g(s)}$$

LowPass, LP

HighPass, HP

$$\underline{H}(s) = \frac{V_2(s)}{\underline{U}_g(s)}$$



$$\underline{H}(s) = \frac{V_3(s)}{\underline{U}_g(s)}$$

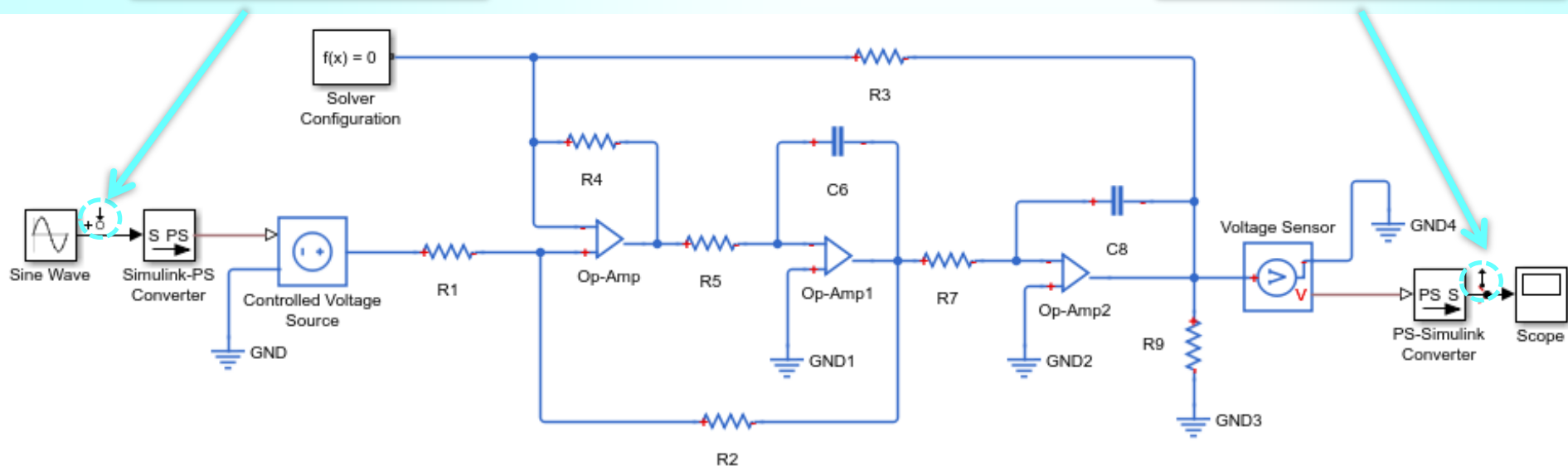
BandPass, BP

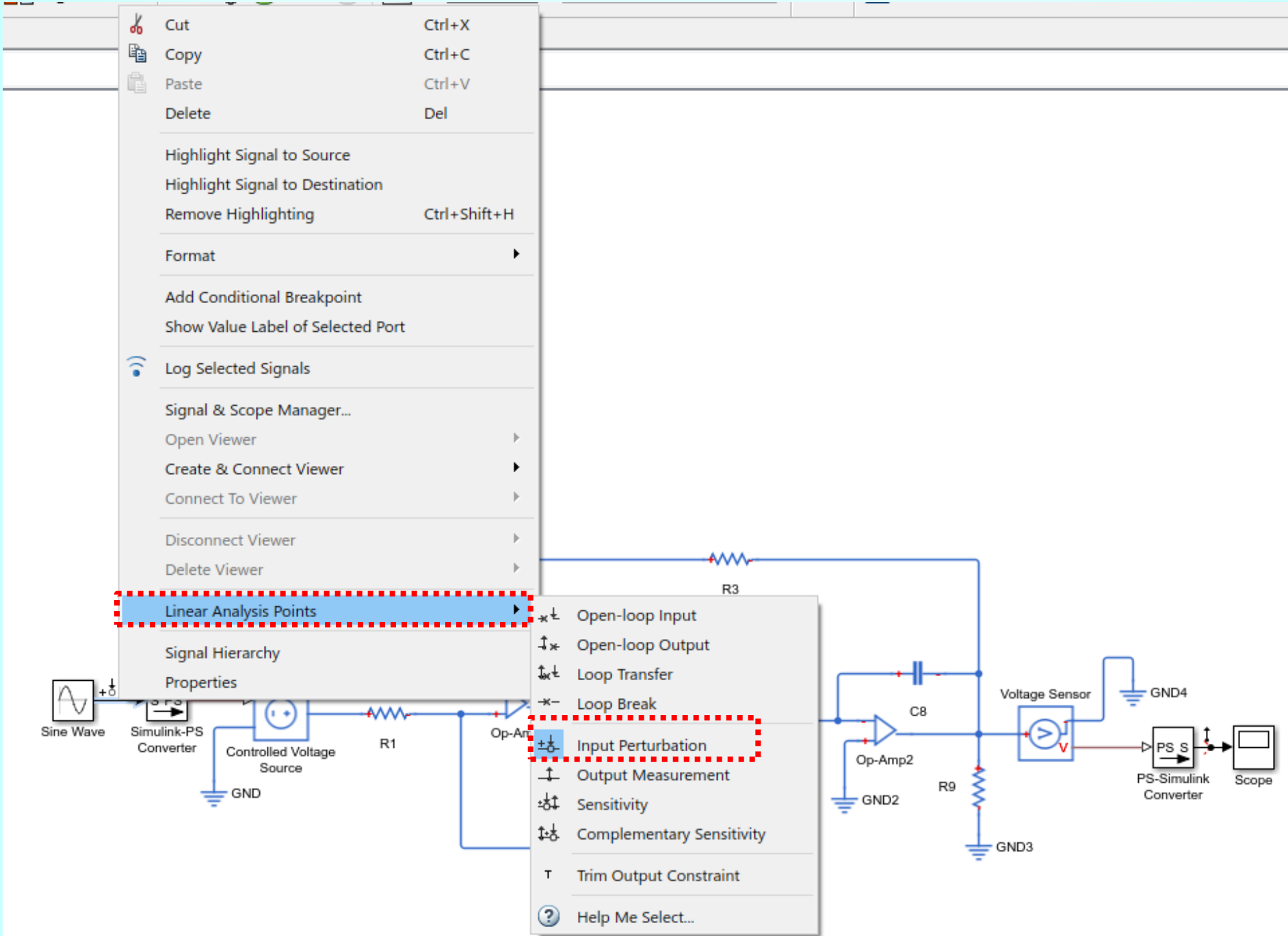
УЛАЗ – ИЗЛАЗ КОЛА (СИСТЕМА)

