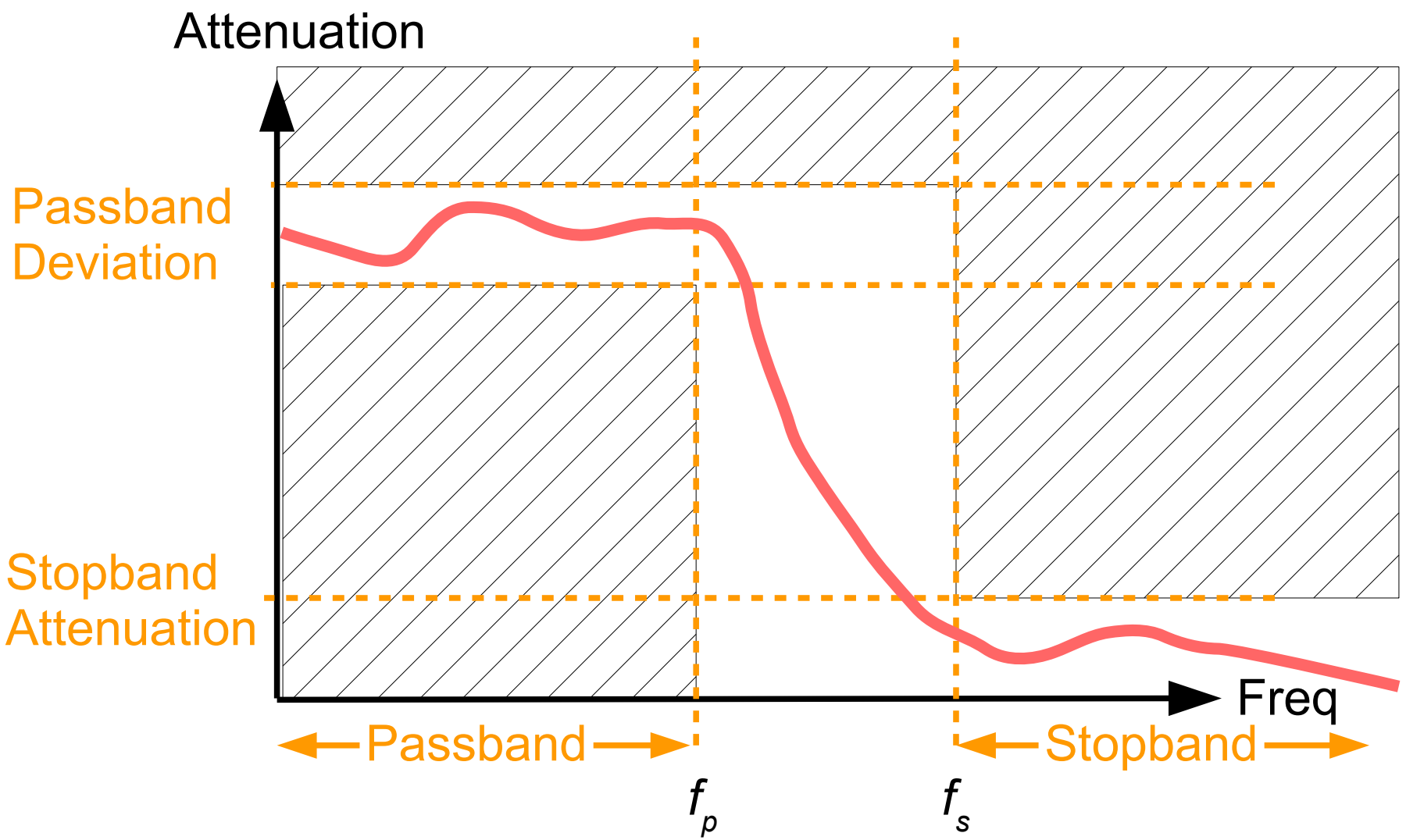
# Filter Design

**Filter Design**

**Slide 4A.2**

# Filter Requirements

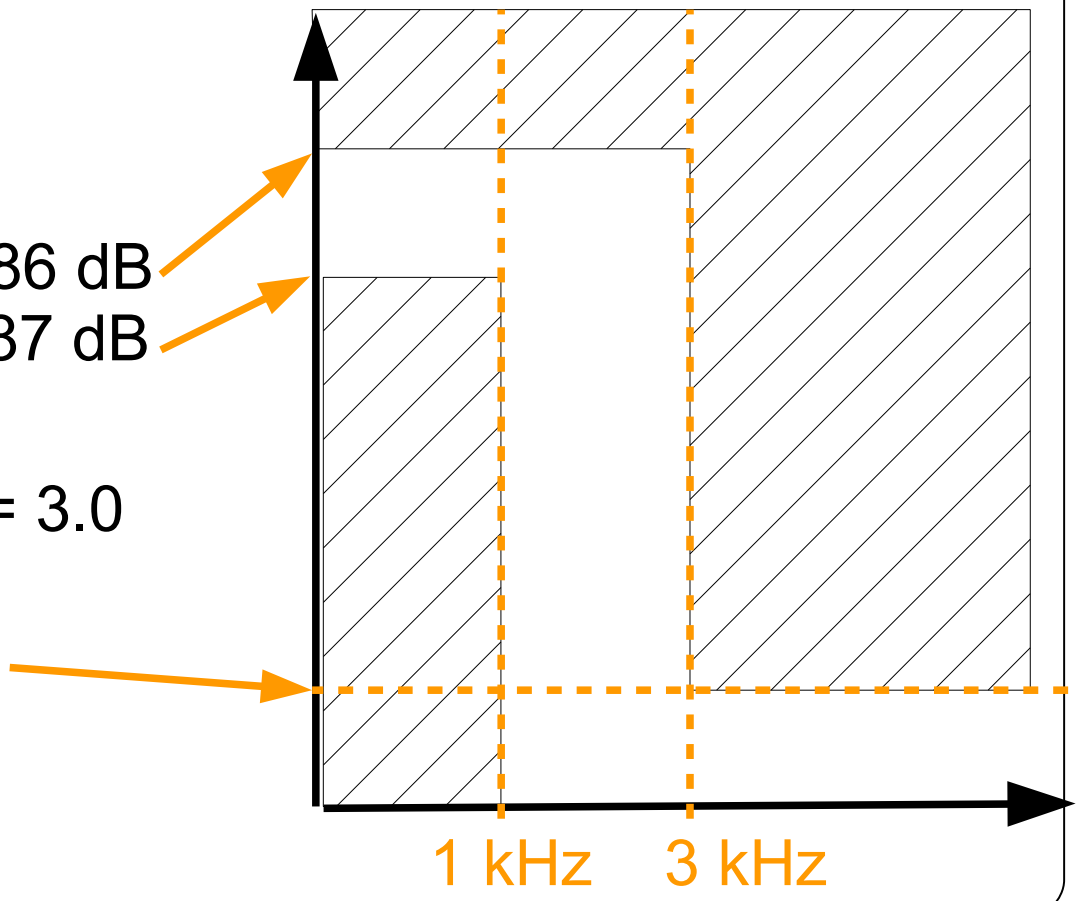


# Examples

"Keep (±1%) content below 1kHz.
Eliminate (<0.1%) content above 3kHz"

- Low-pass filter
- Passband: $f_p$ = 1kHz
- Max Passband deviation:
  20 log10 (1 + .01) = +0.086 dB
  20 log10 (1 – .01) = –0.087 dB
- Stopband: $f_s$ = 3kHz

  $F_s = f_s / f_p$ = 3kHz / 1kHz = 3.0
- Min. stopband attenuation:
  $20 \log_{10}(0.001)$ = –60 dB

