Elektroakustika

L11A: Reproduktorová sústava s predradeným tvarovacím filtrom

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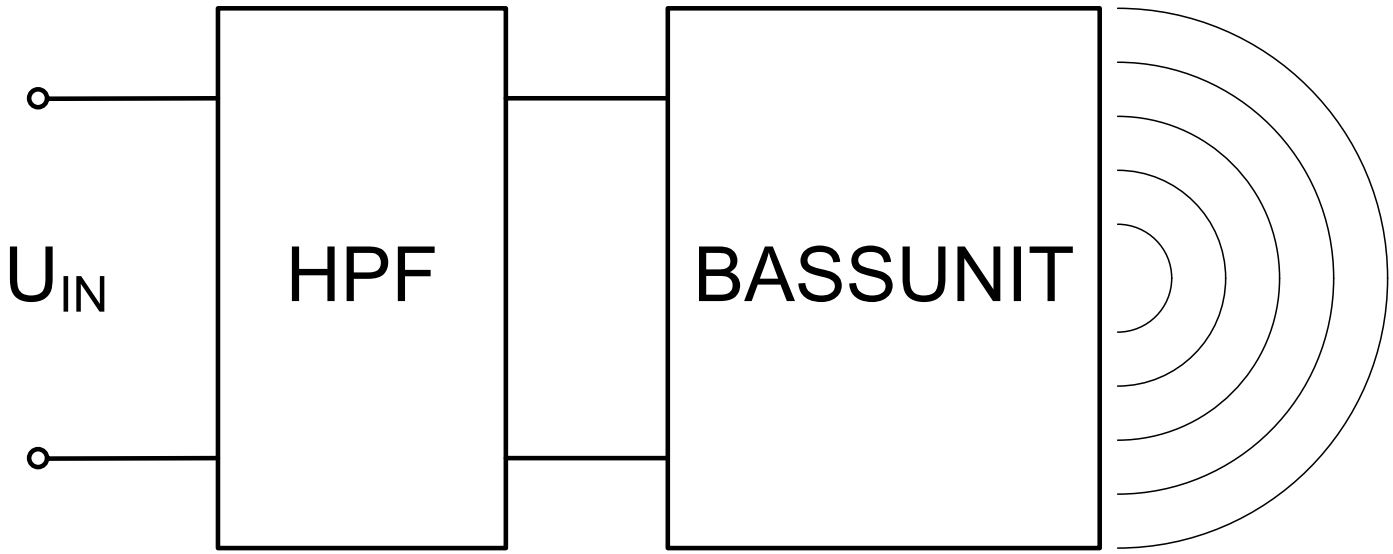
http://voice.kemt.fei.tuke.sk


U_{IN}
HPF
BASSUNIT

Prenosová funkcia predradeného filtra

$$H_{HPF}(s) = \frac{s_e^{\,2}}{s_e^{\,2} + a_1 s_e + 1} = \frac{s_e^{\,2}}{s_e^{\,2} + s_e / Q_e + 1}$$

$$s_e = \frac{s}{\omega_e}$$

$$a_1 = \frac{1}{Q_e}$$

Prenosová funkcia reproduktora v zatvorenej ozvučnici

$$G_{CB}(s) = \frac{s_C{}^2}{s_C{}^2 + a_1 s_C + 1} = \frac{s_C{}^2}{s_C{}^2 + s_C / Q_{TC} + 1}$$