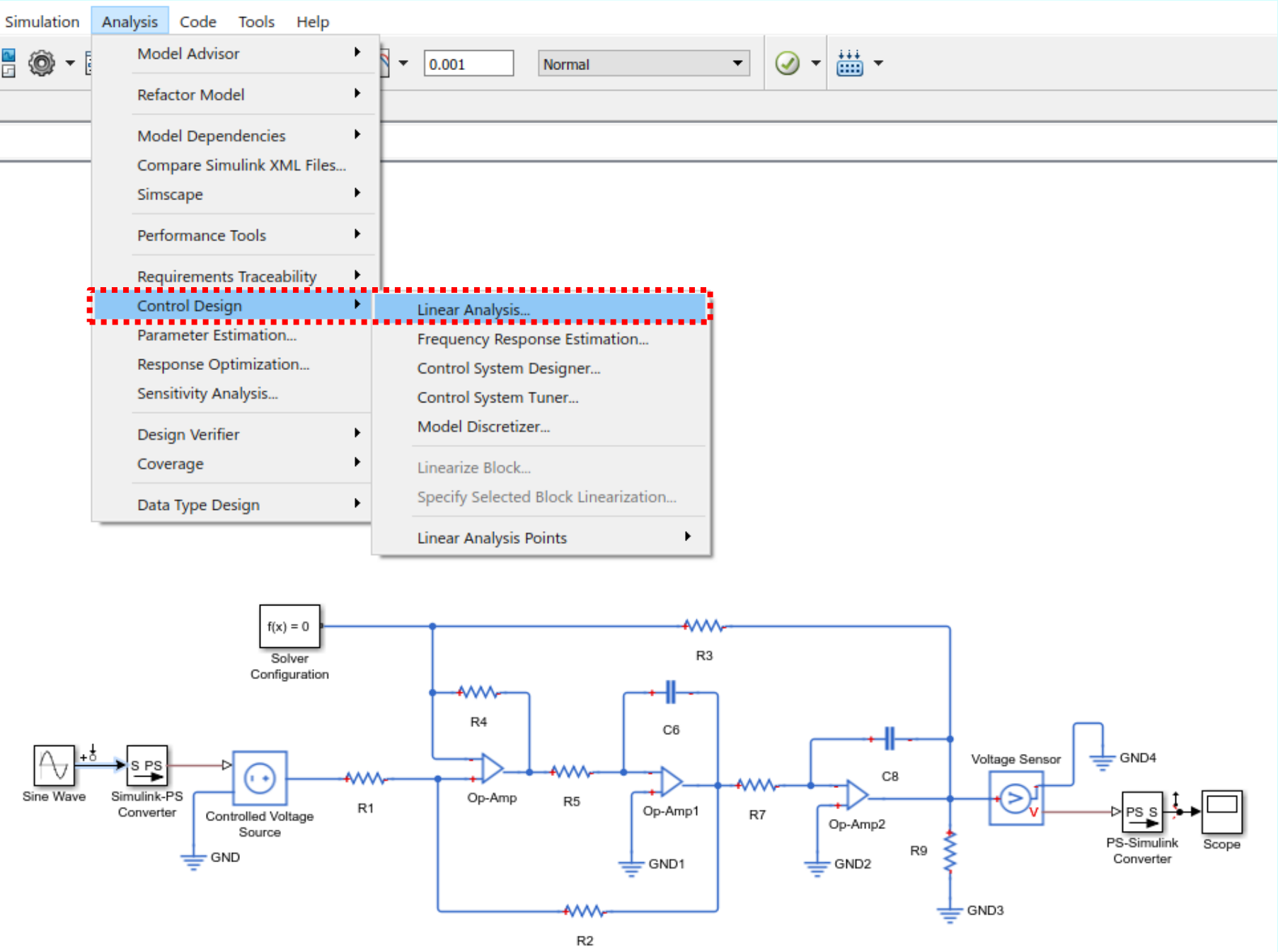
Филтар пропусник ниских учестаности

Input Perturbation

Output Measurement







LINEAR ANALYSIS

ESTIMATION

PLOTS AND RESULTS

VIEW

Load Session

Save Session

Preferences

Analysis I/Os: Model I/Os

Operating Point: Model Initial Condition

Parameter Variations: None

☐ Result Viewer

☐ Diagnostic Viewer

More Options

Bode Plot 1

Step

Bode

Impulse

Nyquist

FILE

SETUP

OPTIONS

LINEARIZE

Data Browser

Search workspace variables

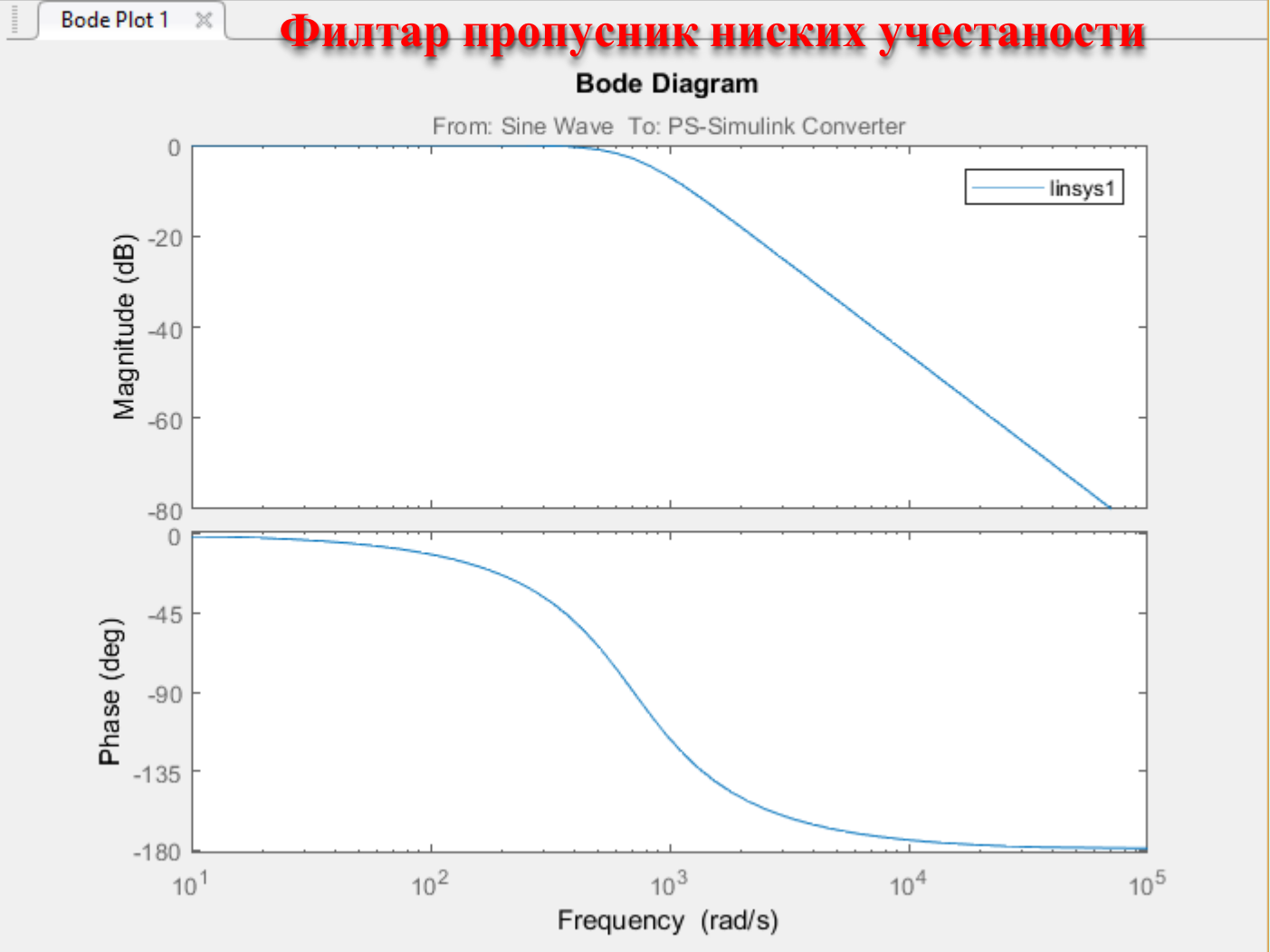