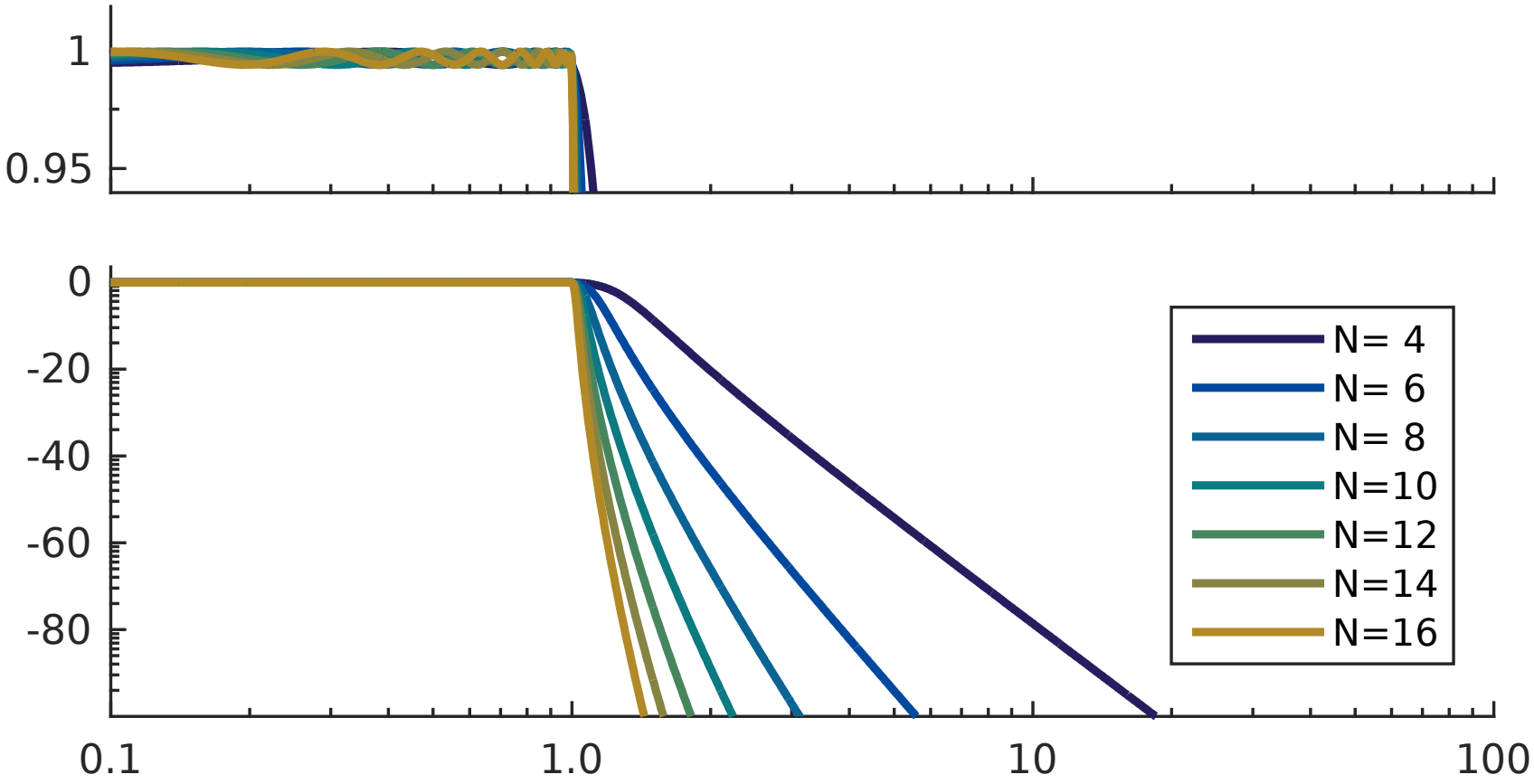


**Filter Design**

**Slide 4A.4**

# Low pass filters

Chebychev filter with 0.05 dB passband deviation