$$s_C = \frac{s}{\omega_C}$$

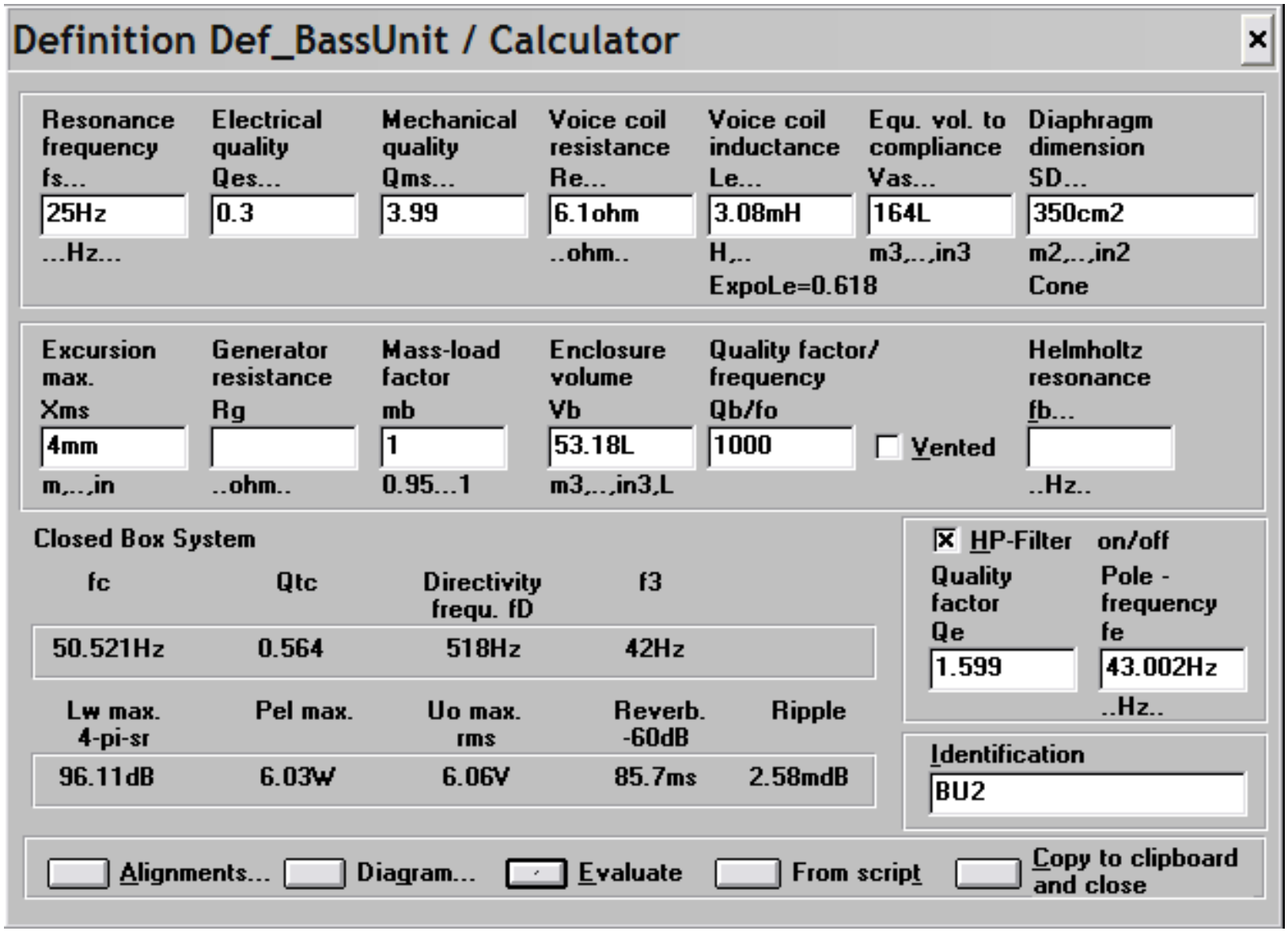
$$a_1 = \frac{1}{Q_{TC}}$$

Prenosová funkcia reproduktora v zatvorenej ozvučnici s predradeným filtrom

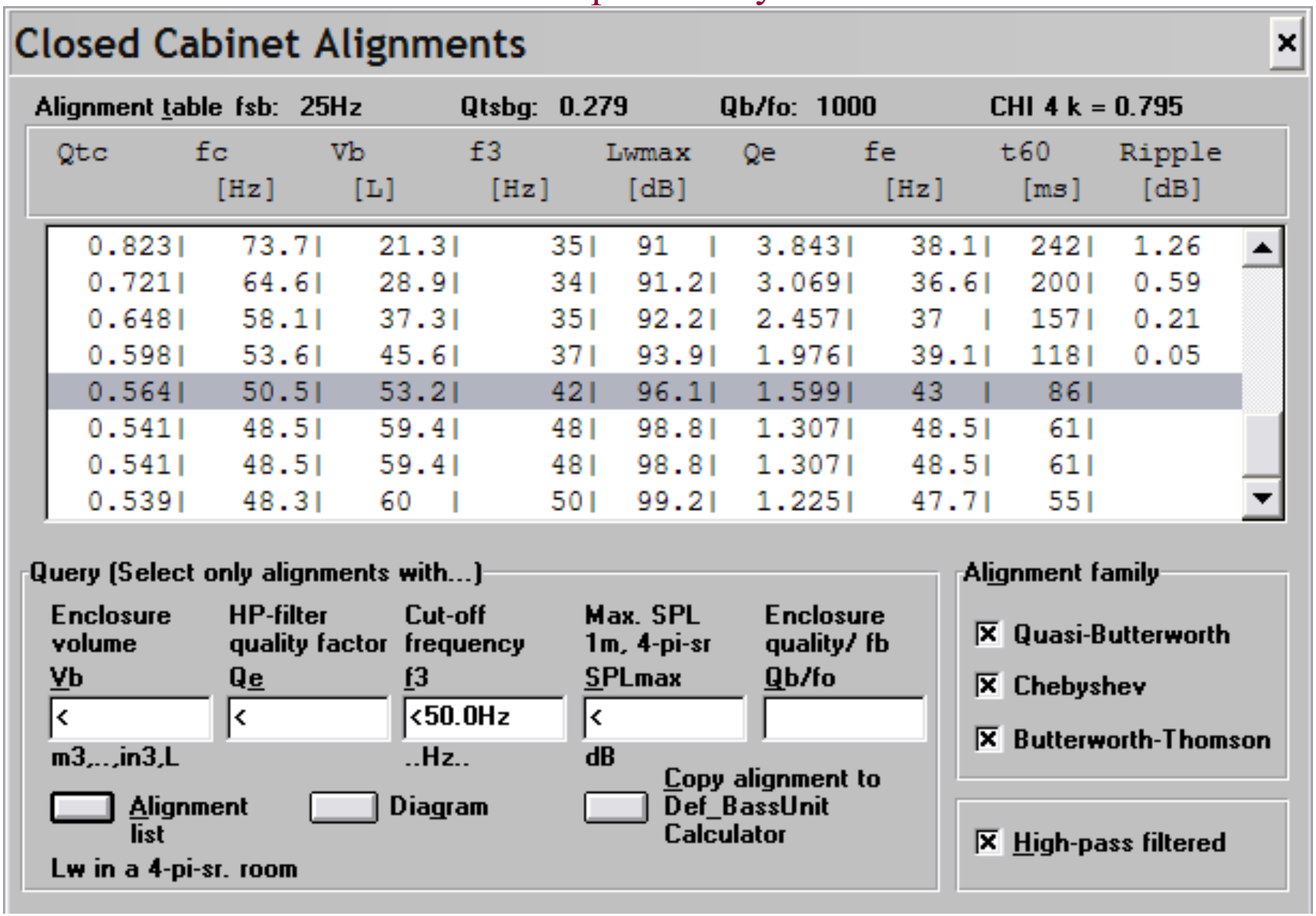
$$H_{CB}(s) = H_{HPF}(s) \cdot G_{CB}(s) = \frac{s_e^{\,2}}{s_e^{\,2} + s_e/Q_e + 1} \frac{s_C^{\,2}}{s_C^{\,2} + s_C/Q_{TC} + 1}$$

