

Projetar as funções de transferência dos filtros ativos que seguem com aproximação Butterworth:

Deve ser apresentado todo o equacionamento para se obter as funções de transferência a partir das funções normalizadas (polinômios de Butterworth). A partir da função de transferência, apresentar a resposta em frequência do filtro (magnitude e fase). Apresentar ao menos simulações de sinais senoidais (sobrepor sinal de entrada e saída) na banda passante, na frequência de corte e na banda de rejeição dos filtros. Comparar os resultados obtidos na simulação com os previstos pela resposta em frequência.

```
K = 1;
s = tf('s');
interval = {0, 10^10};
rad_s = 2 * pi; % 1 Hz = 2 * pi rad/s

function simulate_filter_response(H, f, T)
    dt = 1e-5;
    t = 0:dt:T;
    u = sin(2 * pi*f*t);

    [y, t_out] = lsim(H, u, t);

    figure;
    plot(t_out, u, 'b', t_out, y, 'r');
    xlabel('Tempo (s)');
    ylabel('Amplitude');
    legend('Entrada', 'Saída');
    title(['Resposta do Filtro (f = ' num2str(f) ' Hz, Tempo Simulado = '
num2str(T) ' s)']);
    grid on;
end
```

1) Passa-baixas de primeira ordem com frequência de corte de 250 Hz.

```
disp("Passa baixa 250Hz - 1ª Ordem");
```

Passa baixa 250Hz - 1ª Ordem

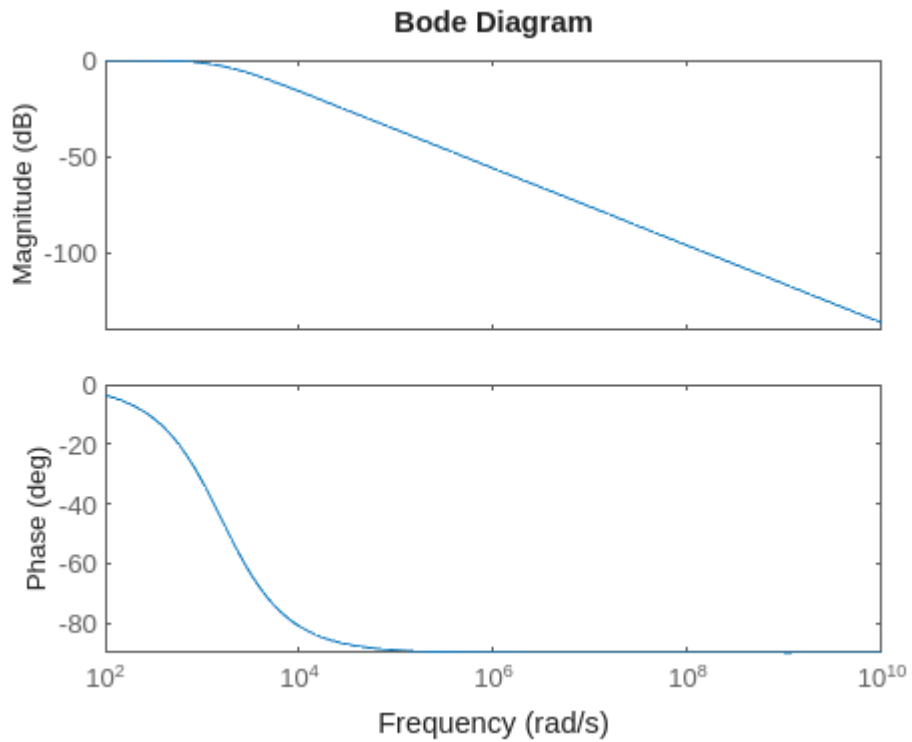
```
Hz = 250;
a = s / (Hz * rad_s);

butterworth_p_1 = a + 1;
H = 1 / butterworth_p_1
```