**Filter Design**

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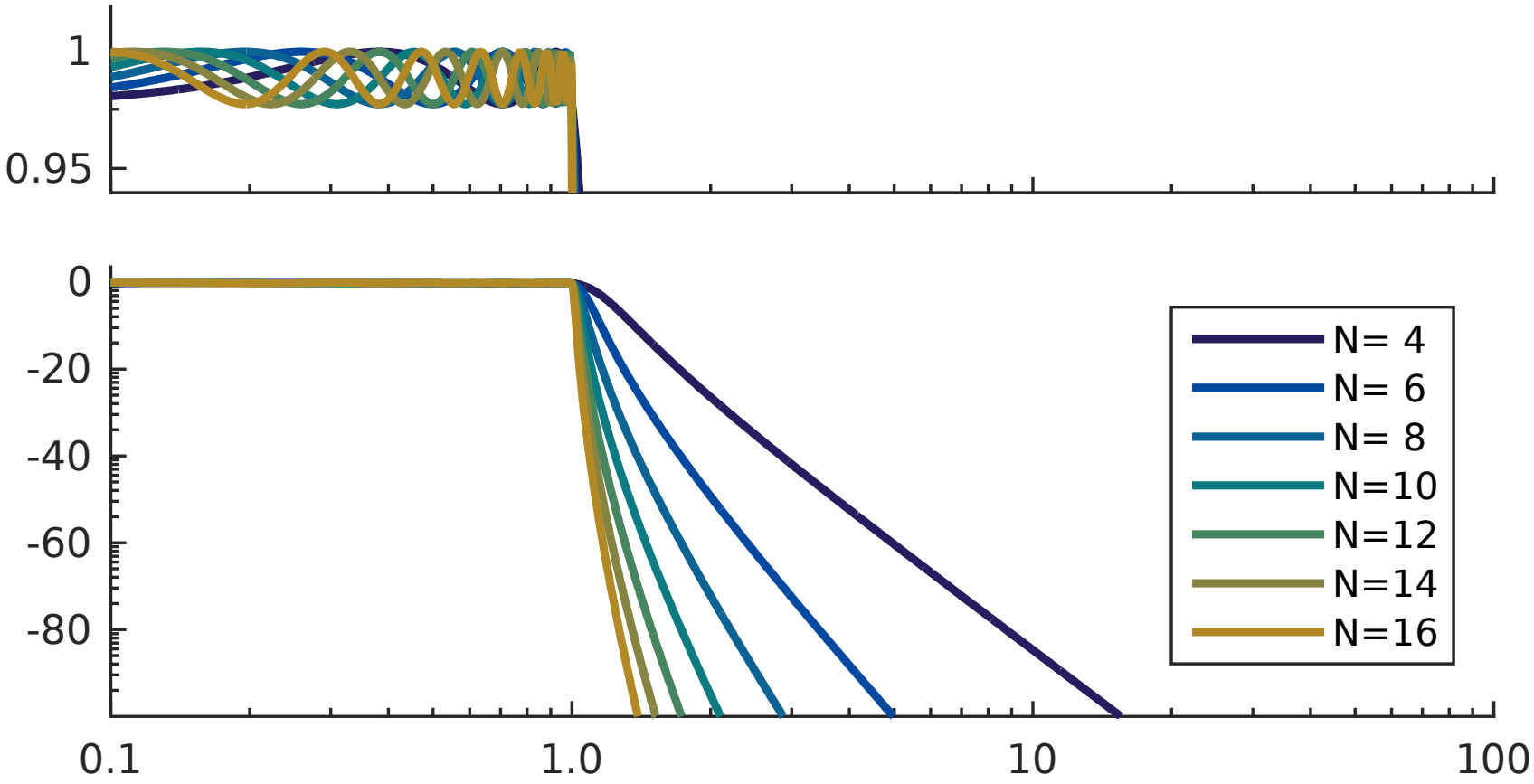
# Low pass filters