MATLAB Workspace

Name	Value
ans	1x1 mupad

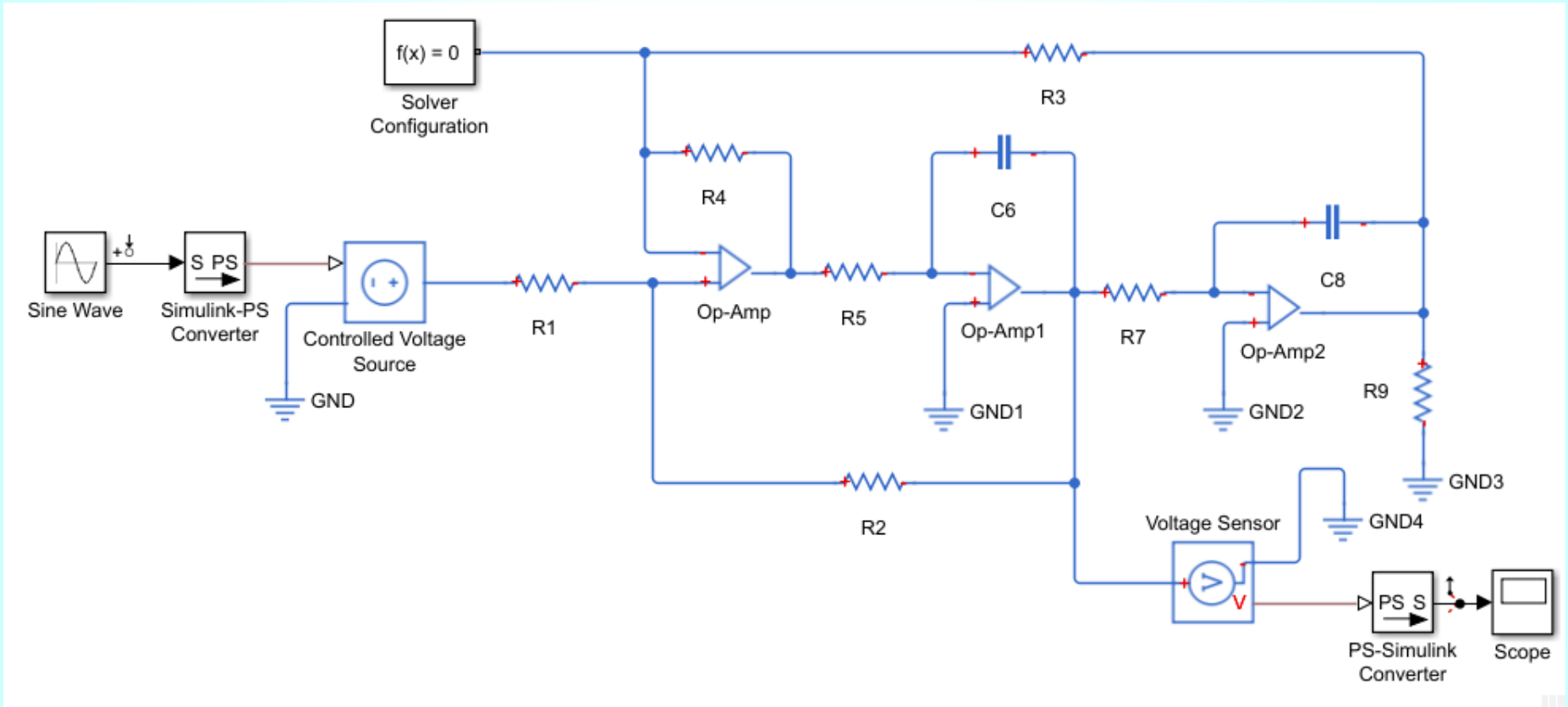
Linear Analysis Workspace

Name	Value
linsys1	1x1 ss

Variable Preview



Филтар пропусник опсега учестаности



LINEAR ANALYSIS

ESTIMATION

PLOTS AND RESULTS

BODE PLOT 1

VIEW

Load Session

Analysis I/Os: Model I/Os

Save Session

Operating Point: Model Initial Condition

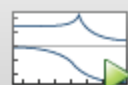
Preferences

Parameter Variations: None

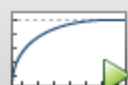
Result Viewer

Diagnostic Viewer

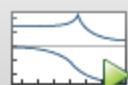