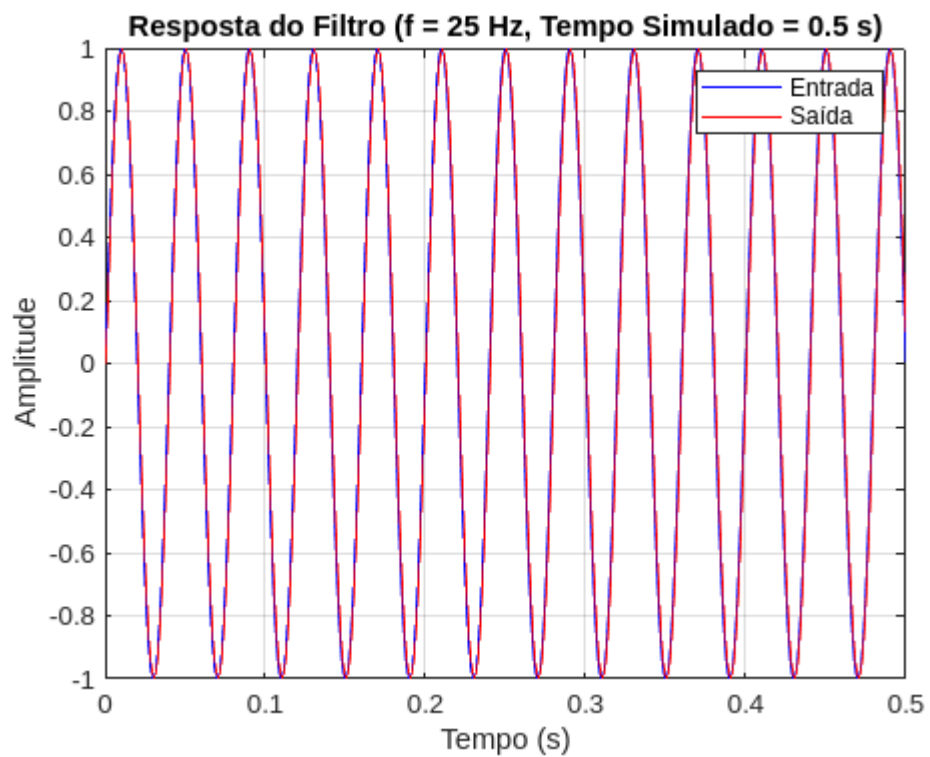
```
H =
    1571
-----
    s + 1571
```

Continuous-time transfer function.
Model Properties

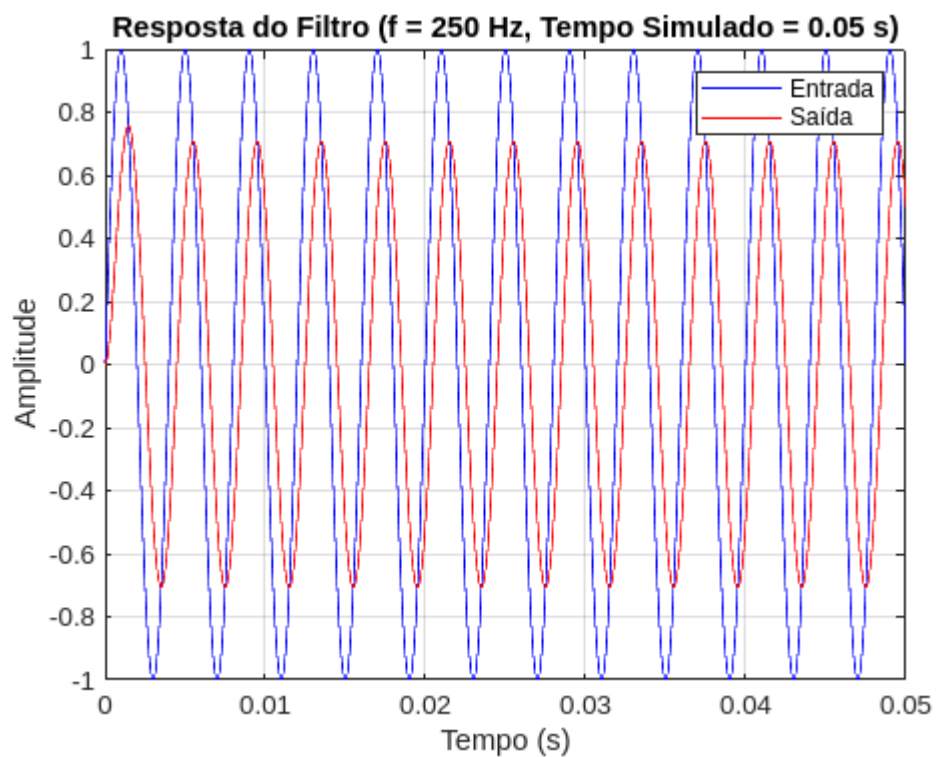
```
bode(H, interval)
```



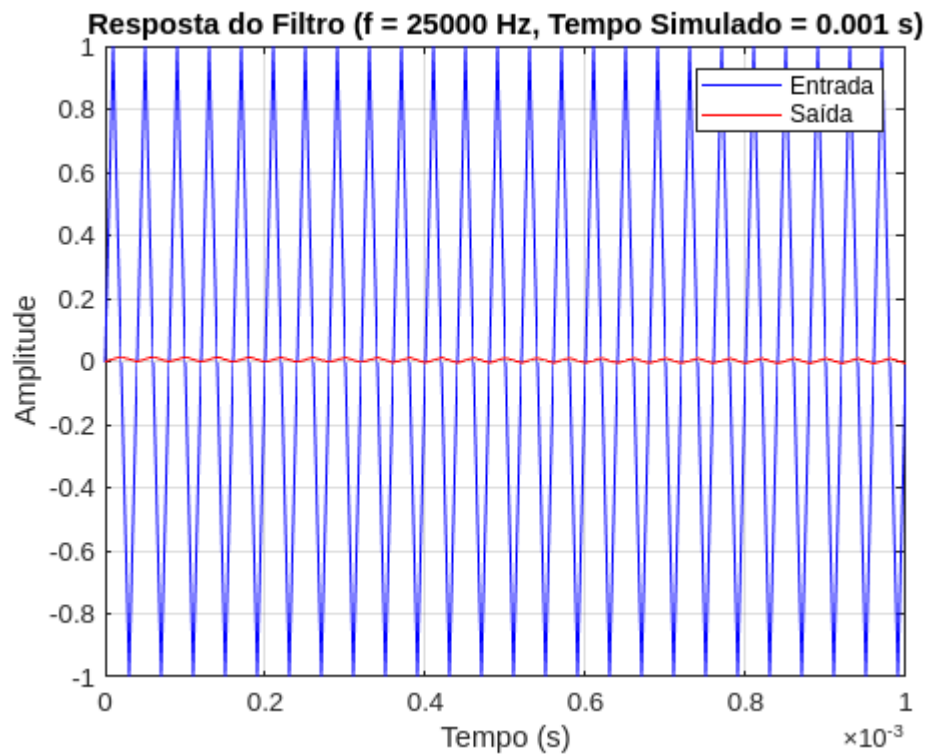
```
simulate_filter_response(H, Hz/10, 0.5);
```



```
simulate_filter_response(H, Hz, 0.05);
```



```
simulate_filter_response(H, Hz*100, 0.001);
```



2) Passa-altas de primeira ordem com frequência de corte de 250 Hz.

```
disp("Passa alta 250Hz - 1ª Ordem");
```

Passa alta 250Hz - 1ª Ordem

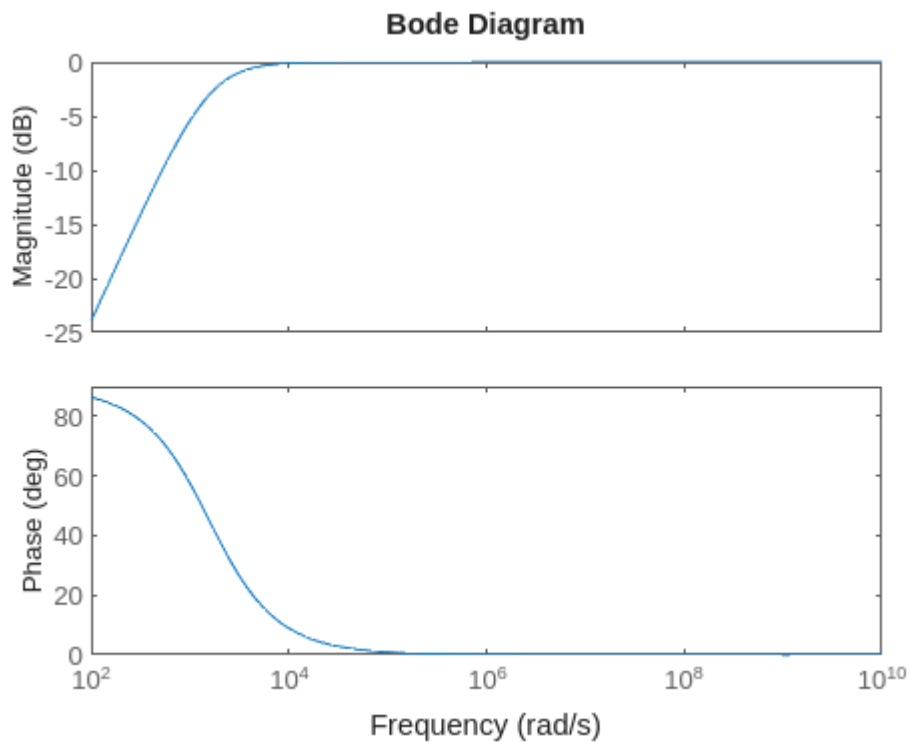
```
Hz = 250;  
a = s / (Hz * rad_s);  
  
butterworth_p_1 = a + 1;  
H = (a^1) / butterworth_p_1
```

H =

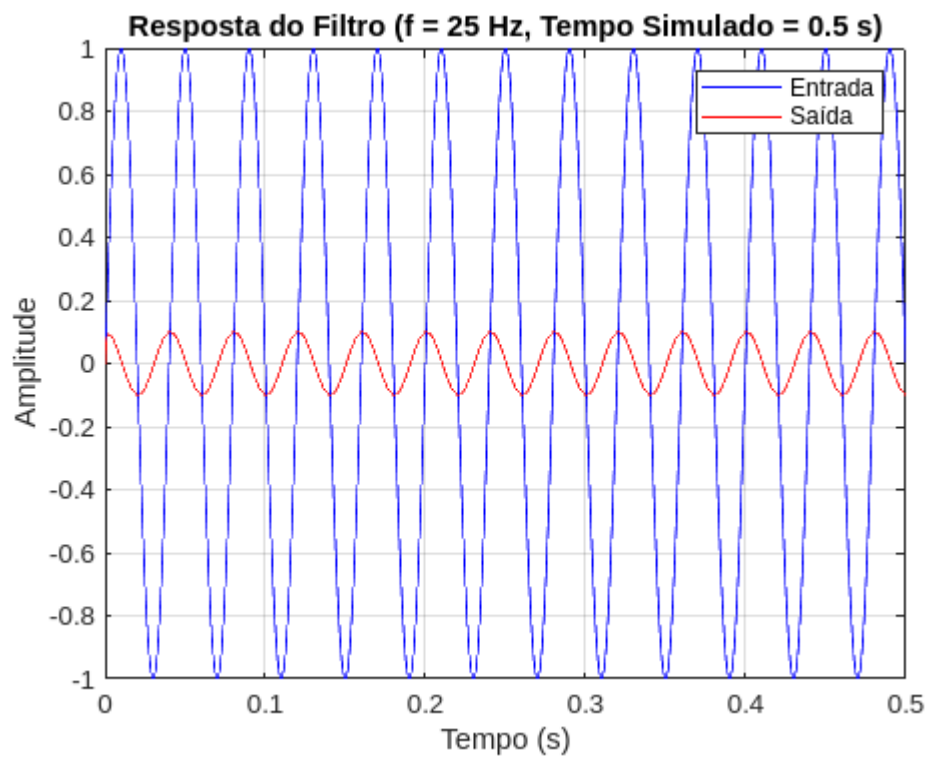
$$\frac{1571 \text{ s}}{1571 \text{ s} + 2.467\text{e}06}$$