Chebychev filter with 0.20 dB passband deviation

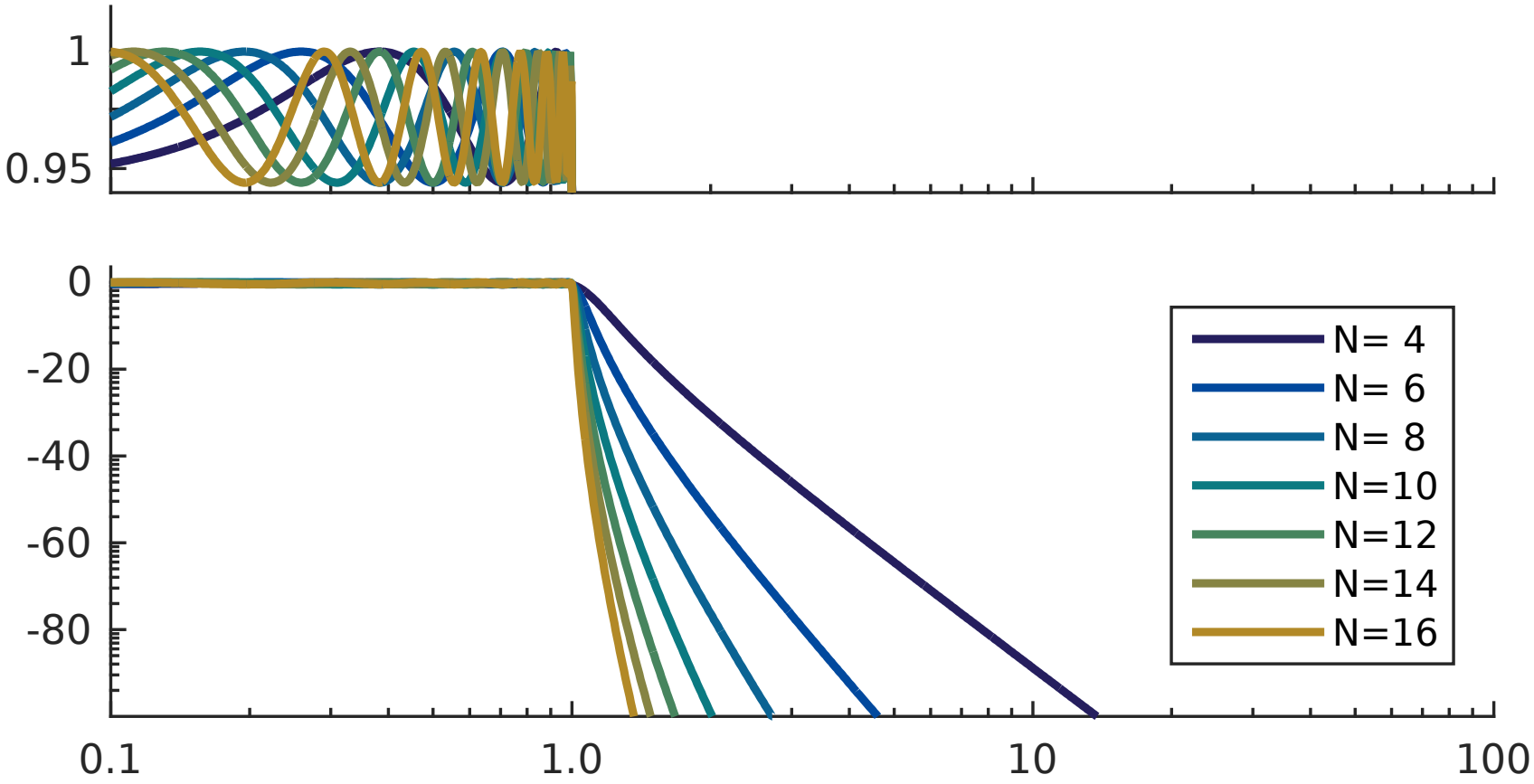


**Filter Design**

**Slide 4A.6**

# Low pass filters

Chebychev filter with 0.50 dB passband deviation

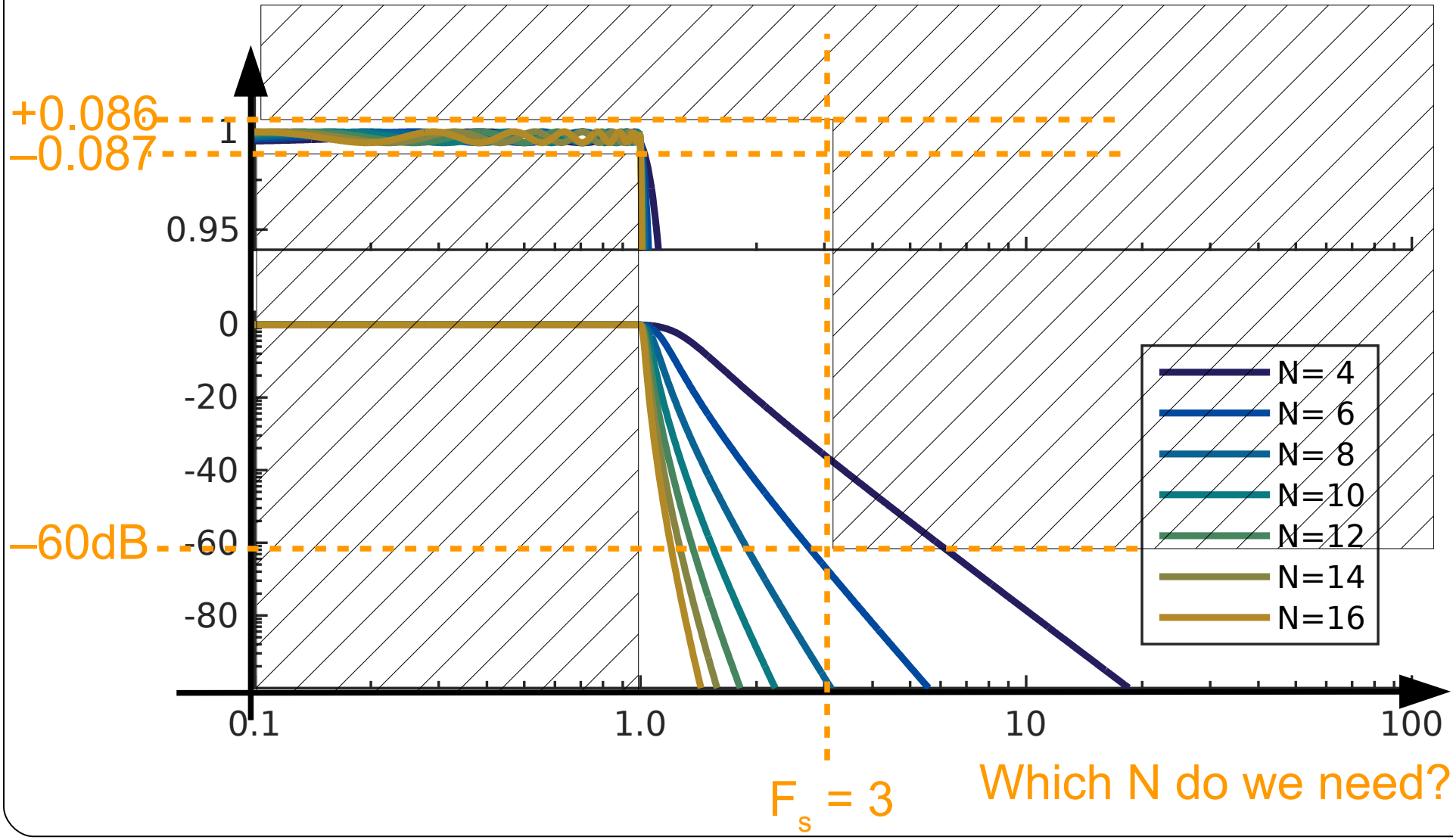


**Filter Design**

**Slide 4A.7**

# Choosing a filter

Chebychev filter with 0.05 dB passband deviation



**Filter Design**

**Slide 4A.8**

# Filter Table

| $N$ | $F_s$(40dB) | $F_s$(60dB) | $F_s$(80dB) | $f_n$ | $\zeta$ | $f_n$ | $\zeta$ | $f_n$ | $\zeta$ | $f_n$ | $\zeta$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FILTER = Chebychev 0.05dB | | | | | | | | | | | |
| 2 | 21.58 | 68.23 | 215.77 | 2.162 | 0.668 | | | | | | |
| 4 | 3.37 | 5.89 | 10.42 | 0.885 | 0.833 | 1.221 | 0.250 | | | | |
| 6 | 1.90 | 2.67 | 3.85 | 0.569 | 0.860 | 0.870 | 0.412 | 1.091 | 0.120 | | |
| 8 | 1.48 | 1.86 | 2.39 | 0.422 | 0.870 | 0.670 | 0.464 | 0.912 | 0.228 | 1.050 | 0.069 |