More Options



Bode Plot 1



Step



Bode



Impulse



Nyquist

FILE

SETUP

OPTIONS

LINEARIZE

Data Browser

Search workspace variables

MATLAB Workspace

Name	Value
ans	1x1 mupad

Linear Analysis Workspace

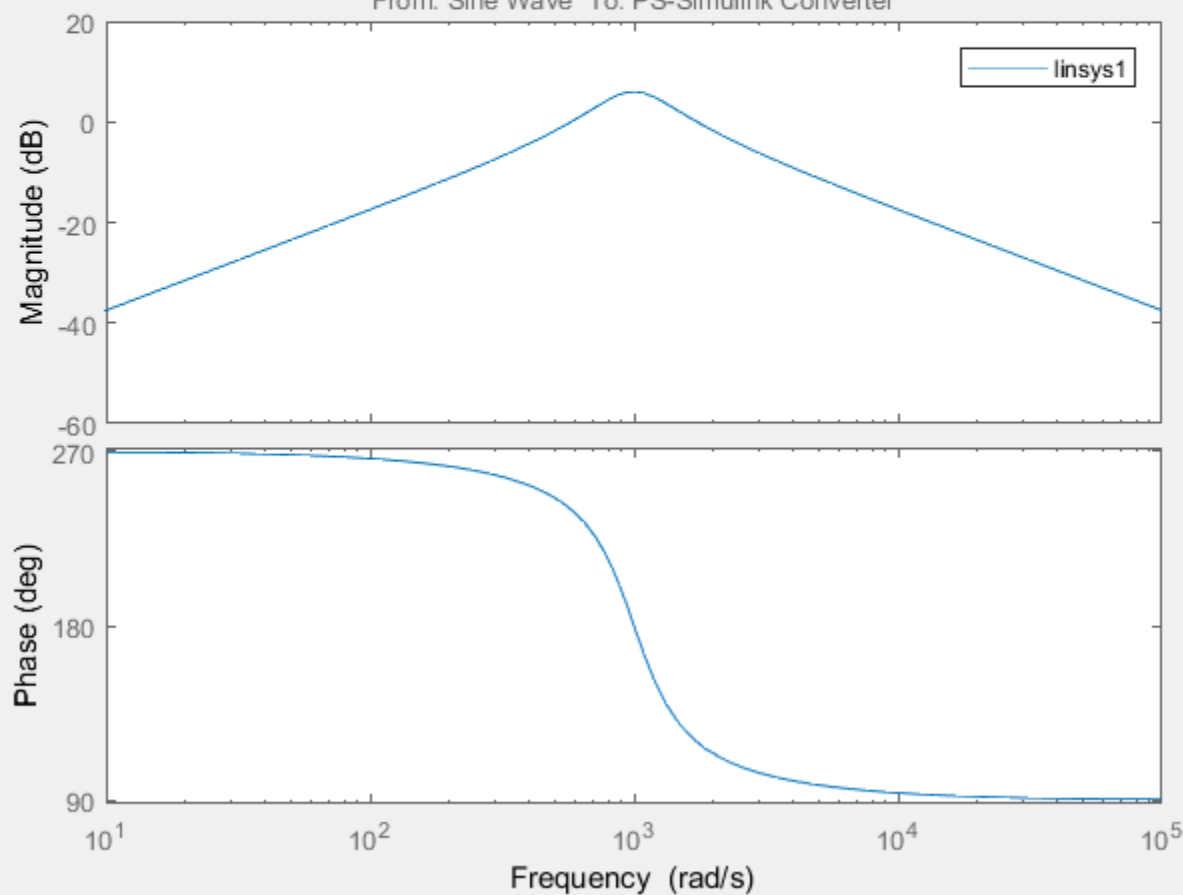
Name	Value
linsys1	1x1 ss

Variable Preview

Филтар пропусник опсега учестаности

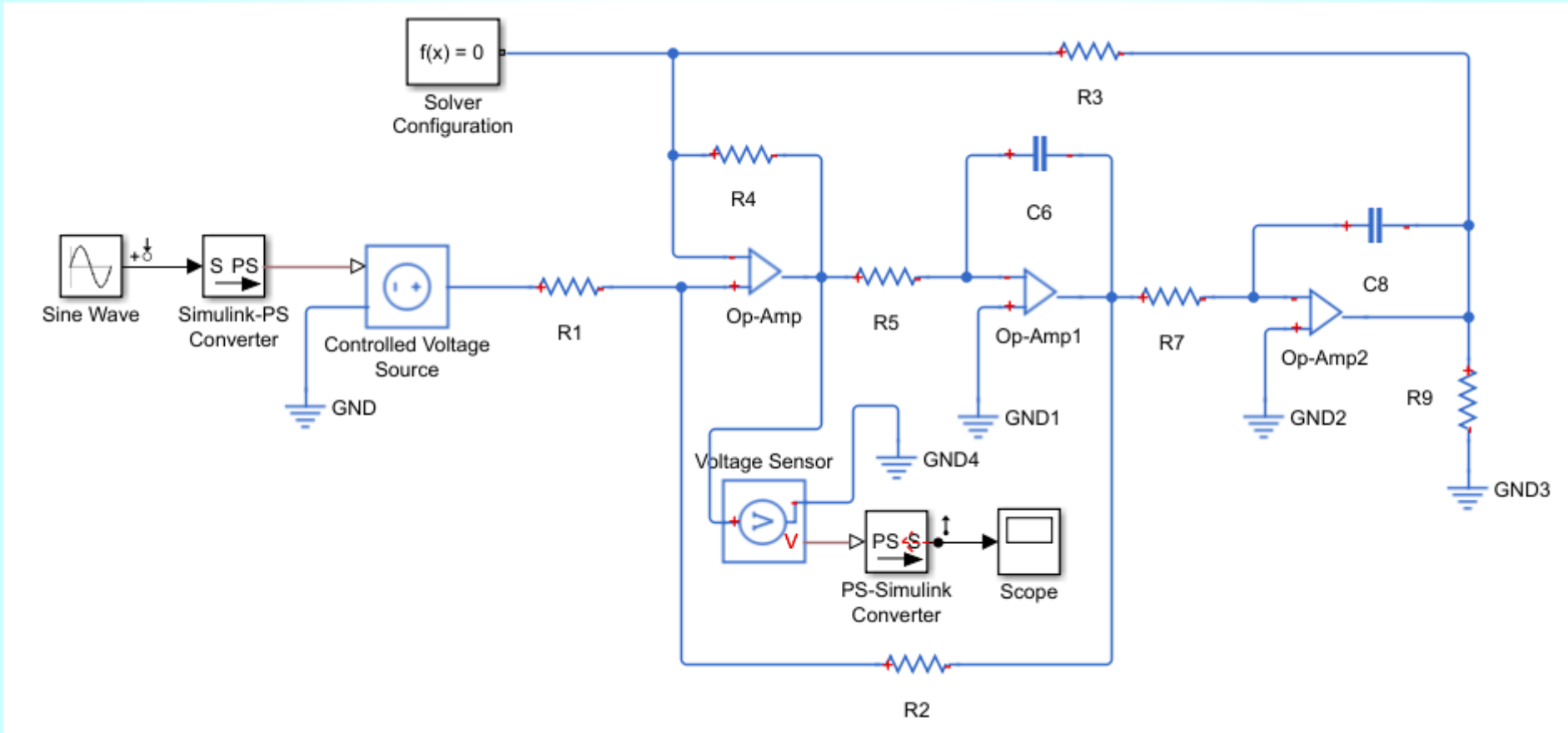
Bode Diagram

From: Sine Wave To: PS-Simulink Converter



The linearization result "linsys1" is created in the Linear Analysis Workspace.