Continuous-time transfer function.
Model Properties

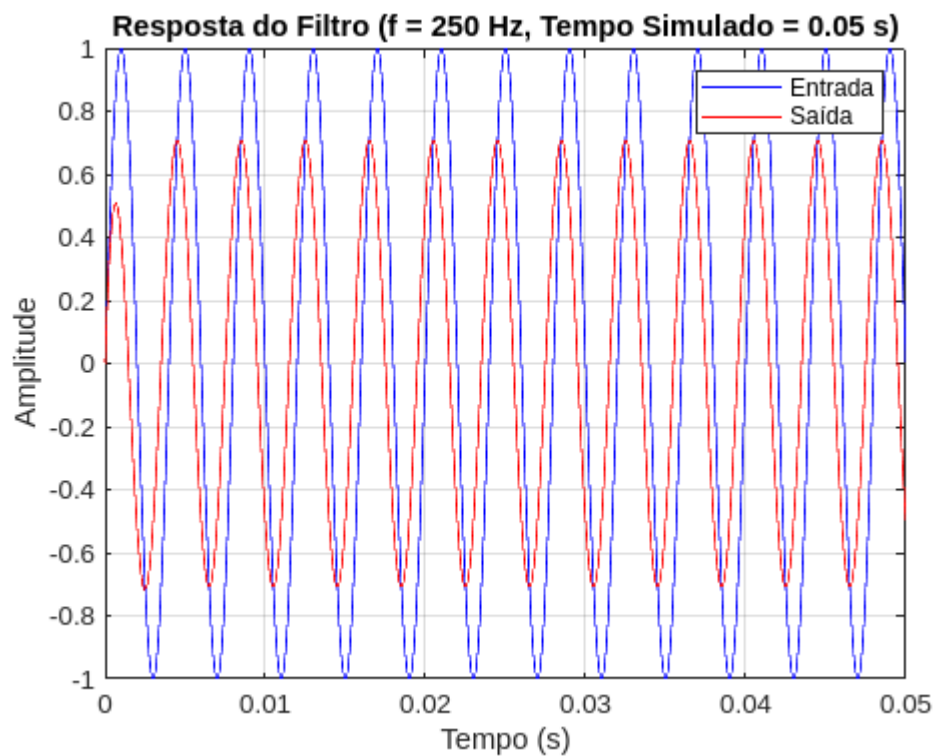
```
bode(H, interval)
```



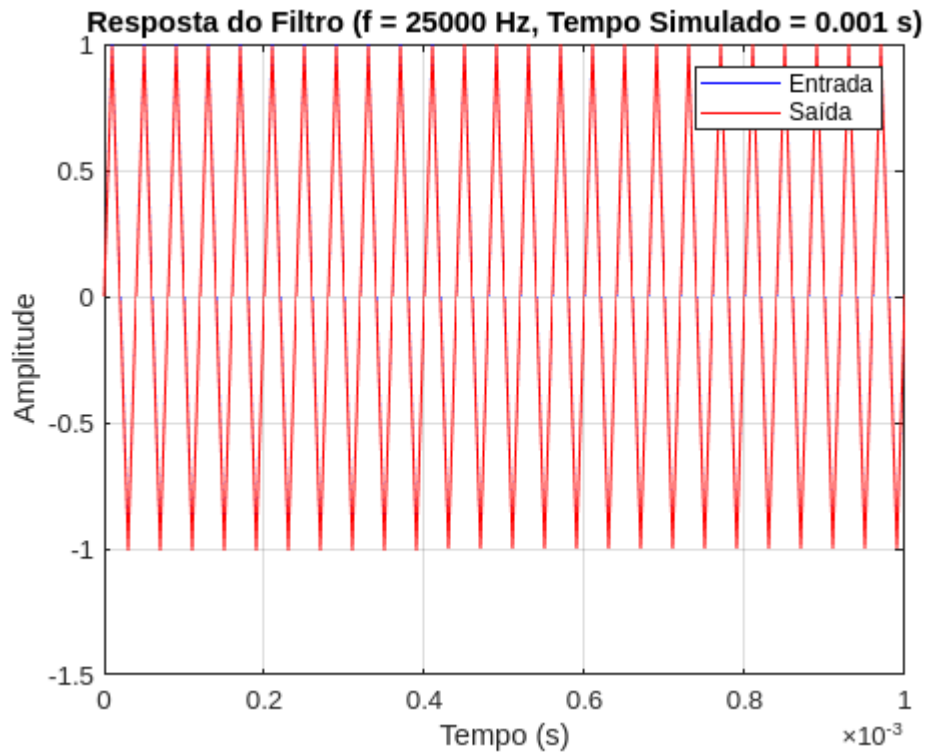
```
simulate_filter_response(H, Hz/10, 0.5);
```



```
simulate_filter_response(H, Hz, 0.05);
```



```
simulate_filter_response(H, Hz*100, 0.001);
```



3) Passa-baixas de segunda ordem com frequência de corte de 250 Hz.

```
disp("Passa baixa 250Hz - 2ª Ordem");
```

Passa baixa 250Hz - 2ª Ordem

```
a = s / (Hz * rad_s);
```

```
butterworth_p_2 = a^2 + a*1.4142 + 1;
```

```
H = 1 / butterworth_p_2
```

H =

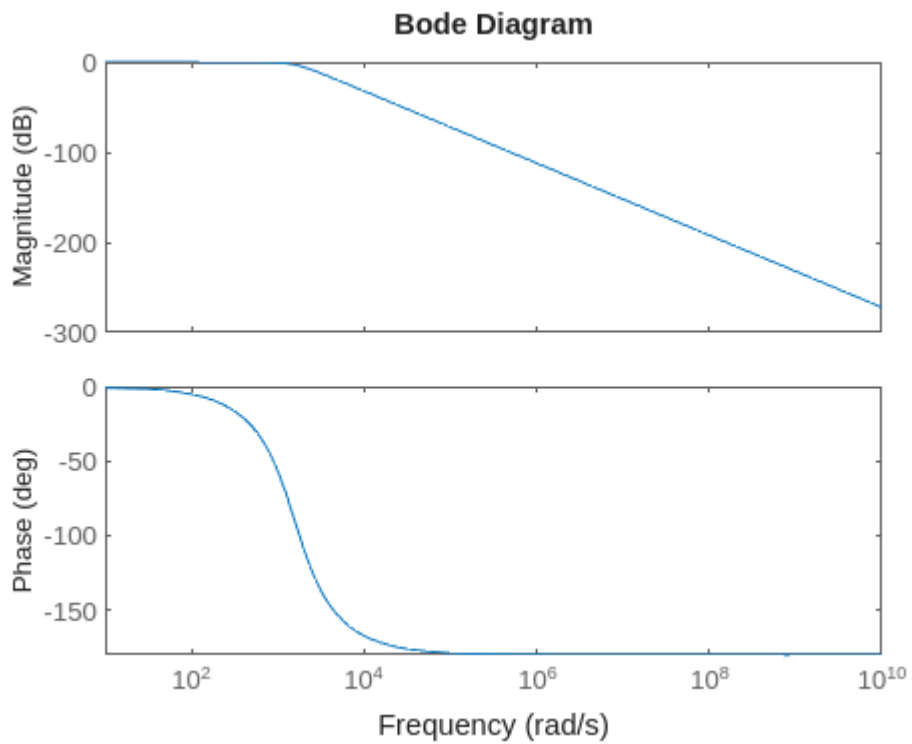
```

      3.876e09
-----
1571 s^2 + 3.489e06 s + 3.876e09

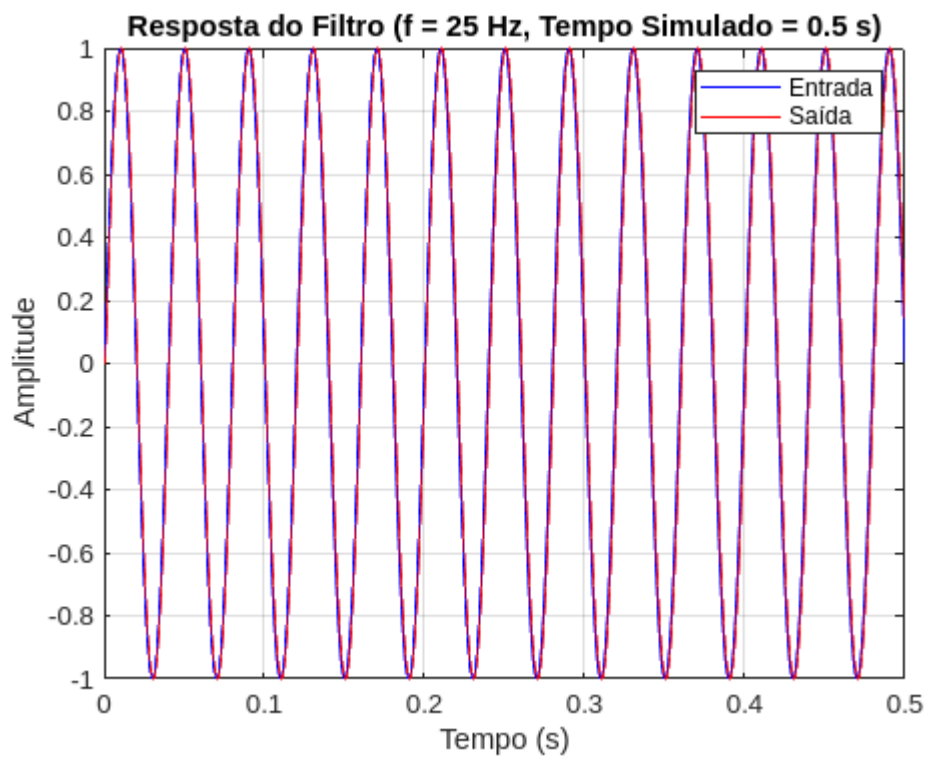
```