| FILTER = Chebychev 0.10dB | | | | | | | | | | | |
| 2 | 18.11 | 57.28 | 181.13 | 1.820 | 0.652 | | | | | | |
| 4 | 3.10 | 5.41 | 9.55 | 0.789 | 0.808 | 1.153 | 0.229 | | | | |
| 6 | 1.81 | 2.54 | 3.64 | 0.513 | 0.834 | 0.834 | 0.375 | 1.063 | 0.108 | | |
| 8 | 1.43 | 1.79 | 2.30 | 0.382 | 0.843 | 0.645 | 0.423 | 0.894 | 0.204 | 1.034 | 0.062 |
| FILTER = Chebychev 0.20dB | | | | | | | | | | | |
| 2 | 15.21 | 48.08 | 152.05 | 1.535 | 0.628 | | | | | | |
| 4 | 2.85 | 4.95 | 8.75 | 0.701 | 0.774 | 1.095 | 0.205 | | | | |
| 6 | 1.72 | 2.40 | 3.44 | 0.460 | 0.799 | 0.803 | 0.335 | 1.038 | 0.095 | | |
| 8 | 1.39 | 1.73 | 2.21 | 0.343 | 0.807 | 0.623 | 0.377 | 0.878 | 0.179 | 1.021 | 0.054 |
| FILTER = Chebychev 0.50dB | | | | | | | | | | | |
| 2 | 11.99 | 37.84 | 119.67 | 1.231 | 0.579 | | | | | | |
| 4 | 2.55 | 4.42 | 7.78 | 0.597 | 0.709 | 1.031 | 0.170 | | | | |
