Butterworth filter

The Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the passband. It is also referred to as a maximally flat magnitude filter. In MatDeck the environment filter design is performed by defining filter order, response type, cut-off frequencies, and sampling rate. First, we illustrate the design of the lowpass and highpass Butterworth filter. Later in this document we will illustrate the design of bandpass and bandstop Butterworth filters.

Design of low pass Butterworth filter

The function buttlohi() in MatDeck is used to design lowpass or high pass filters. buttlohi() returns the filter coefficients in matrix form, and later we extract the denominator and numerator coefficients. The filter design is illustrated below.

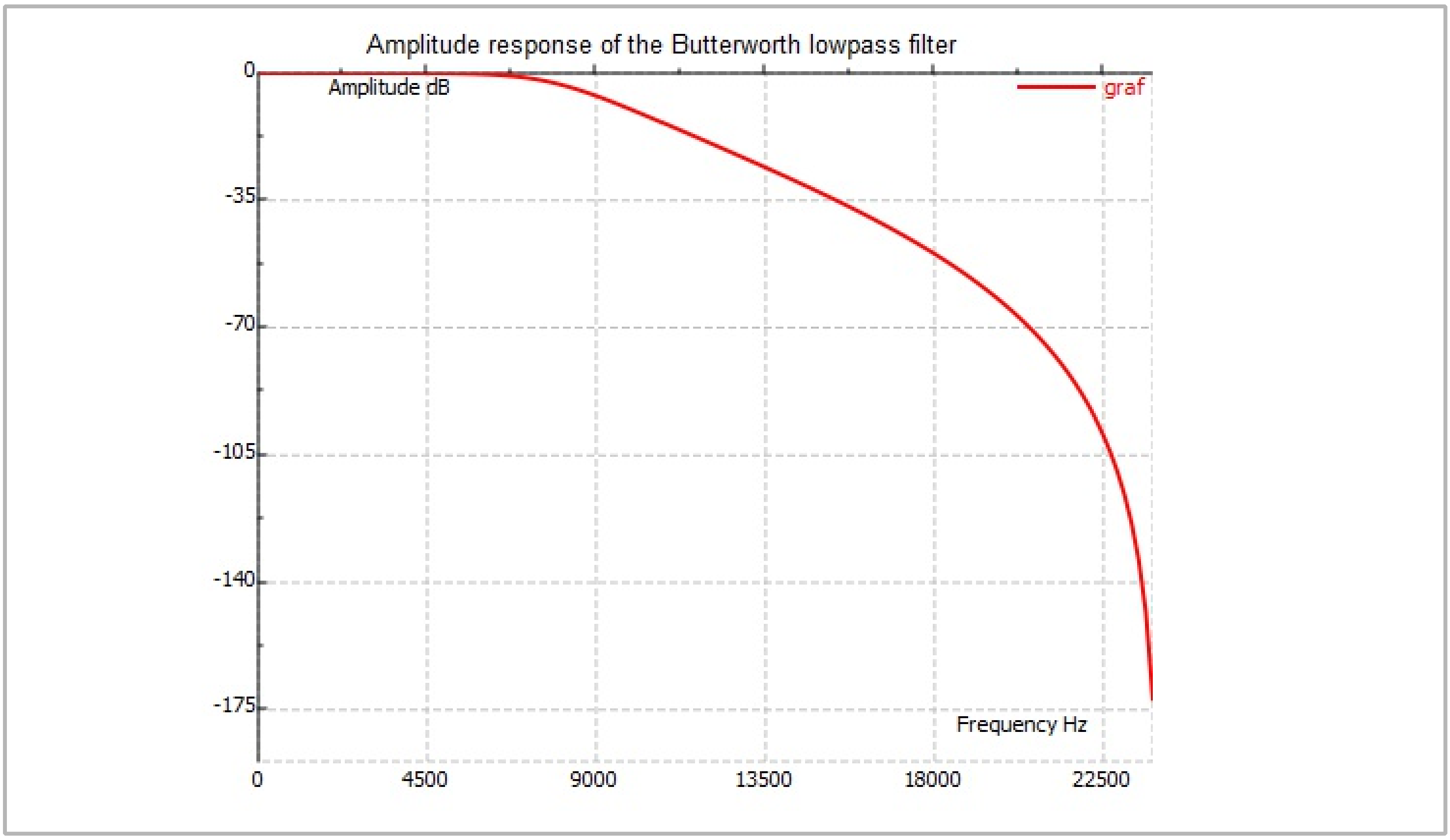
```
n:=4    Filter order
highorlow:=0    Response type, 0 - lowpass, 1 - highpass, 2 - passband, 3 - bandstop
fc:=4000    Hz, cut-off frequency
Fs:=24000    Hz, sampling rate
a:=buttlohi(n , highorlow , fc , Fs)    Filter design, for given set of parameters
DenomCoeff:=col2vec(a , 1)    Denominator coefficients
NumCoeff:=col2vec(a , 0)    Numerator coefficients
```