Continuous-time transfer function.
Model Properties

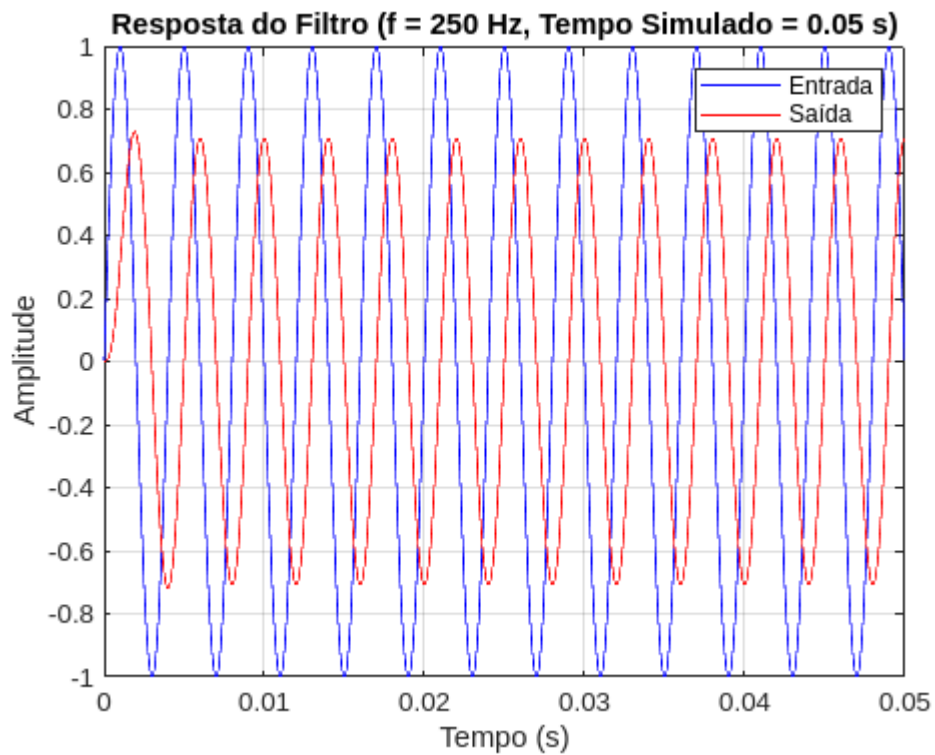
```
bode(H, interval)
```



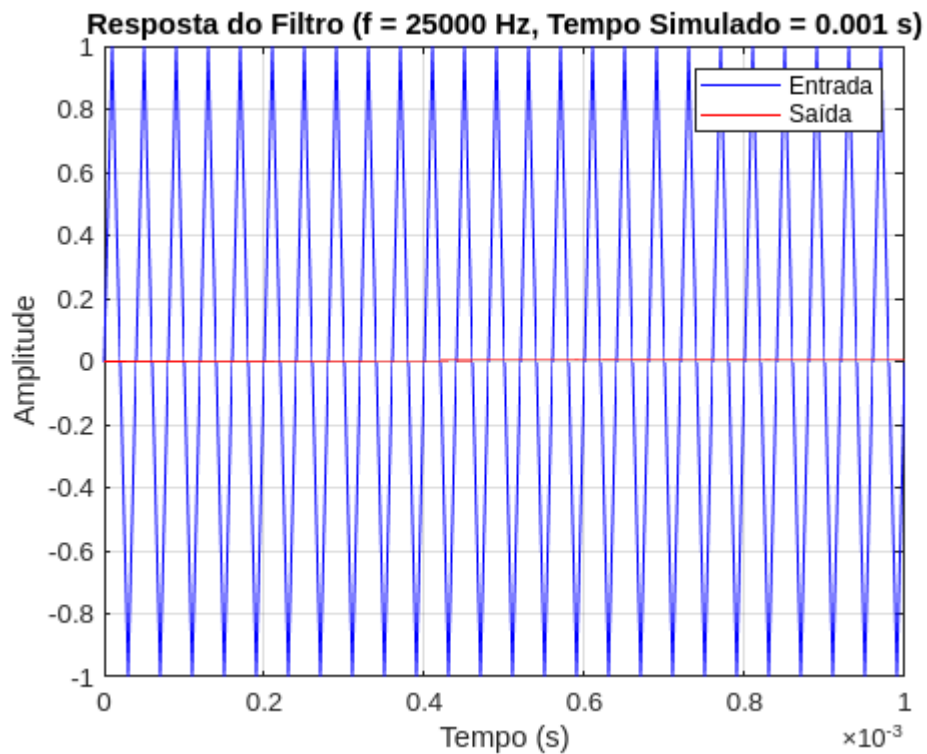
```
simulate_filter_response(H, Hz/10, 0.5);
```



```
simulate_filter_response(H, Hz, 0.05);
```



```
simulate_filter_response(H, Hz*100, 0.001);
```



4) Passa-altas de segunda ordem com frequência de corte de 250 Hz.

```
disp("Passa alta 250Hz - 2ª Ordem");
```


Passa alta 250Hz - 2ª Ordem

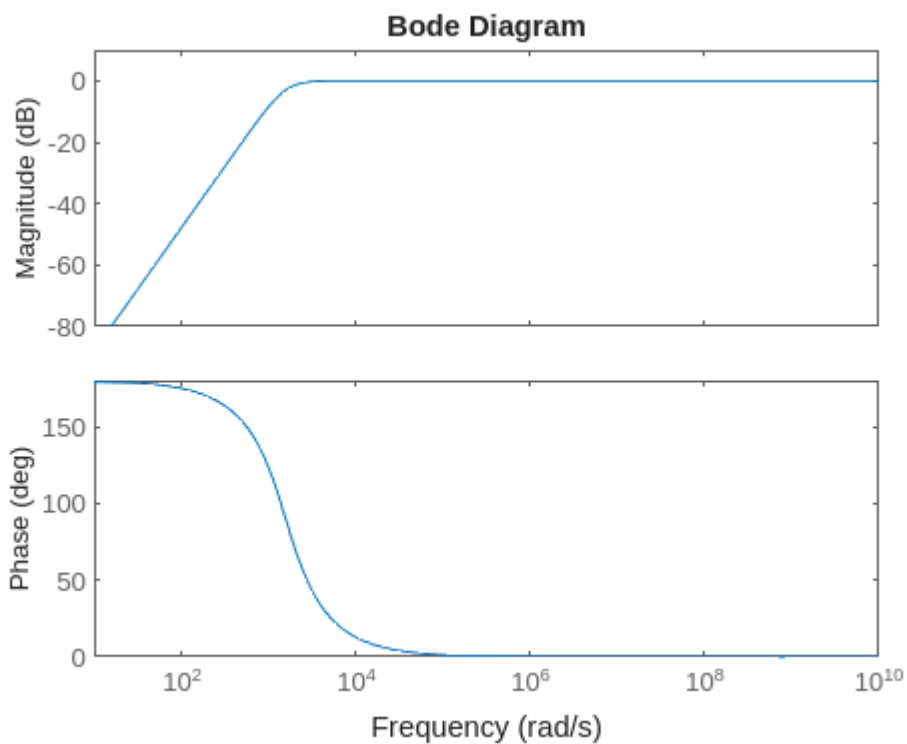
```
Hz = 250;  
a = s / (Hz * rad_s);  
  
butterworth_p_2 = a^2 + a*1.4142 + 1;  
H = (a^2) / butterworth_p_2
```