$$s_e = \frac{s}{\omega_e} \qquad s_C = \frac{s}{\omega_C}$$

BassUnit - Dialog



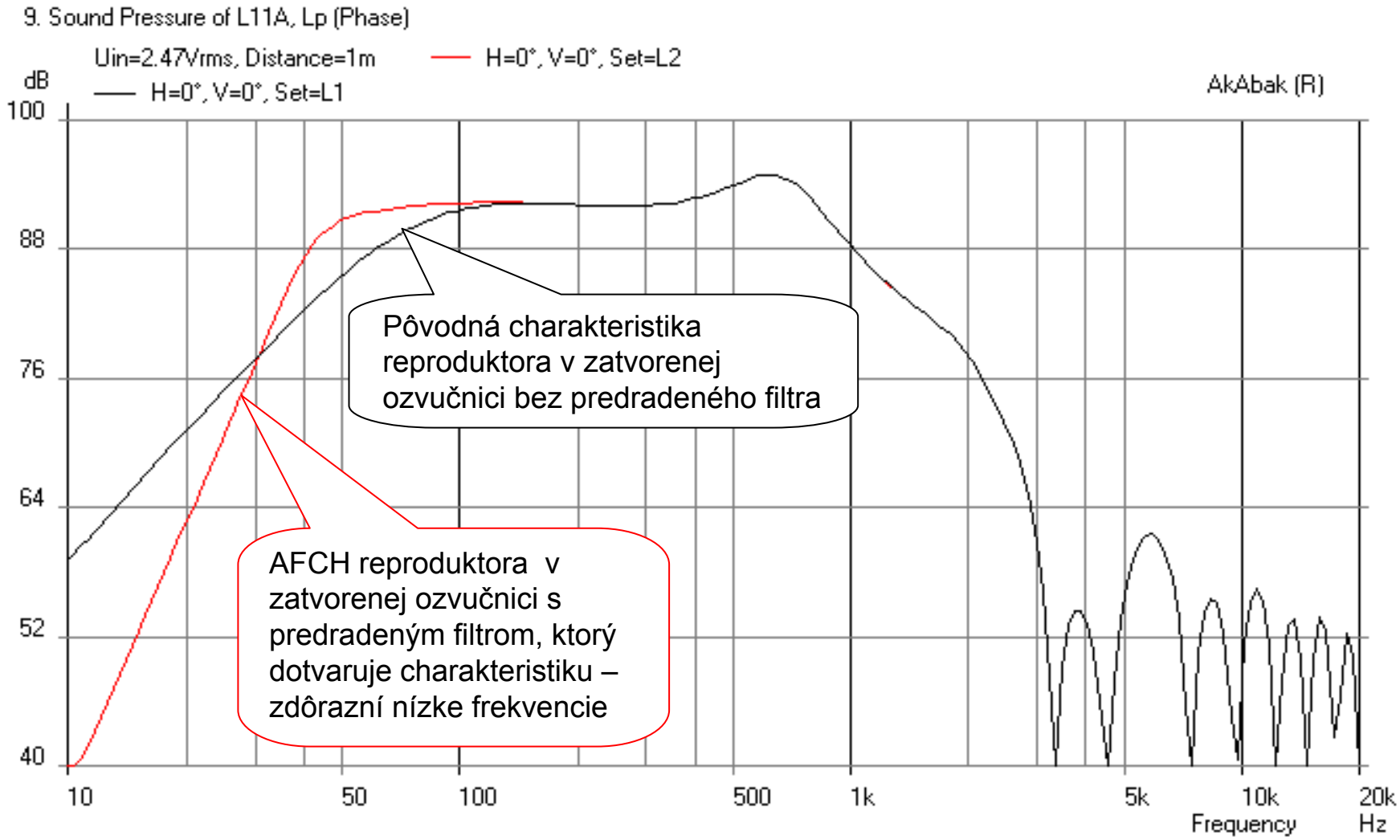
BassUnit – Dialog/Alignments: Výber realizácie reproduktora v zatvorenej ozvučnici s predradeným filtrom