| 6 | 1.61 | 2.23 | 3.19 | 0.396 | 0.731 | 0.768 | 0.276 | 1.011 | 0.077 | | |
| 8 | 1.33 | 1.64 | 2.09 | 0.297 | 0.739 | 0.599 | 0.310 | 0.861 | 0.144 | 1.006 | 0.043 |
| FILTER = Chebychev 1.00dB | | | | | | | | | | | |
| 2 | 9.95 | 31.41 | 99.31 | 1.050 | 0.523 | | | | | | |
| 4 | 2.34 | 4.03 | 7.08 | 0.529 | 0.637 | 0.993 | 0.140 | | | | |
| 6 | 1.54 | 2.11 | 3.01 | 0.353 | 0.657 | 0.747 | 0.227 | 0.995 | 0.062 | | |
| 8 | 1.29 | 1.58 | 2.01 | 0.265 | 0.664 | 0.584 | 0.256 | 0.851 | 0.117 | 0.997 | 0.035 |
| FILTER = Chebychev 2.00dB | | | | | | | | | | | |
| 2 | 8.13 | 25.59 | 80.91 | 0.907 | 0.443 | | | | | | |
| 4 | 2.14 | 3.65 | 6.41 | 0.471 | 0.538 | 0.964 | 0.109 | | | | |
| 6 | 1.46 | 1.99 | 2.82 | 0.316 | 0.555 | 0.730 | 0.176 | 0.983 | 0.048 | | |
| 8 | 1.25 | 1.52 | 1.93 | 0.238 | 0.560 | 0.572 | 0.197 | 0.842 | 0.090 | 0.990 | 0.027 |