H =

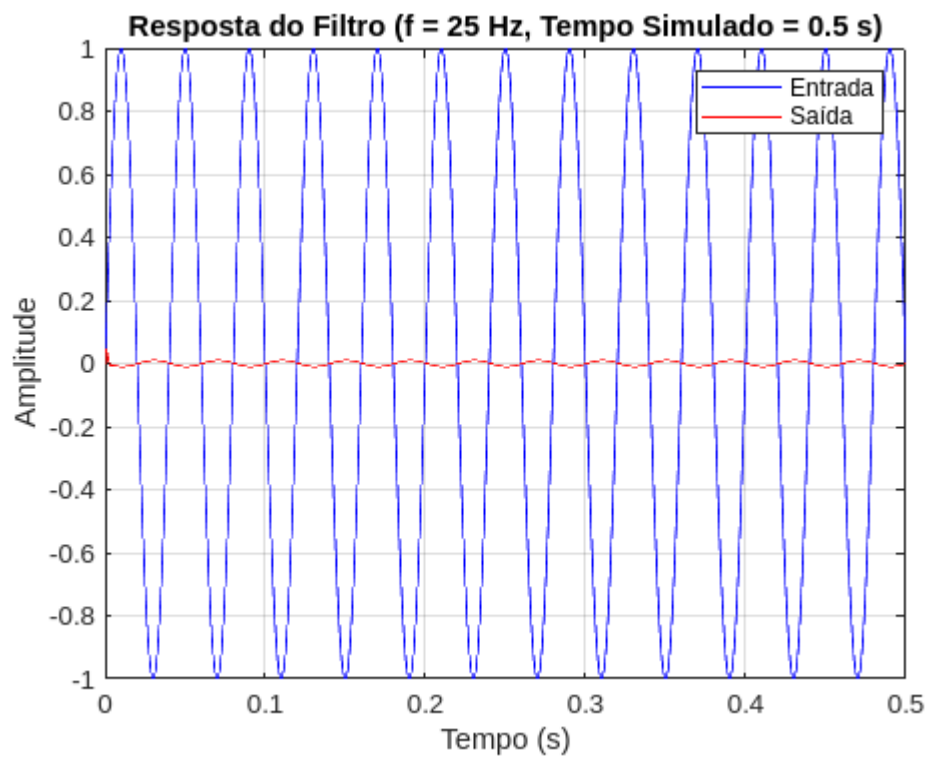
$$\frac{3.876e09 \text{ s}^2}{3.876e09 \text{ s}^2 + 8.61e12 \text{ s} + 9.563e15}$$

Continuous-time transfer function.
Model Properties

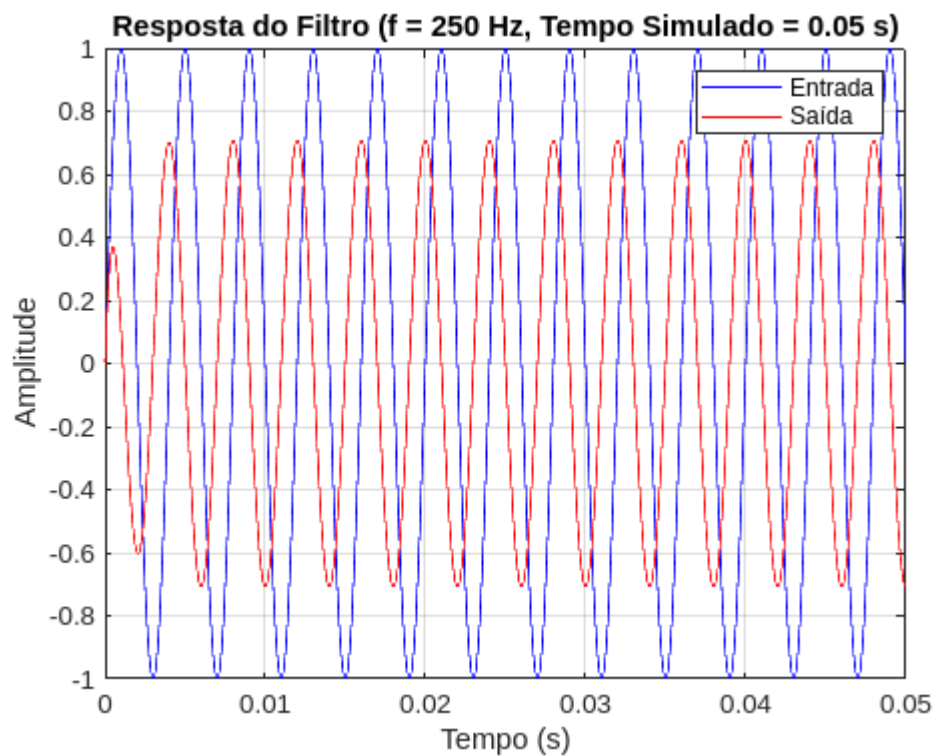
```
bode(H, interval)
```



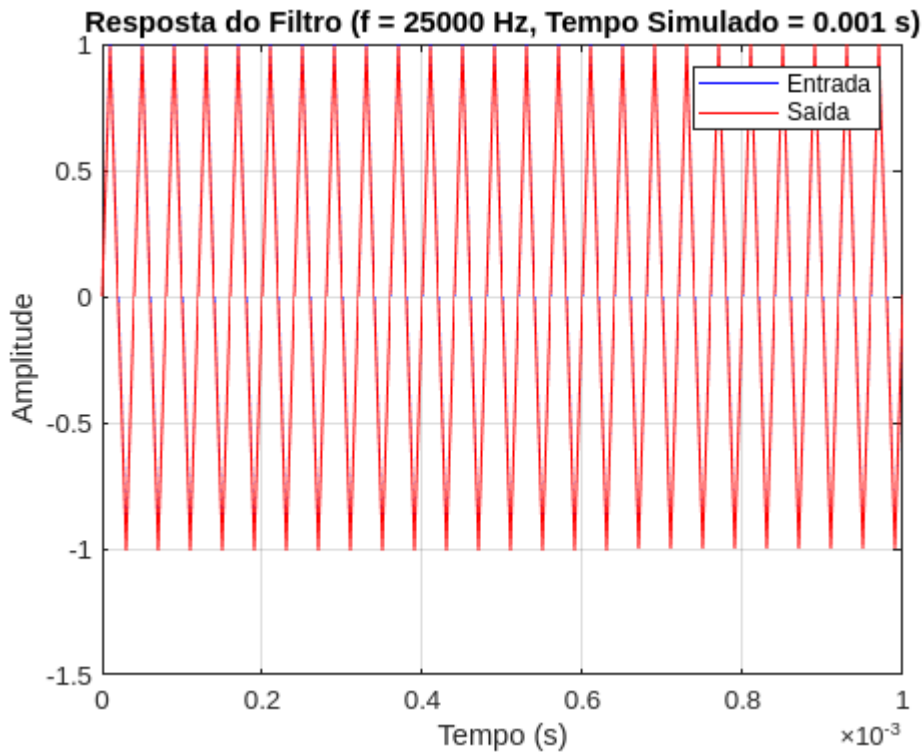
```
simulate_filter_response(H, Hz/10, 0.5);
```



```
simulate_filter_response(H, Hz, 0.05);
```



```
simulate_filter_response(H, Hz*100, 0.001);
```



5) Passa-banda de segunda ordem com frequência central de 250 Hz e banda passante de 1000 Hz.

```
disp("Passa Banda 250Hz ~ 1000Hz - 2ª Ordem");
```

Passa Banda 250Hz ~ 1000Hz - 2ª Ordem

```
% Passa baixa 1000
Hz1 = 1000;
a = s / (Hz1 * rad_s);
butterworth_p_2 = a^2 + a*1.4142 + 1;
H1 = 1 / butterworth_p_2;

% Passa alta 250
Hz2 = 250;
a = s / (Hz2 * rad_s);
butterworth_p_2 = a^2 + a*1.4142 + 1;
H2 = (a^2) / butterworth_p_2;

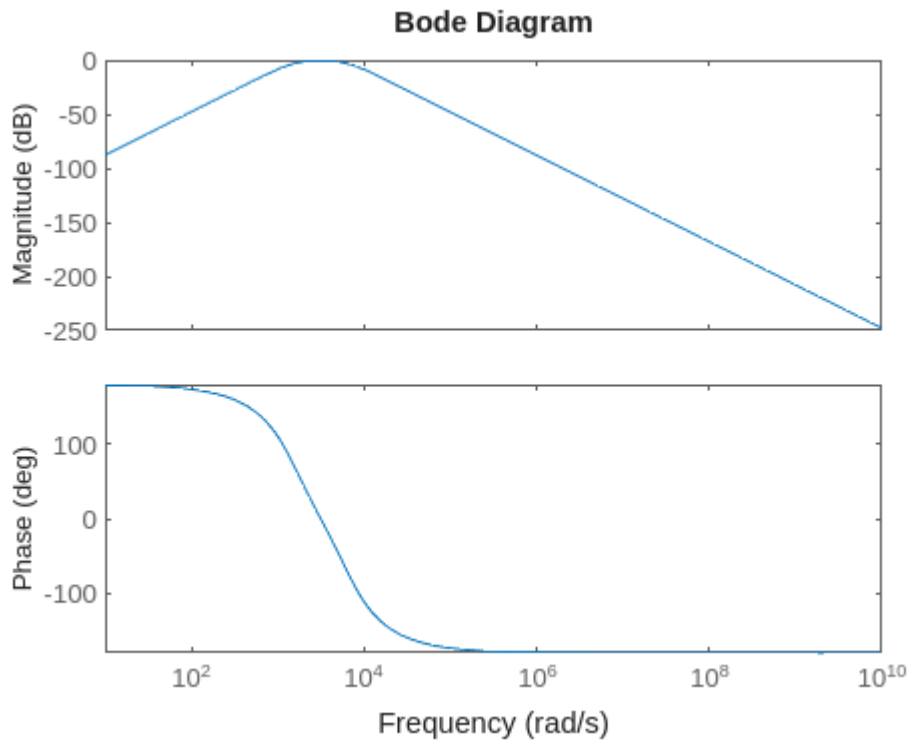
H = H1*H2 %em série
```