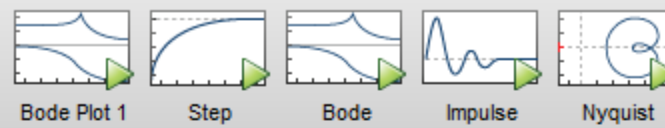
Филтар пропусник високих учестаности



- Load Session
- Save Session
- Preferences

Analysis I/Os: Model I/Os
 Operating Point: Model Initial Condition
 Parameter Variations: None

- Result Viewer
- Diagnostic Viewer
- More Options



Data Browser

Search workspace variables

▼ MATLAB Workspace

Name ▲	Value
ans	1x1 mupad

▼ Linear Analysis Workspace

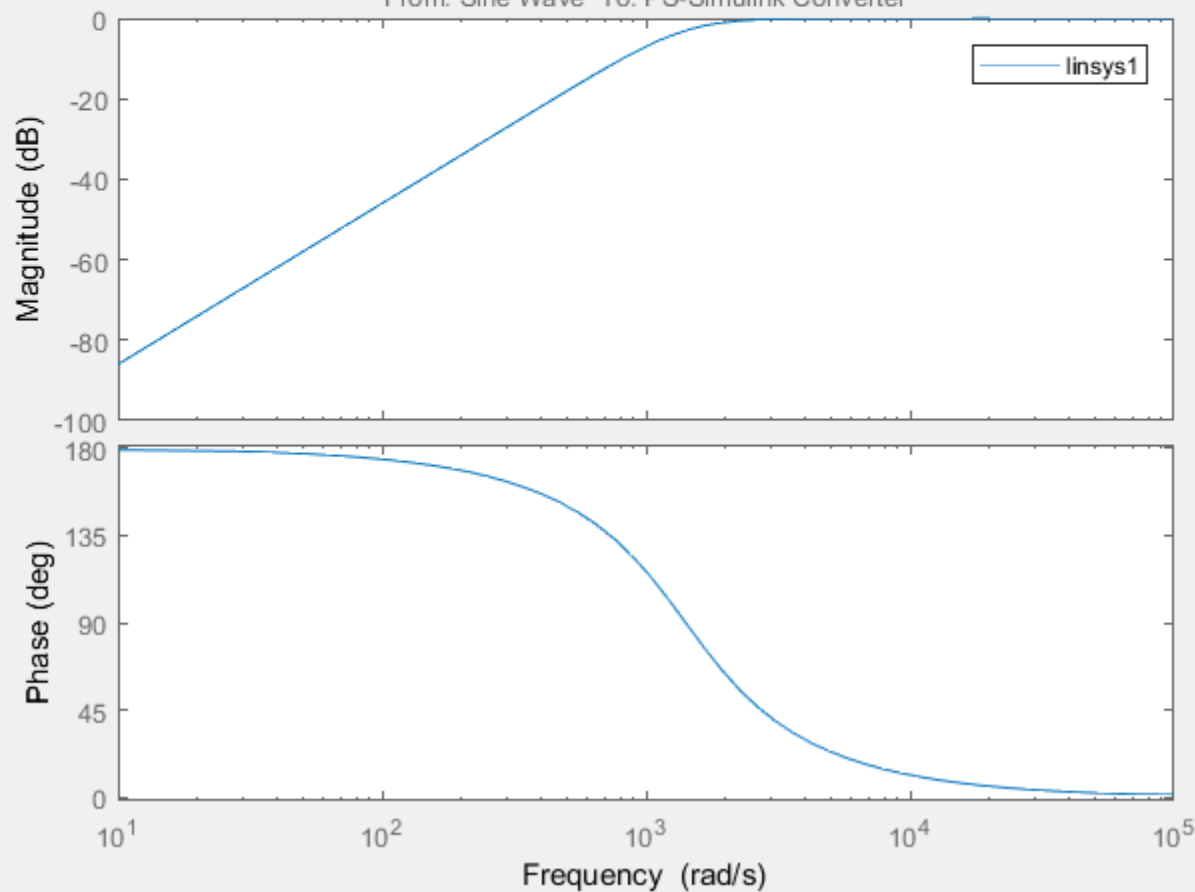
Name ▲	Value
linsys1	1x1 ss

▼ Variable Preview

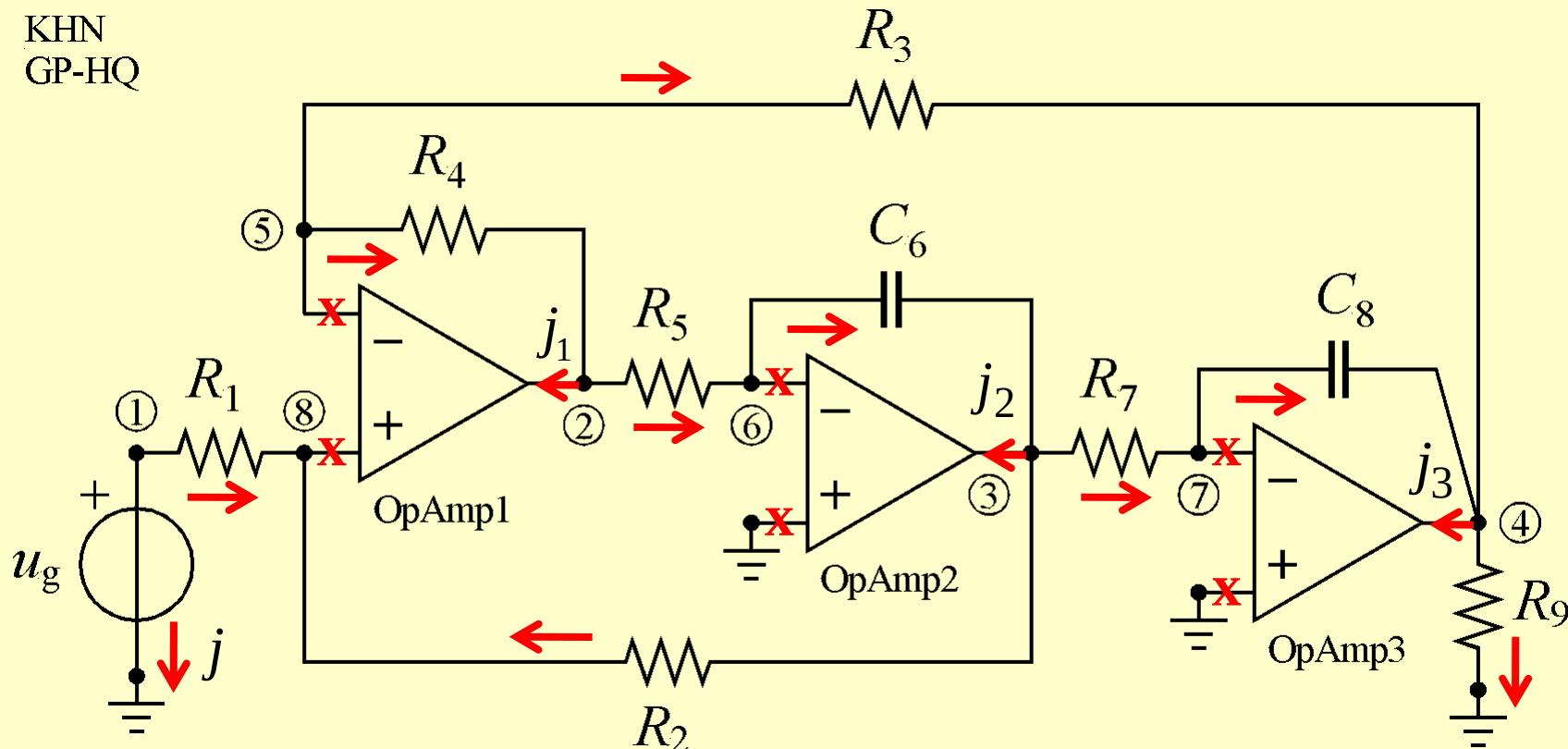
Филтар пропусник високих учестаности

Bode Diagram

From: Sine Wave To: PS-Simulink Converter



KHN active filter

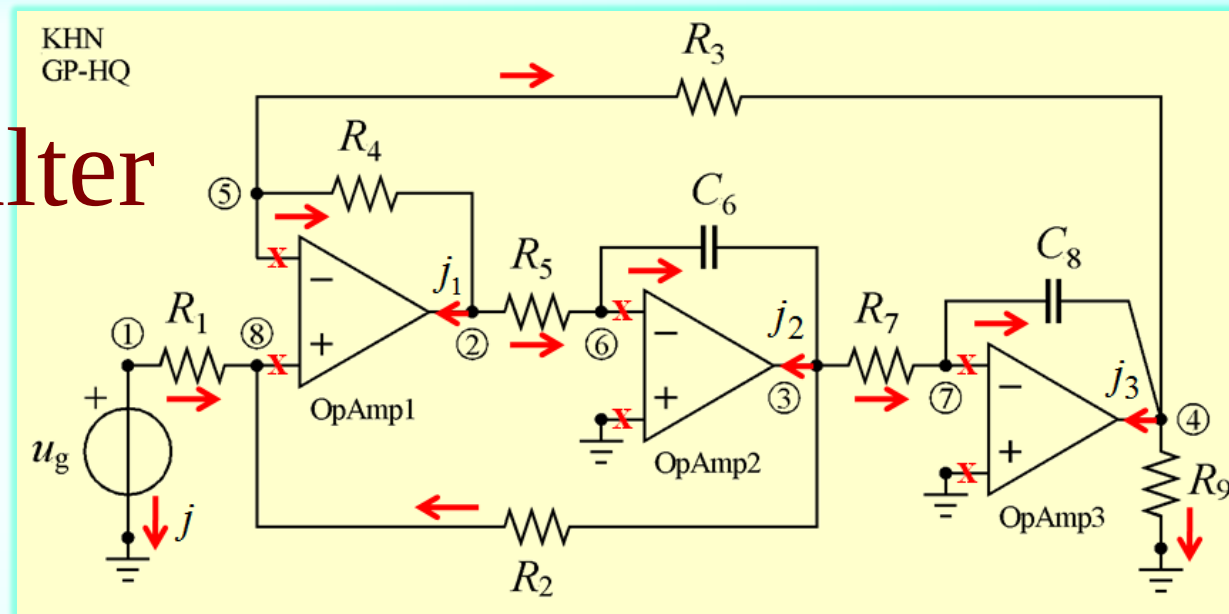


$$H_{\text{LowPass}}(s) = \frac{V_4(s)}{V_1(s)} = ?$$

$$H_{\text{BandPass}}(s) = \frac{V_3(s)}{V_1(s)} = ?$$

$$H_{\text{HighPass}}(s) = \frac{V_2(s)}{V_1(s)} = ?$$

KHN active filter



$$(1) \underline{J} + (\underline{V}_1 - \underline{V}_8)/R_1 = 0$$

$$(2) \underline{J}_1 + (\underline{V}_2 - \underline{V}_6)/R_5 - (\underline{V}_5 - \underline{V}_2)/R_4 = 0$$

$$(3) \underline{J}_2 + (\underline{V}_3 - \underline{V}_8)/R_2 + (\underline{V}_3 - \underline{V}_7)/R_7 - sC_6(\underline{V}_6 - \underline{V}_3) = 0$$

$$(4) \underline{J}_3 - (\underline{V}_5 - \underline{V}_4)/R_3 + \underline{V}_4/R_9 - sC_8(\underline{V}_7 - \underline{V}_4) = 0$$

$$(5) (\underline{V}_5 - \underline{V}_2)/R_4 + (\underline{V}_5 - \underline{V}_4)/R_3 = 0$$