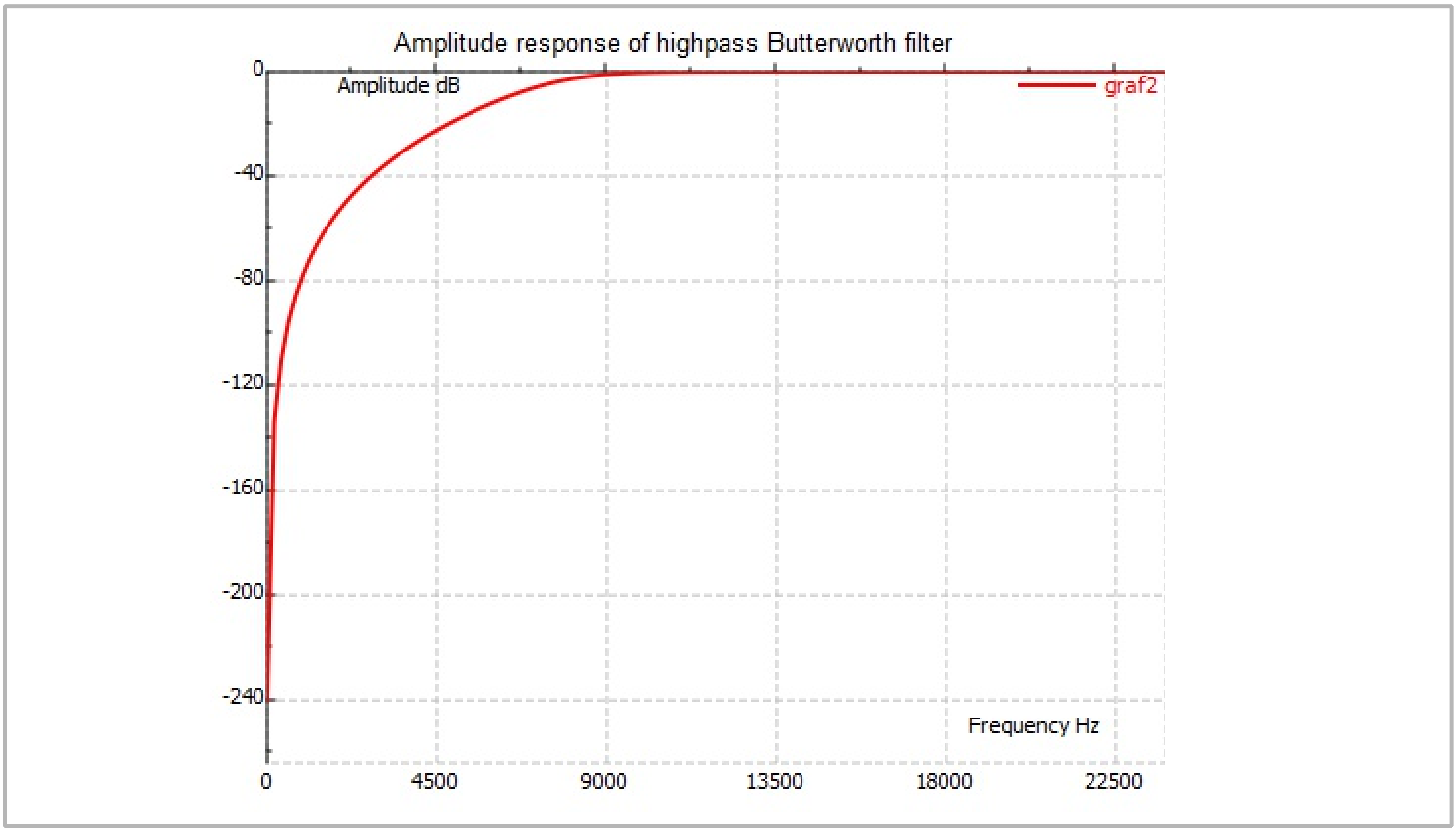
The next task is to analyze the filter, for that purpose we calculate the frequency response of the filter. Based on the frequency response, we plot the amplitude response of the obtained filter.

```
Hr:=iirfreqres(DenomCoeff , NumCoeff , 128 , 1)    Frequency response of the filter
Hm:=20 log(|Hr|)    Amplitude response in dB, i.e. in log scale
f:=ynodes(x , 0 , 1-1/128 , 128)    Frequency axis
graf:=join mat cols(f Fs , Hm)    Graph of the amplitude response
```