H =

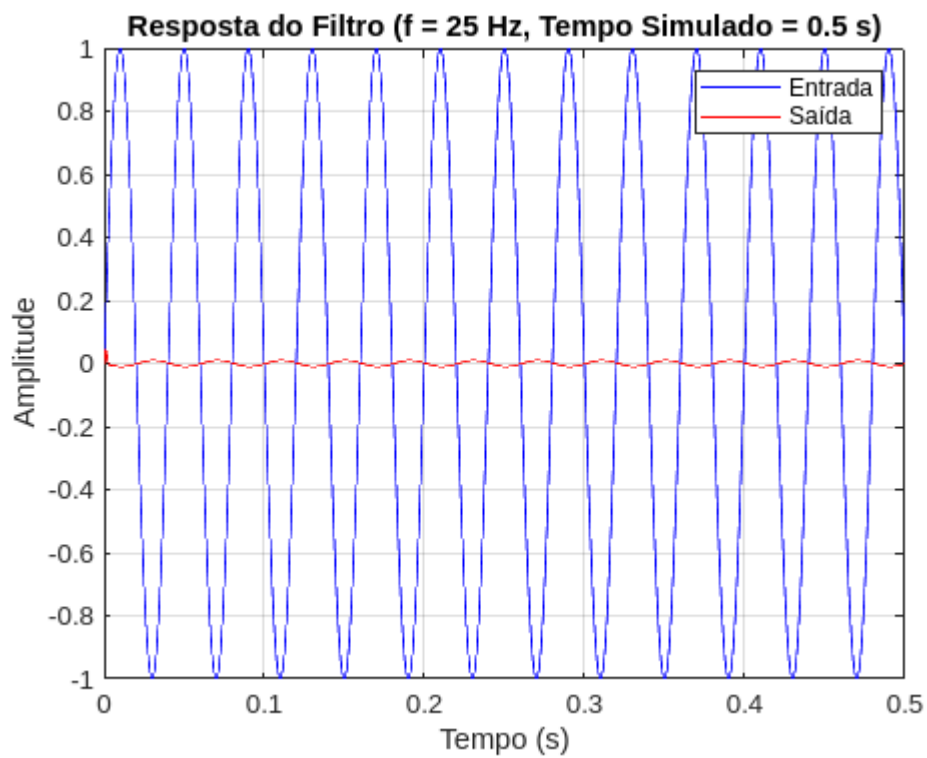
$$\frac{9.614e20 \text{ s}^2}{2.435e13 \text{ s}^4 + 2.705e17 \text{ s}^3 + 1.502e21 \text{ s}^2 + 2.67e24 \text{ s} + 2.372e27}$$

Continuous-time transfer function.
Model Properties

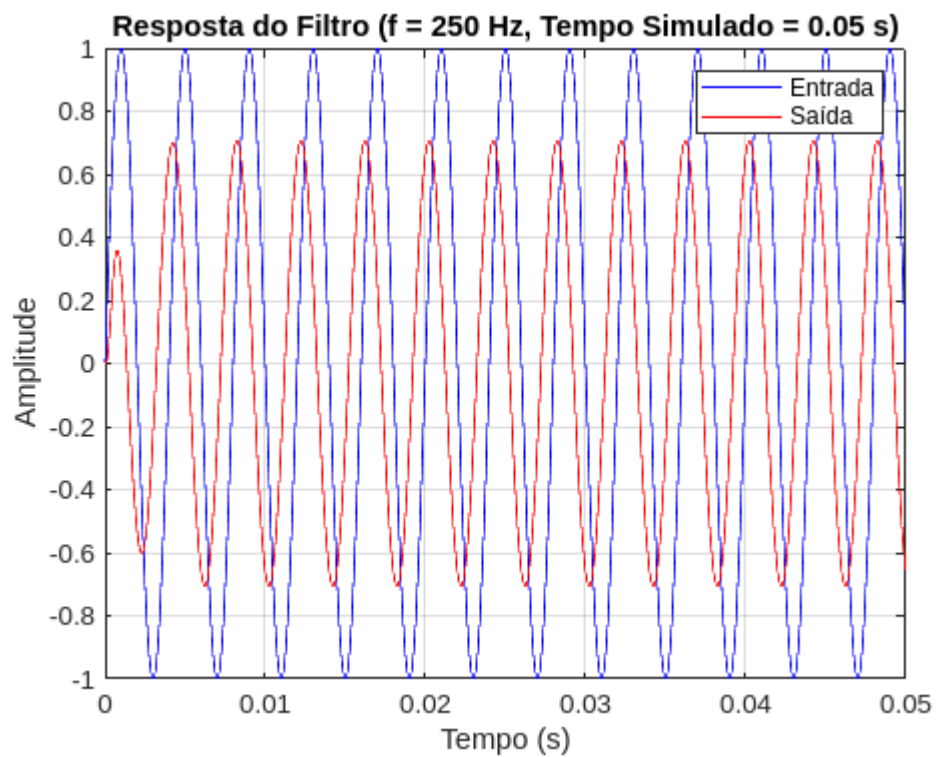
```
bode(H, interval)
```



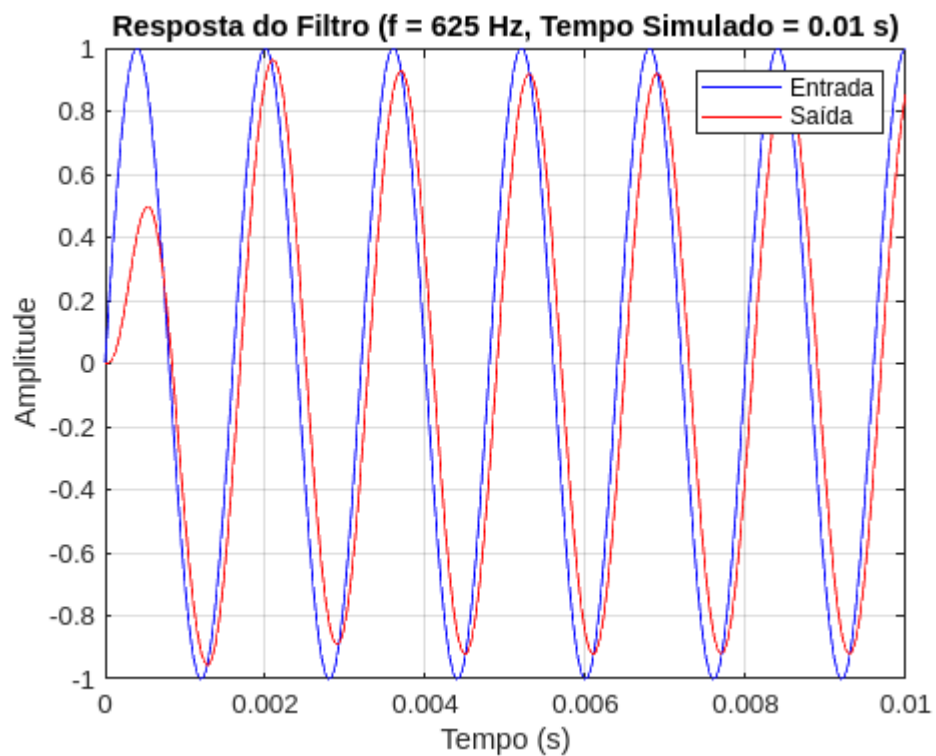
```
simulate_filter_response(H, Hz2/10, 0.5);
```