Skript

```
| Seas Prestige CA26RE4X H1316
| Revc=6.1Ohms; Levc=3.08mH; Bl=11.6N/A; Mmd=38.5g; Mmrd=3.8g;
|Rms=1.66Ns/m; Cms=1.1mm/N; Sd=350cm2
| Fs=25Hz; Qts=0.28; Qms=3.99; Qes=0.30; Vas=164lit.,
|ymax=4mm; sens=91dB; Pe(lt)=80W

Def_BassUnit  'BU2'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=53.18L
  Qe=1.599  fe=43.0Hz
  |Performance in sealed enclosure:
  | fc    Qtc      fD       f3
  | 50.5Hz       0.564   517.6Hz         41.8Hz
  | Lwmax       Pelmax          UoRms          t60       Ripple
  | 96.1dB       6.0W   6.06V  85.7ms2.6mdB

System 'L2'
  BassUnit    'B2'  Def='BU2'  Node=1=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```

AFCH charakteristiky - porovnanie



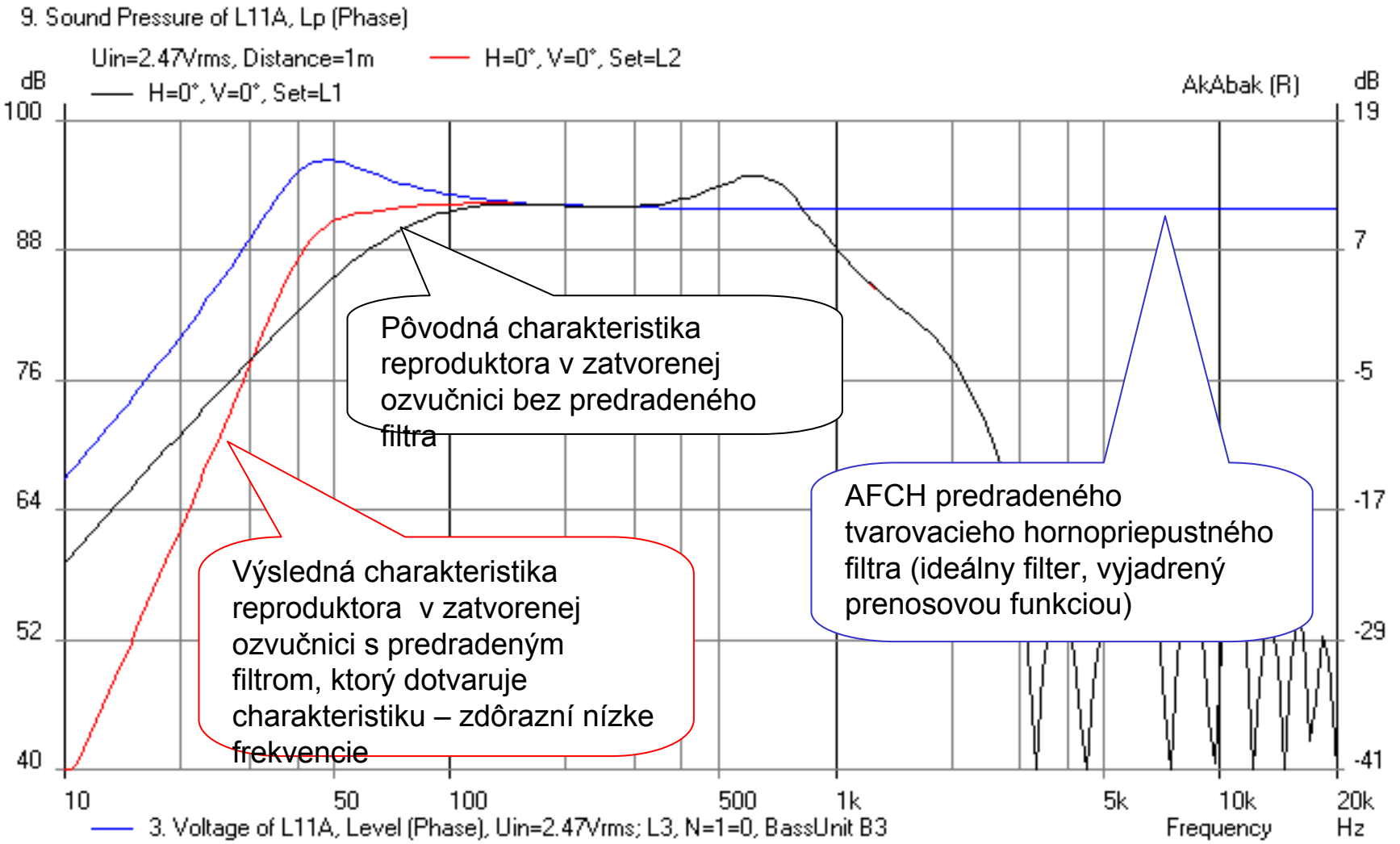
Skript: BassUnit+Filter

```
| Seas Prestige CA26RE4X H1316
| Revc=6.1Ohms; Levc=3.08mH; Bl=11.6N/A; Mmd=38.5g;
|Mmrd=3.8g; Rms=1.66Ns/m; Cms=1.1mm/N; Sd=350cm2
| Fs=25Hz; Qts=0.28; Qms=3.99; Qes=0.30; Vas=164lit.,
| ymax=4mm; sens=91dB; Pe(lt)=80W