$$(6) -(\underline{V}_2 - \underline{V}_6)/R_5 + sC_6(\underline{V}_6 - \underline{V}_3) = 0$$

$$(7) -(\underline{V}_3 - \underline{V}_7)/R_7 + sC_8(\underline{V}_7 - \underline{V}_4) = 0$$

$$(8) -(\underline{V}_1 - \underline{V}_8)/R_1 - (\underline{V}_3 - \underline{V}_8)/R_2 = 0$$

$$\underline{V}_5 = \underline{V}_8$$

$$\underline{V}_6 = 0$$

$$\underline{V}_7 = 0$$

$$\underline{V}_1 = \underline{U}_g$$

```
clear variables
close all

syms C C6 C8 R R1 R2 R3 R4 R5 R7 Ug s w
assume(0<R1 & 0<R2 & 0<R3 & 0<R4 & 0<R5 & 0<C6 & 0<R7 & 0<C8 & 0<R & 0<C & 0<Ug & s~= 0 & 0<w)
```

Zamene

```
zamena_LowPass = [R1 == R, R2 == R/2, R3 == R, R4 == R/2, R5 == R, C6 == C, R7 == R, C8 == C]
```

zamena_LowPass =
 $\left(R_1 = R \quad R_2 = \frac{R}{2} \quad R_3 = R \quad R_4 = \frac{R}{2} \quad R_5 = R \quad C_6 = C \quad R_7 = R \quad C_8 = C\right)$

```
zamena_BandPass = [R1 == R, R2 == 2 * R, R3 == R, R4 == R, R5 == R, C6 == C, R7 == R, C8 == C]
```

zamena_BandPass = $\left(R_1 = R \quad R_2 = 2 R \quad R_3 = R \quad R_4 = R \quad R_5 = R \quad C_6 = C \quad R_7 = R \quad C_8 = C\right)$

```
zamena_HighPass = [R1 == R, R2 == R/2, R3 == R, R4 == 2 * R, R5 == R, C6 == C, R7 == R, C8 == C]
```

zamena_HighPass =
 $\left(R_1 = R \quad R_2 = \frac{R}{2} \quad R_3 = R \quad R_4 = 2 R \quad R_5 = R \quad C_6 = C \quad R_7 = R \quad C_8 = C\right)$