In the same manner with the same function we can design the high pass filter.

```
a1:=buttlohi(n , "high" , fc , Fs)    Filter design
DenomCoeff1:=col2vec(a1 , 1)
NumCoeff1:=col2vec(a1 , 0)
Hr1:=iirfreqres(DenomCoeff1 , NumCoeff1 , 128 , 1)
Hm1:=20 log(|Hr1|)
graf2:=join mat cols(f Fs , Hm1)    Graph of the amplitude response of the highpass filter
```





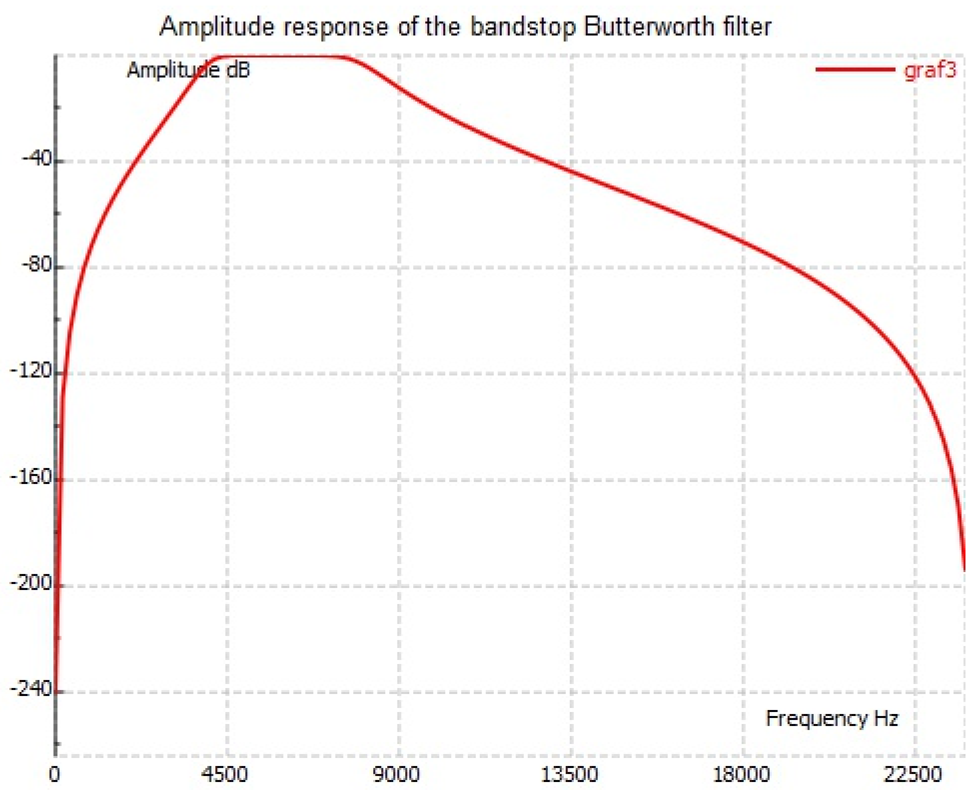
Design of bandpass and bandstop Butterworth filter