Def_BassUnit  'BU2'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=53.18L
  |Qe=1.599  fe=43.0Hz
  |Performance in sealed enclosure:
  |  fc    Qtc      fD       f3
  |  50.5Hz      0.564   517.6Hz        41.8Hz
  |  Lwmax       Pelmax          UoRms          t60      Ripple
  |  96.1dB      6.0W   6.06V  85.7ms2.6mdB

System 'L3'
  Filter    'HPF1'
    fo=43Hz  vo=1
    {b2=1;
     a2=1;  a1=0.625;  a0=1;  }
  BassUnit    'B3'  Def='BU2'  Node=1=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```

$$f0 = fe = 43\,\mathrm{Hz}$$

$$a1 = \frac{1}{Qe} = \frac{1}{1.599} = 0.625$$

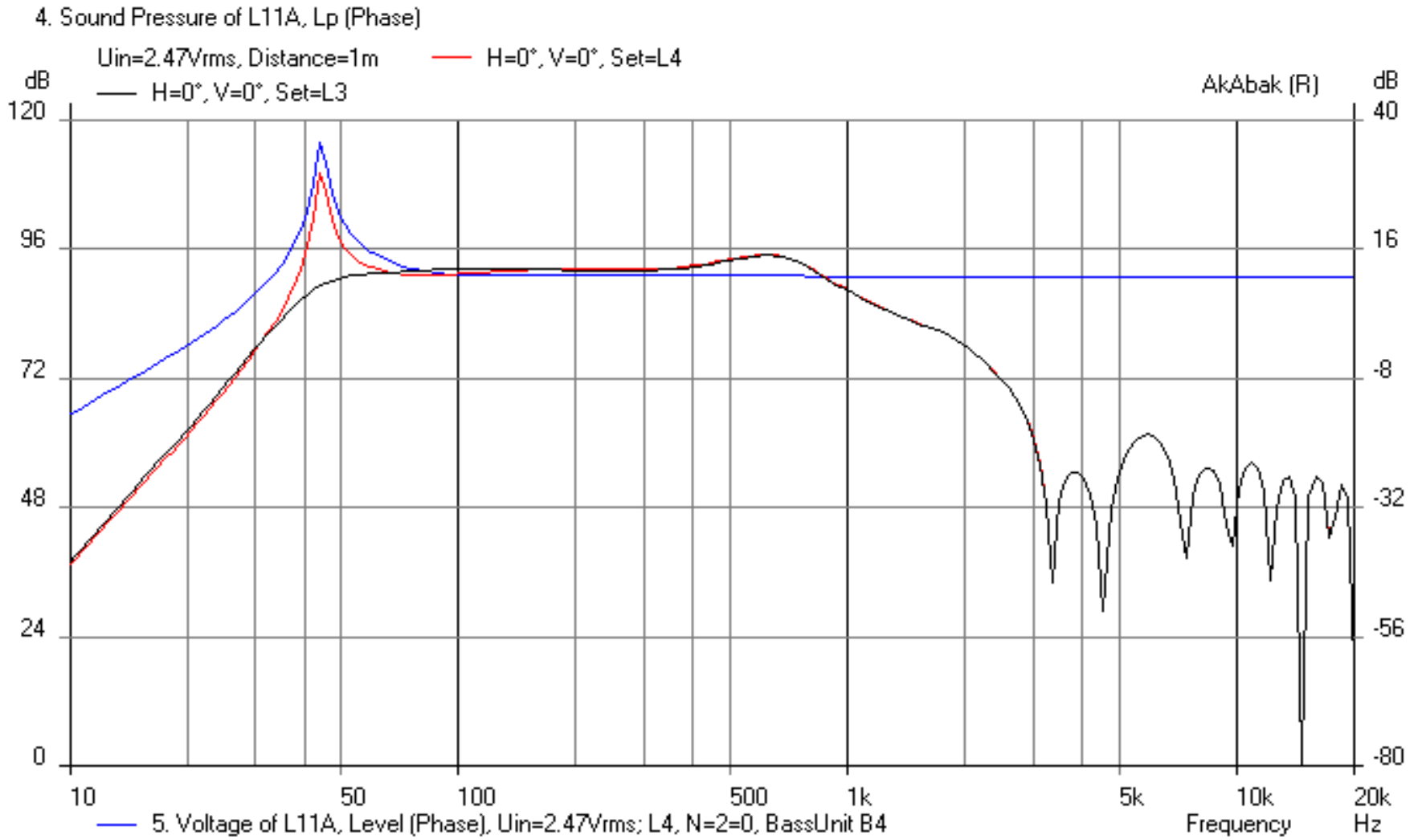
Sústava so zatvorenou ozvučnicou a tvarovacím filtrom (samostatný filter v hlavnej časti skriptu vo forme prenosovej funkcie)