Vrednosti

```
vrednosti = [R == 1, C == 1]
```

vrednosti = $\left(R = 1 \quad C = 1\right)$

w0 = $1/(R*C)$

w0 =
 $\frac{1}{C R}$

Jednacine

```
syms J J1 J2 J3 R9 V1 V2 V3 V4 V5 V6 V7 V8 v4
jednacine = [J + (V1 - V8)/R1 == 0,...
             J1 + (V2 - V6)/R5 - (V5 - V2)/R4 == 0,...
             J2 + (V3 - V8)/R2 + (V3 - V7)/R7 - s*C6*(V6 - V3) == 0,...
             J3 - (V5 - V4)/R3 + v4/R9 - s * C8 * (V7 - V4) == 0,...
             (V5 - V2)/R4 + (V5 - V4)/R3 == 0,...
             -((V2 - V6)/R5) + s * C6 * (V6 - V3) == 0,...
             -((V3 - V7)/R7) + s * C8 * (V7 - V4) == 0,...
             -((V1 - V8)/R1) - (V3 - V8)/R2 == 0,...
             V5 == V8, V6 == 0, V7 == 0, V1 == Ug]
```

jednacine =

$$\left(J + \frac{V_1 - V_8}{R_1} = 0 \quad J_1 + \frac{V_2 - V_5}{R_4} + \frac{V_2 - V_6}{R_5} = 0 \quad J_2 + \frac{V_3 - V_8}{R_2} + \frac{V_3 - V_7}{R_7} + \sigma_2 = 0 \quad J_3 + \frac{V_4 - V_5}{R_3} + \frac{v_4}{R_9} - s C_8 (V_7 - V_4) = 0 \right.$$

where

$$\sigma_1 = C_8 s (V_4 - V_7)$$
$$\sigma_2 = C_6 s (V_3 - V_6)$$

Promenljive

```
promenljive = [V1, V2, V3, V4, V5, V6, V7, V8, J, J1, J2, J3]
promenljive = (V1 V2 V3 V4 V5 V6 V7 V8 J J1 J2 J3)
```

```
odziv = solve(jednacine, promenljive)
```


Low Pass odziv

```
syms V4_1(s) H_LowPass(s) Hjw_LowPass(w)
```

```
V4_1(s) = subs(odziv.V4, lhs(zamena_LowPass), rhs(zamena_LowPass))
```

$$V4_1(s) = \frac{3 R^2 U_g}{4 \left(\frac{3 C^2 R^4 s^2}{2} + \frac{3 C R^3 s}{2} + \frac{3 R^2}{4} \right)}$$

```
H_LowPass(s) = simplify(V4_1(s)/Ug)
```

$$H_LowPass(s) = \frac{1}{2 C^2 R^2 s^2 + 2 C R s + 1}$$

```
Hjw_LowPass(w) = subs(H_LowPass(s), s, 1i*w)
```

$$Hjw_LowPass(w) = \frac{1}{-2 C^2 R^2 w^2 + 2 C R w i + 1}$$

```
Aw_LowPass(w) = simplify(abs(Hjw_LowPass(w)))
```

$$Aw_LowPass(w) = \frac{1}{|-2 C^2 R^2 w^2 + 2 C R w i + 1|}$$

```
phi_LowPass(w) = simplify(angle(Hjw_LowPass(w)))
```

$$\phi_LowPass(w) = \text{angle}\left(\frac{1}{-2 C^2 R^2 w^2 + 2 C R w i + 1}\right)$$

Band Pass odziv

```
syms V3_1(s) H_BandPass(s) Hjw_BandPass(w)
```

```
V3_1(s) = subs(odziv.V3, lhs(zamena_BandPass), rhs(zamena_BandPass))
```

$$V3_1(s) = -\frac{4 C R^3 U_g s}{3 C^2 R^4 s^2 + 2 C R^3 s + 3 R^2}$$

```
H_BandPass(s) = simplify(V3_1(s)/Ug)
```

$$H_BandPass(s) = -\frac{4 C R s}{3 C^2 R^2 s^2 + 2 C R s + 3}$$

```
Hjw_BandPass(w) = subs(H_BandPass(s), s, 1i*w)
```

$$Hjw_BandPass(w) = -\frac{4 C R w i}{-3 C^2 R^2 w^2 + 2 C R w i + 3}$$

```
Aw_BandPass(w) = simplify(abs(Hjw_BandPass(w)))
```

$$Aw_BandPass(w) = \frac{4 C R |w|}{|-3 C^2 R^2 w^2 + 2 C R w i + 3|}$$

```
phi_BandPass(w) = simplify(angle(Hjw_BandPass(w)))
```

$$\phi_BandPass(w) = \text{angle}\left(-\frac{w i}{-3 C^2 R^2 w^2 + 2 C R w i + 3}\right)$$

High Pass odziv

```
syms V2_1(s) H_HighPass(s)
V2_1(s) = subs(odziv.V2, lhs(zamena_HighPass), rhs(zamena_HighPass))
```

$$V2_1(s) = \frac{3 C^2 R^4 U_g s^2}{2 \left(\frac{3 C^2 R^4 s^2}{2} + 3 C R^3 s + 3 R^2 \right)}$$

```
H_HighPass(s) = simplify(V2_1(s)/Ug)
```

$$H_HighPass(s) = \frac{C^2 R^2 s^2}{C^2 R^2 s^2 + 2 C R s + 2}$$

```
Hjw_HighPass(w) = subs(H_HighPass(s), s, 1i*w)
```

$$Hjw_HighPass(w) = \frac{C^2 R^2 w^2}{-C^2 R^2 w^2 + 2 C R w i + 2}$$

```
Aw_HighPass(w) = simplify(abs(Hjw_HighPass(w)))
```

$$Aw_HighPass(w) = \frac{C^2 R^2 |w|^2}{|-C^2 R^2 w^2 + 2 C R w i + 2|}$$

```
phi_HighPass(w) = simplify(angle(Hjw_HighPass(w)))
```