**Filter Design**

**Slide 4A.9**

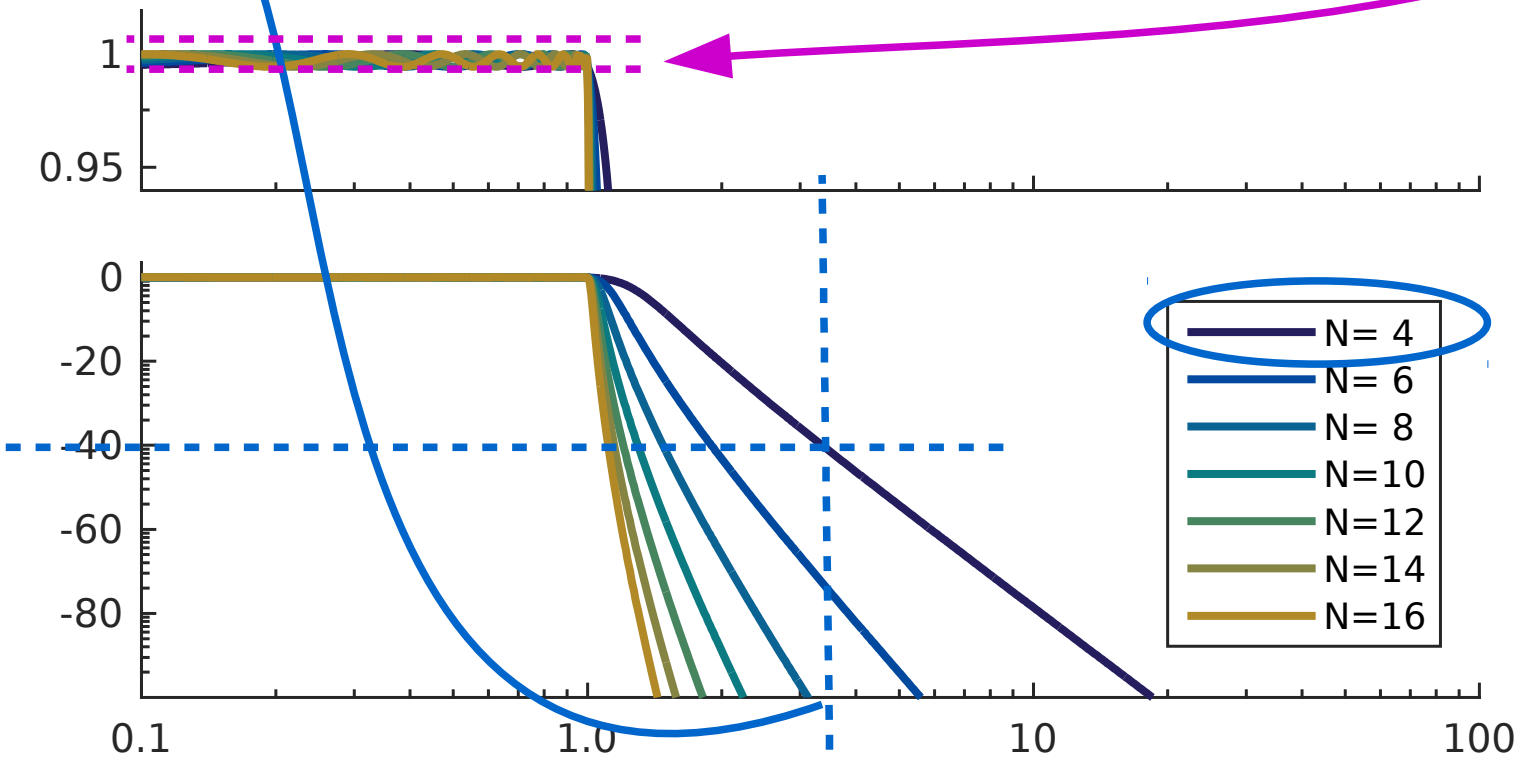
# Filter Table: Cheby 0.05dB

## ←Performance→

| $N$ | $F_s$(40dB) | $F_s$(60dB) | $F_s$(80dB) |
|---|---|---|---|
| 2 | 21.58 | 68.23 | 215.77 |
| 4 | 3.37 | 5.89 | 10.42 |
| 6 | 1.90 | 2.67 | 3.85 |
| 8 | 1.48 | 1.86 | 2.39 |

## ←How to implement→

| $f_n$ | $\zeta$ | $f_n$ | $\zeta$ | $f_n$ | $\zeta$ | $f_n$ | $\zeta$ |
|---|---|---|---|---|---|---|---|
| 2.162 | 0.668 | | | | | | |
| 0.885 | 0.833 | 1.221 | 0.250 | | | | |
| 0.569 | 0.860 | 0.870 | 0.412 | 1.091 | 0.120 | | |
| 0.422 | 0.870 | 0.670 | 0.464 | 0.912 | 0.228 | 1.050 | 0.069 |



# Examples

"Eliminate 60 Hz and lower interference by 80 dB; keep 240 Hz and above (± 5%)"

- High-pass filter
- Passband: $f_p$ = 240 Hz
- Max Passband deviation:
  20 log10 (1 + .05) = +0.424 dB
  20 log10 (1 – .05) = –0.446 dB
- Stopband: $f_s$ = 3kHz
  $F_s = f_p / f_s$ = 240 Hz / 60 Hz = 4.0
- Min. stopband attenuation:
  –80 dB