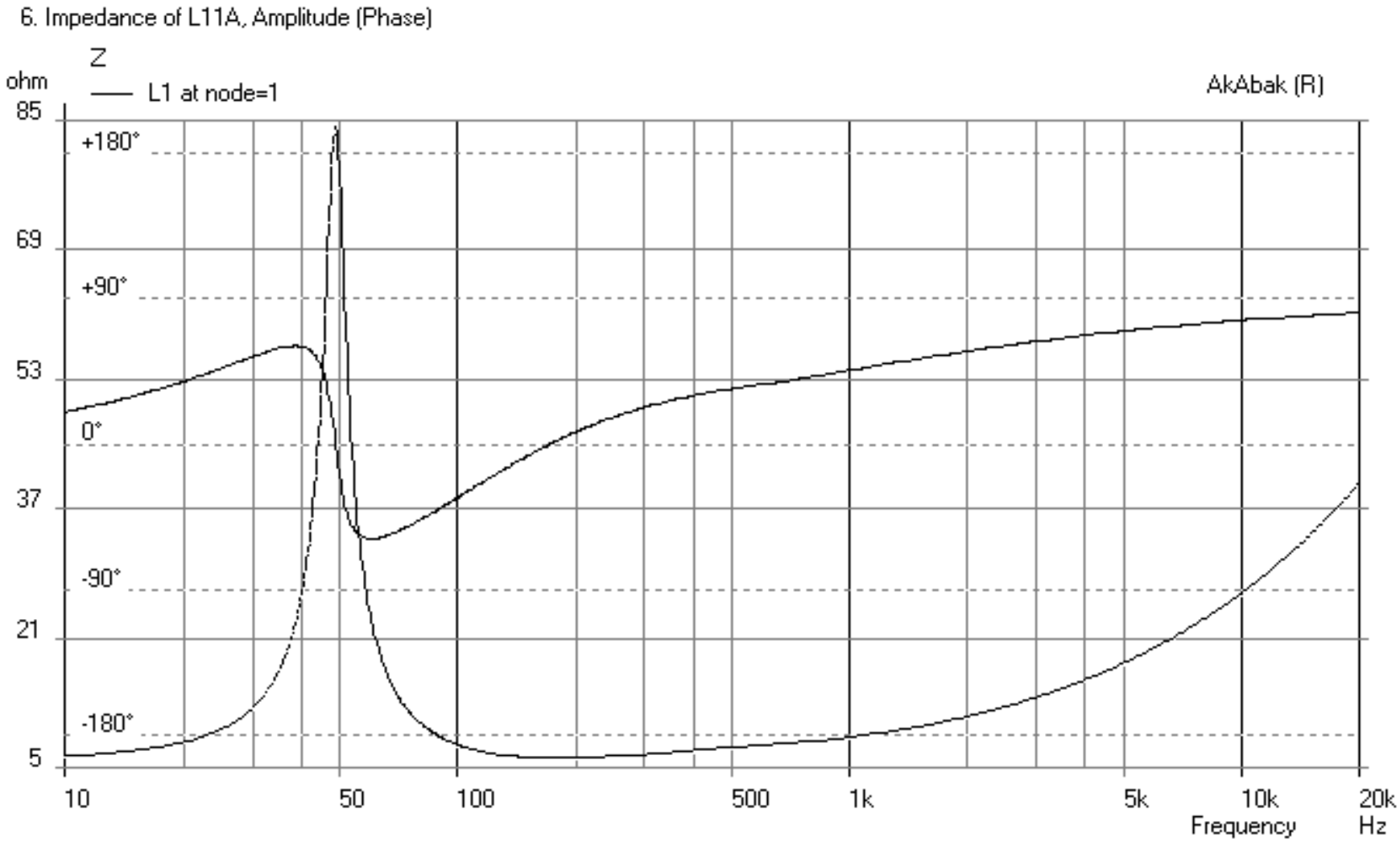
Skript: BassUnit+LCR Filter

```
Def_BassUnit  'BU2'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=53.18L
  |Qe=1.599  fe=43.0Hz
  |Performance in sealed enclosure:
  |  fc    Qtc      fD       f3
  |  50.5Hz      0.564   517.6Hz        41.8Hz
  |  Lwmax       Pelmax          UoRms          t60      Ripple