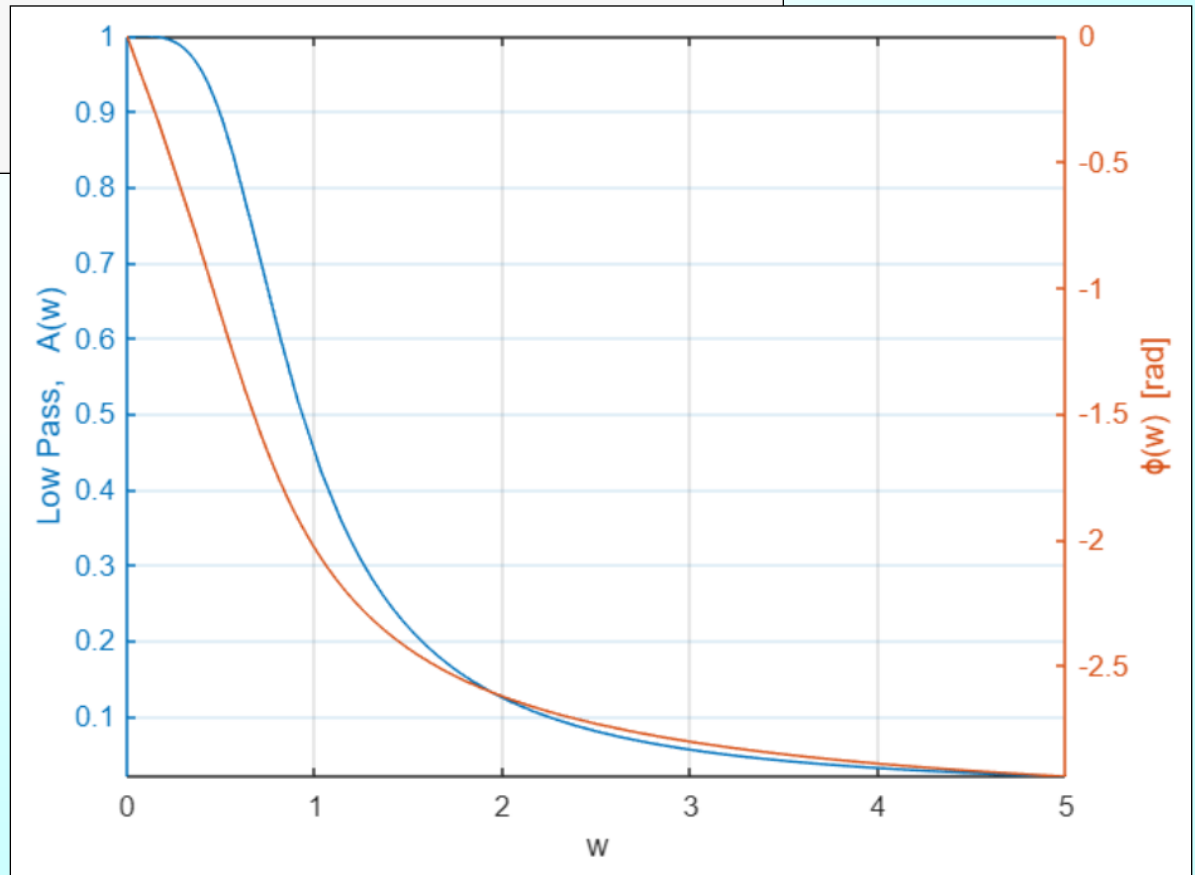
$$phi_HighPass(w) = \text{angle} \left(-\frac{w^2}{-C^2 R^2 w^2 + 2 C R w i + 2} \right)$$

Crtanje grafika frekvencijskih karakteristika

```
figure
yyaxis left
fplot(subs(Aw_LowPass(w), lhs(vrednosti), rhs(vrednosti)), [0, 5])
ylabel('Low Pass, A(w)')

yyaxis right
fplot(w, subs(phi_LowPass(w), lhs(vrednosti), rhs(vrednosti)), [0, 5])
ylabel('\phi(w) [rad]')

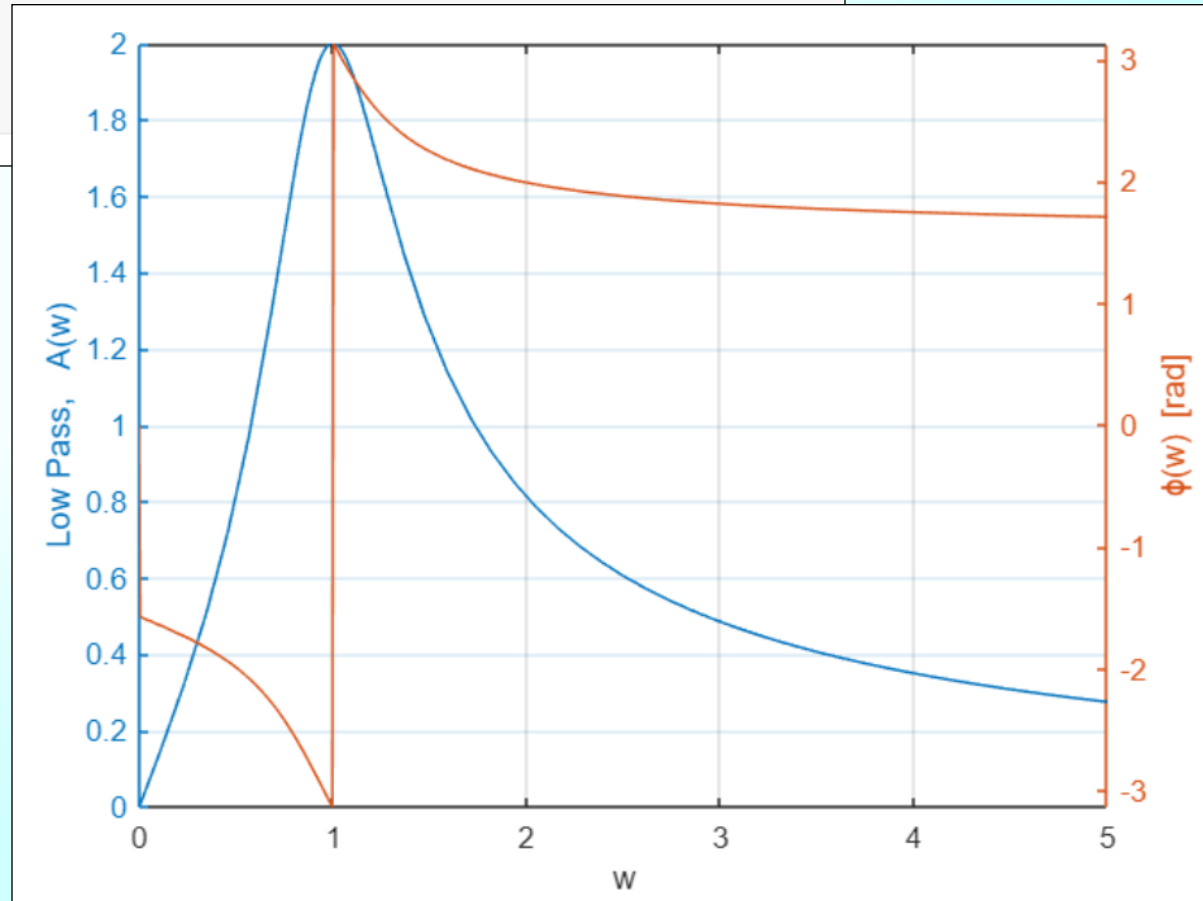
xlabel('w')
grid on
```



```
figure
yyaxis left
fplot(subs(Aw_BandPass(w), lhs(vrednosti), rhs(vrednosti)), [0, 5])
ylabel('Low Pass, A(w)')

yyaxis right
fplot(w, subs(phi_BandPass(w), lhs(vrednosti), rhs(vrednosti)), [0, 5])
ylabel('\phi(w) [rad]')

xlabel('w')
grid on
```



```
figure
yyaxis left
fplot(subs(Aw_HighPass(w), lhs(vrednosti), rhs(vrednosti)), [0, 5])
ylabel('Low Pass, A(w)')

yyaxis right
fplot(w, subs(phi_HighPass(w), lhs(vrednosti), rhs(vrednosti)), [0,5])
ylabel('\phi(w) [rad]')

xlabel('w')
grid on
```