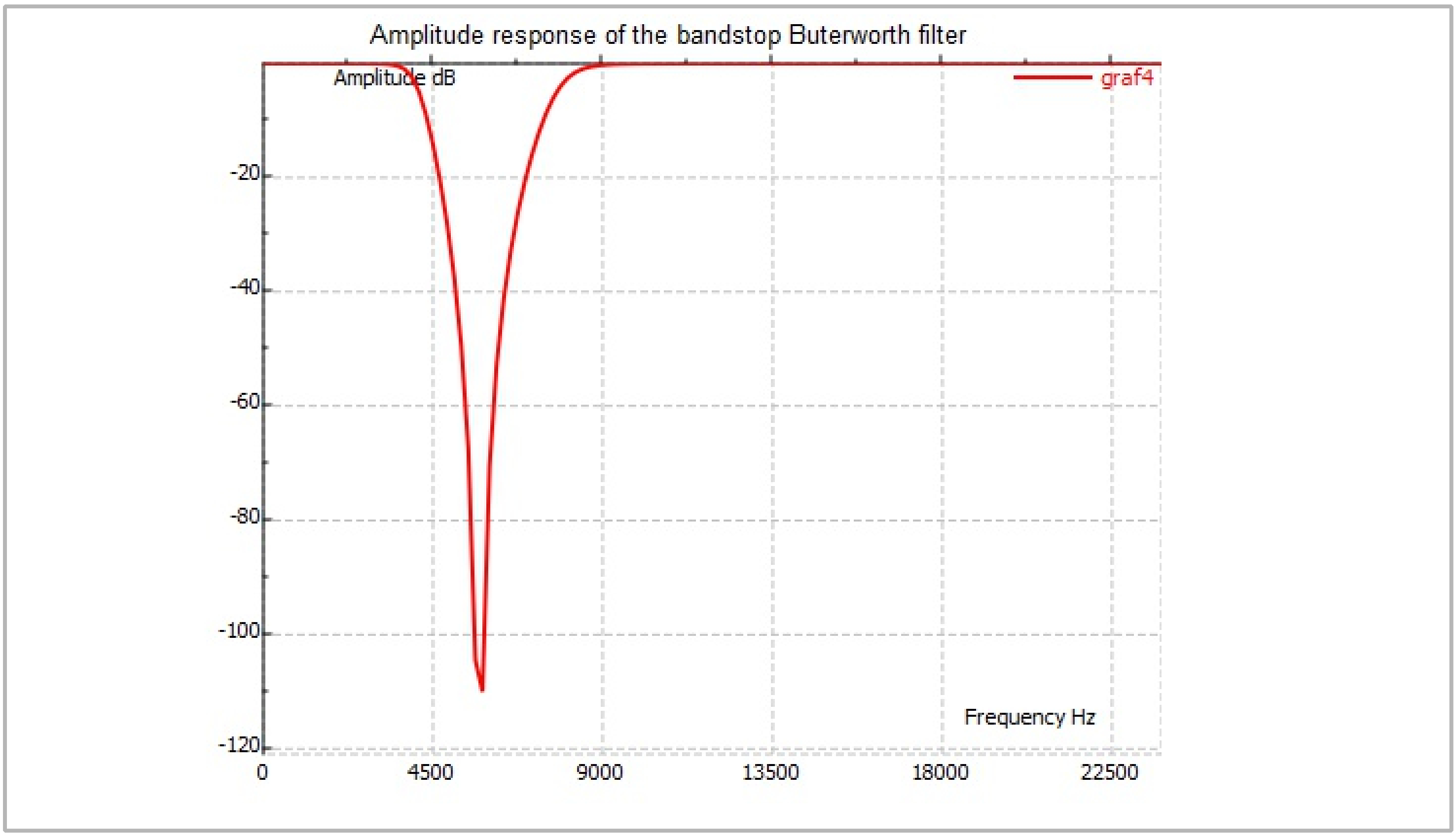
In order to construct a bandpass and bandstop Butterworth filter we have to specify the two cutoff frequencies. In this case, there are three different bands, therefore there is a cut-off frequency at band

```
n1 := 4        Filter order
fc1 := 2000    Lower cut-off frequency
fc2 := 4000    Upper cut-off frequency
aband := buttband(n , "pass" , fc1 , fc2 , Fs)    Filter design, response type is defined by string "pass"
DenomCoeff2 := col2vec(aband , 1)    Deniminator coefficients
NumCoeff2 := col2vec(aband , 0)    Numerator coeffcients
Hr2 := iirfreqres(DenomCoeff2 , NumCoeff2 , 128 , 1)
graf3 := join mat cols(f Fs , 20 log(|Hr2|))    Graph of the amplitude response of the filter
```

The highpass case is very similar to the bandpass case, just the response type is different

```
astop := buttband(n , "stop" , fc1 , fc2 , Fs)    Filter design
DenomCoeff3 := col2vec(astop , 1)
NumCoeff3 := col2vec(astop , 0)
Hr3 := iirfreqres(DenomCoeff3 , NumCoeff3 , 128 , 1)
graf4 := join mat cols(f Fs , 20 log(|Hr3|))    Graph of the amplitude response of the bandstop filter
```




Amplitude response of the bandstop Buterworth filter
Amplitude dB
graf4
-20
-40
-60
-80
-100
-120
Frequency Hz
0
4500
9000
13500
18000
22500