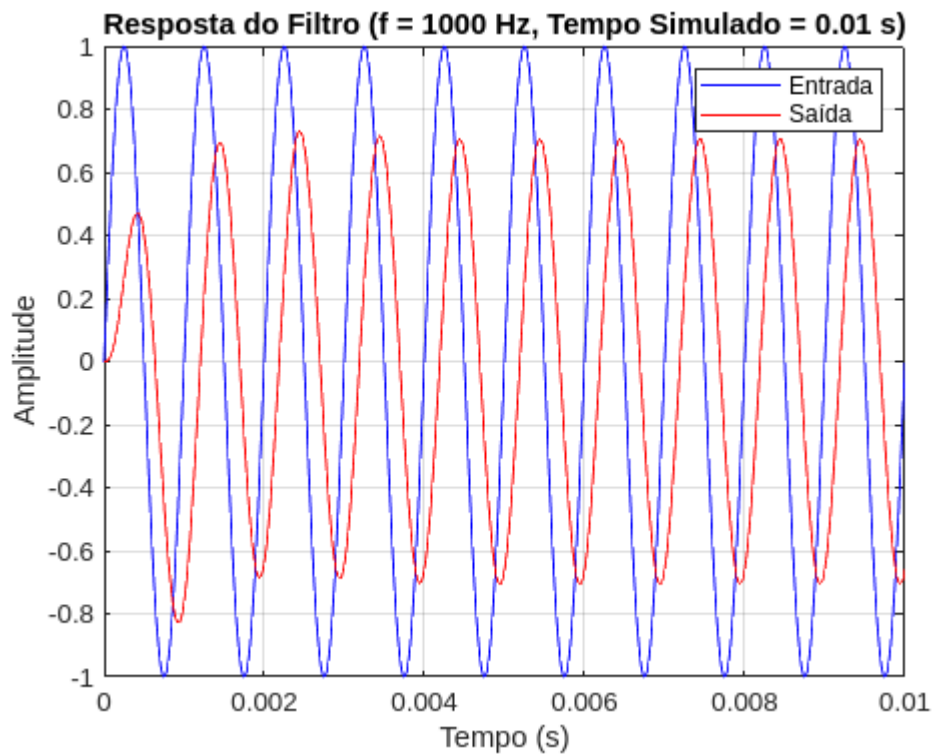
```
simulate_filter_response(H, Hz2, 0.05);
```



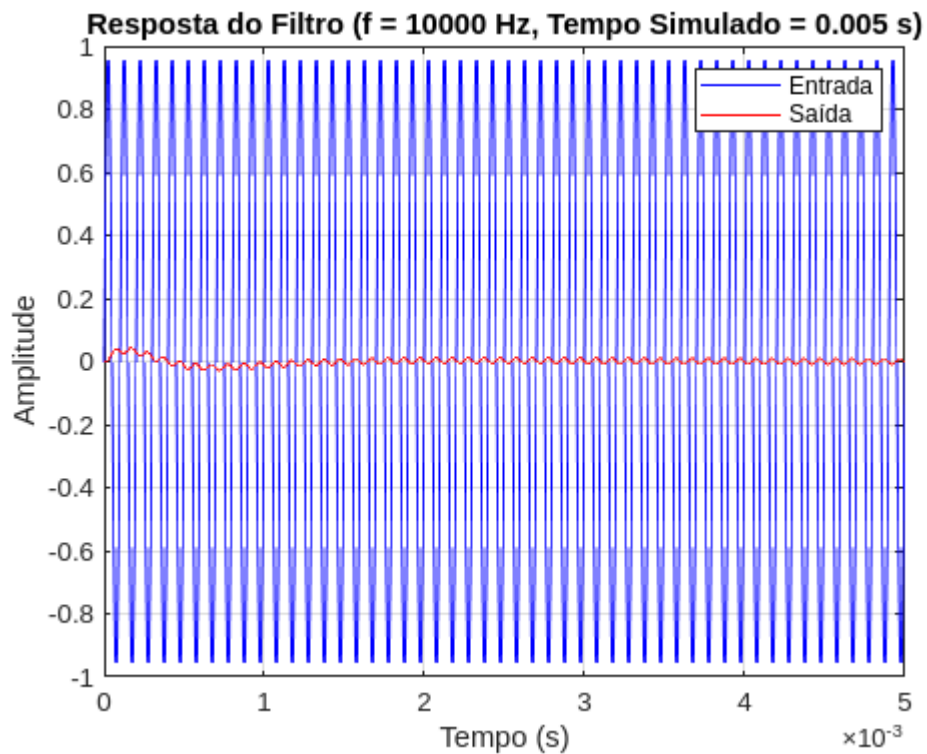
```
simulate_filter_response(H, ((Hz1 - Hz2)/2)+Hz2 , 0.01);
```



```
simulate_filter_response(H, Hz1, 0.01);
```



```
simulate_filter_response(H, Hz1 * 10, 0.005);
```



6) Rejeita-banda de segunda ordem com frequência central de 250 Hz e banda passante de 1000 Hz.

```
disp("Rejeita Banda 250Hz ~ 1000Hz - 2ª Ordem");
```

Rejeita Banda 250Hz ~ 1000Hz - 2ª Ordem

```
% Passa baixa 1000
Hz1 = 250;
a = s / (Hz1 * rad_s);
butterworth_p_2 = a^2 + a*1.4142 + 1;
H1 = 1 / butterworth_p_2;

% Passa alta 250
Hz2 = 1000;
a = s / (Hz2 * rad_s);
butterworth_p_2 = a^2 + a*1.4142 + 1;
H2 = (a^2) / butterworth_p_2;

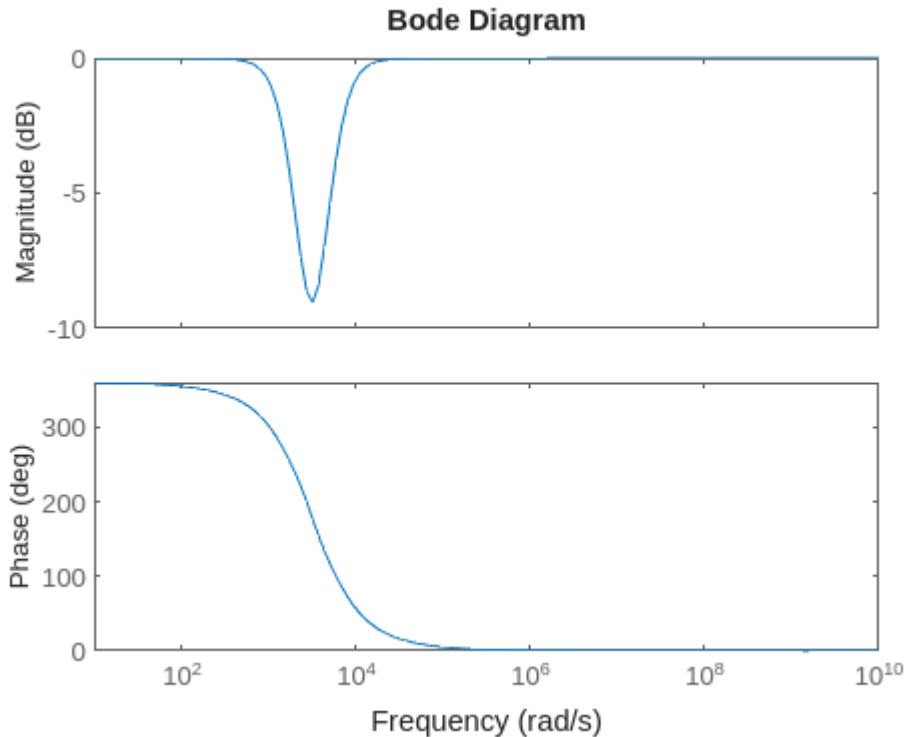
H = H1+H2 % em paralelo
```

H =

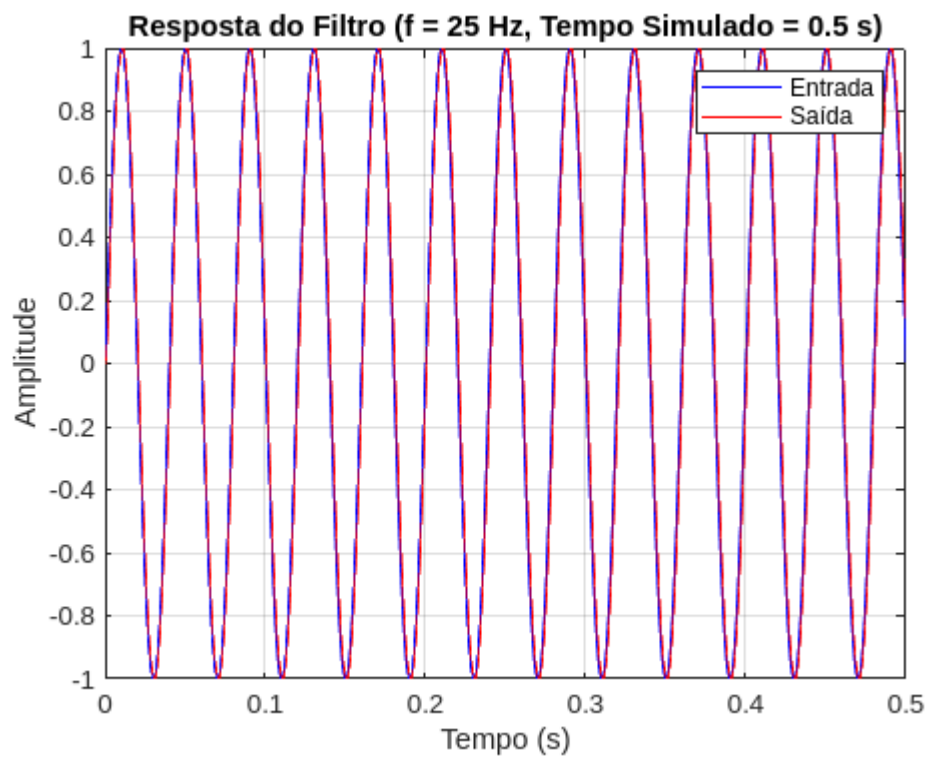
$$\frac{3.896e14 s^4 + 8.655e17 s^3 + 1.923e21 s^2 + 8.543e24 s + 3.795e28}{3.896e14 s^4 + 4.328e18 s^3 + 2.403e22 s^2 + 4.271e25 s + 3.795e28}$$

Continuous-time transfer function.
Model Properties

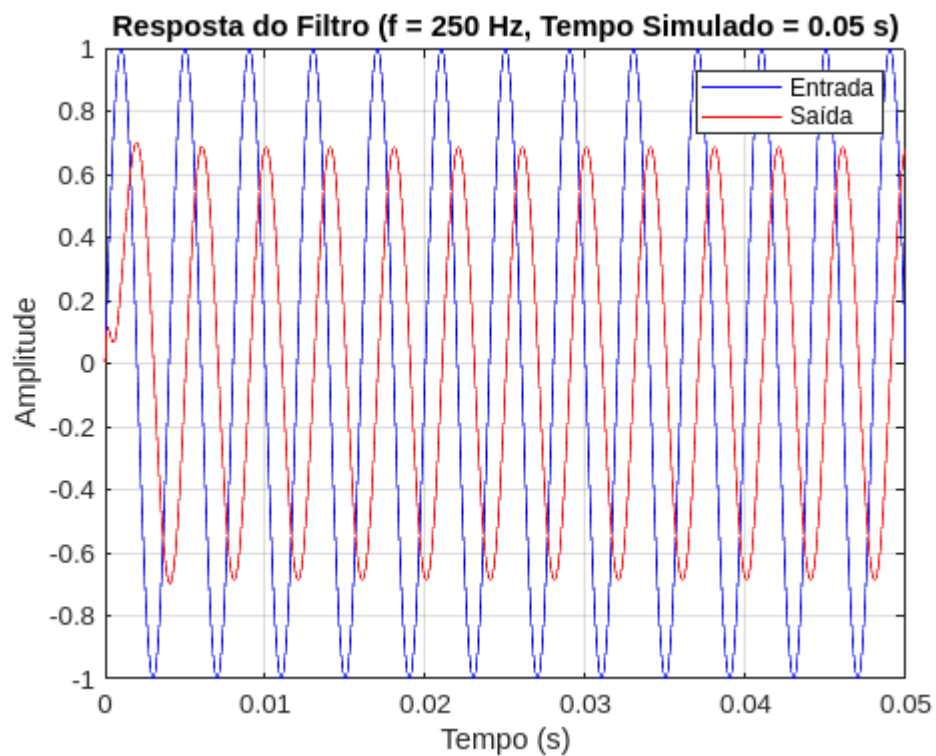
```
bode(H, interval)
```



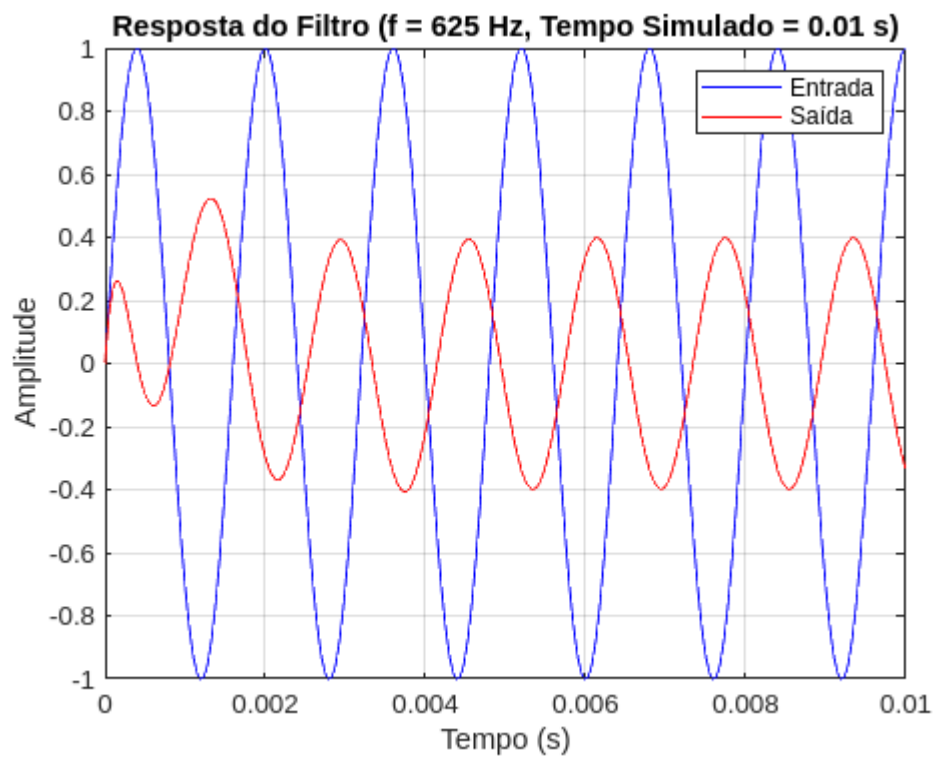
```
simulate_filter_response(H, Hz1/10, 0.5);
```



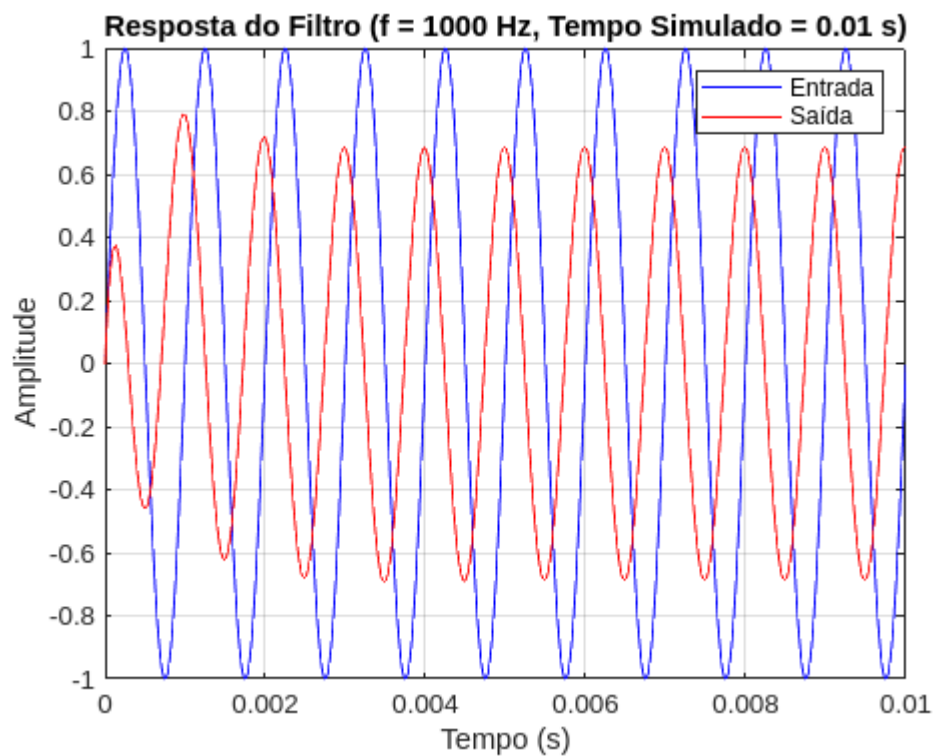
```
simulate_filter_response(H, Hz1, 0.05);
```



```
simulate_filter_response(H, ((Hz2 - Hz1)/2)+Hz1 , 0.01);
```

```
simulate_filter_response(H, Hz2, 0.01);
```



```
simulate_filter_response(H, Hz2 * 10, 0.005);
```