  |  96.1dB      6.0W   6.06V  85.7ms2.6mdB

System 'L4'
  Capacitor  Node=1=2  C=0.971mF
  Coil       Node=2=0  L=14.111mH
  SynthesisInfo
    Passive  FirstNode=1  RL=6.1ohm  QL=0
    fo=43Hz  vo=1
    {b2=1;
     a2=1;  a1=0.625;  a0=1;  }

  BassUnit    'B4'  Def='BU2'  Node=2=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```

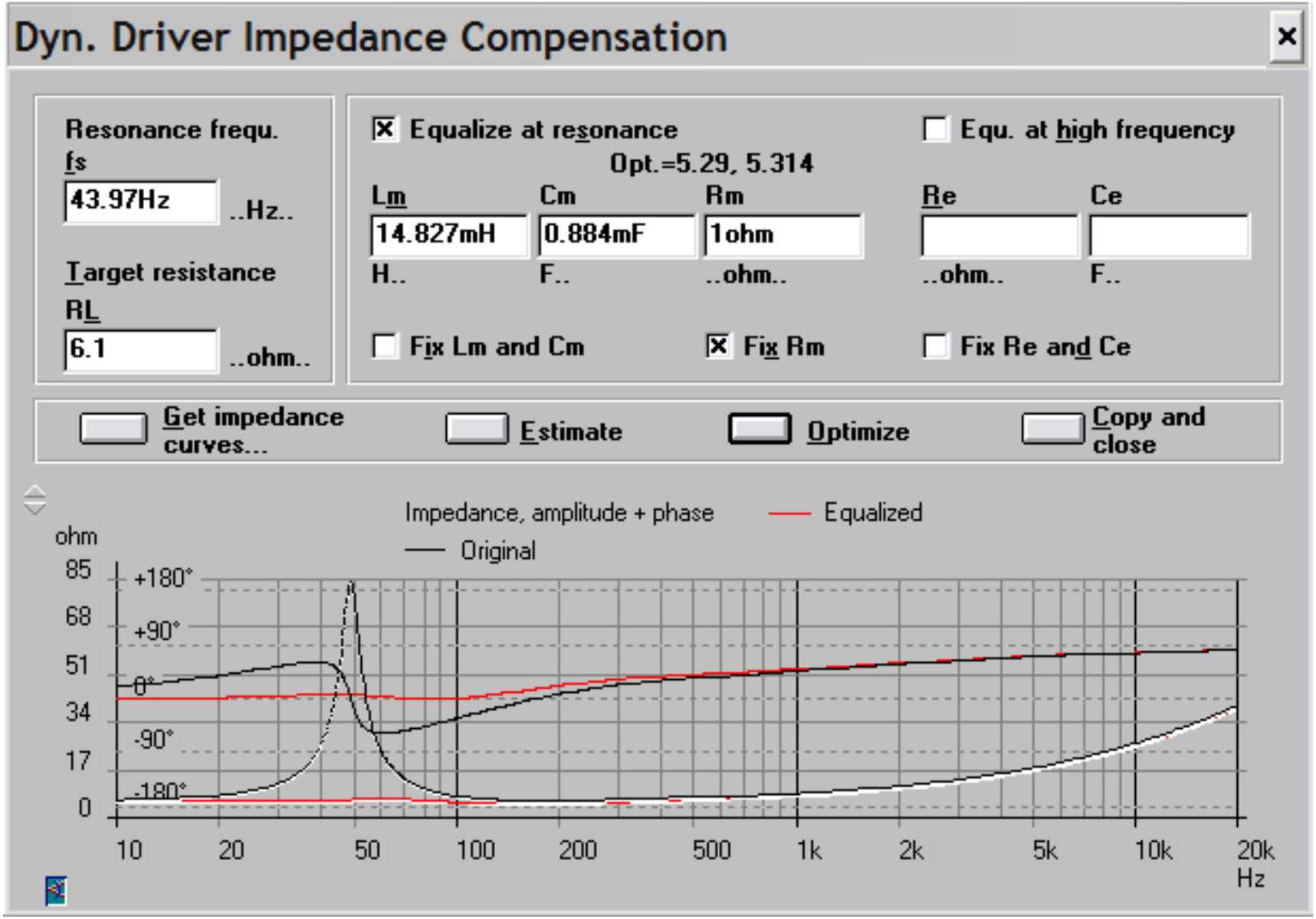
Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (samostatný filter v hlavnej časti skriptu vo forme obvodovej realizácie)



Impedancia reproduktora v zatvorenej ozvučnici



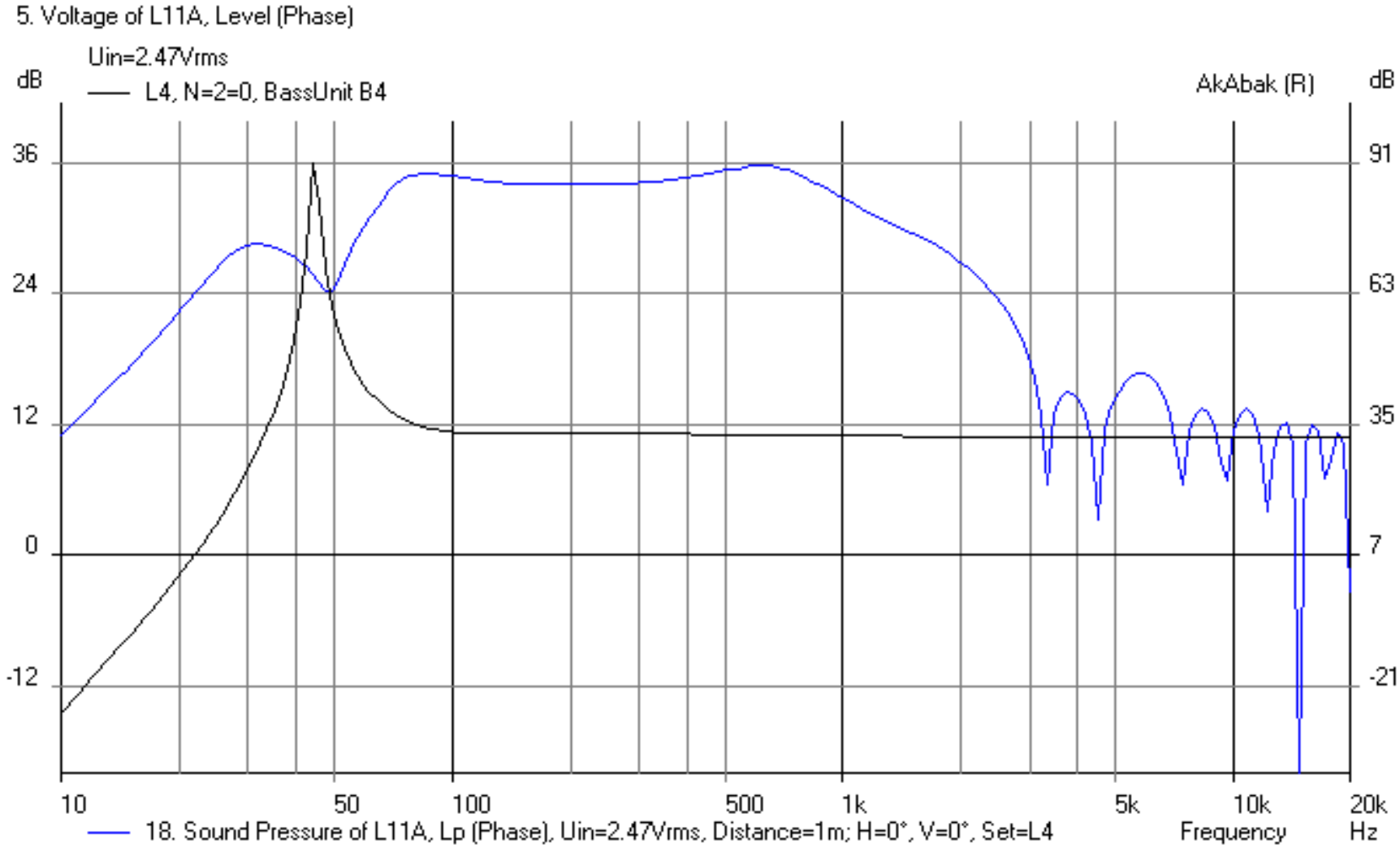
Tools/Impedance Compensation



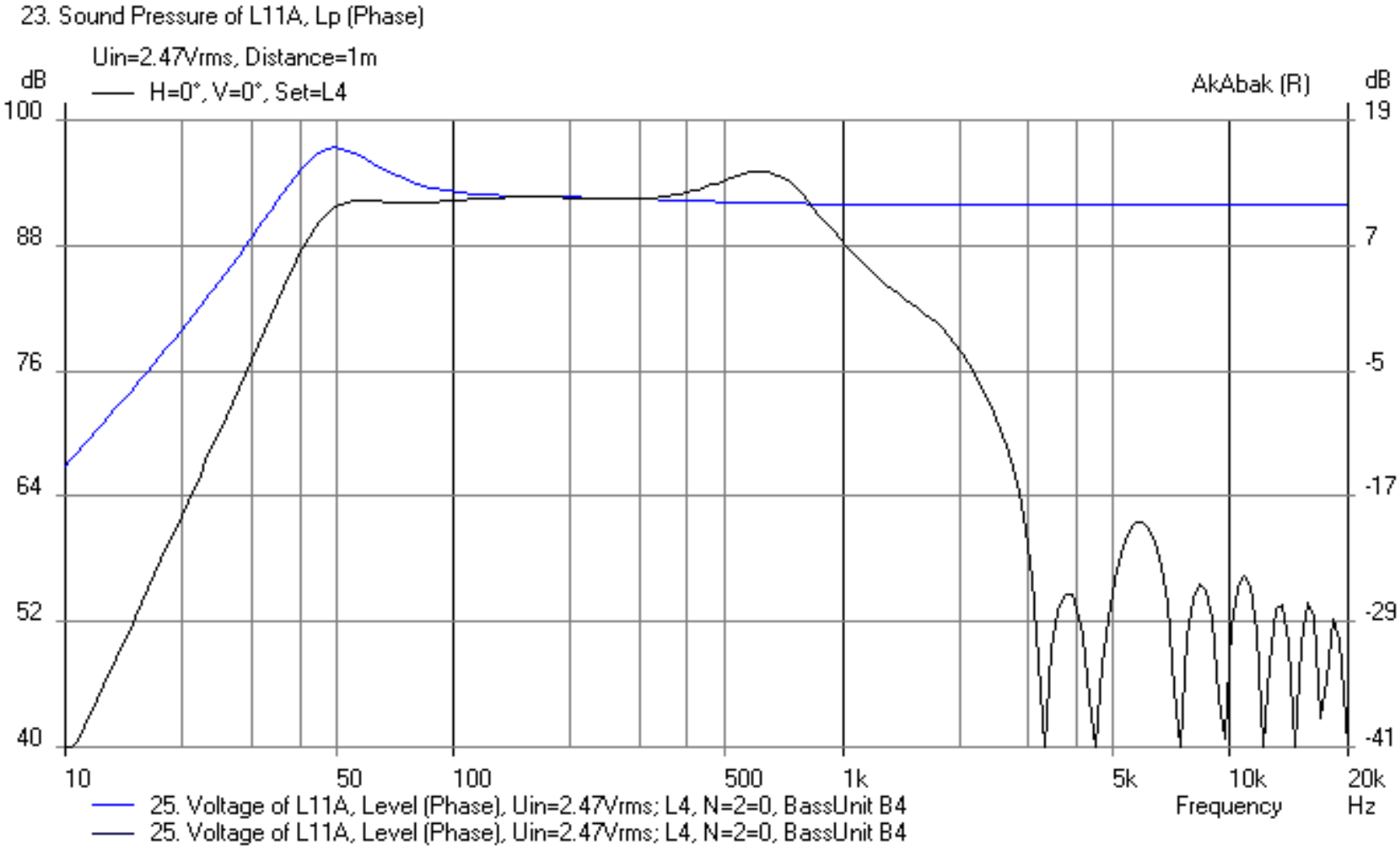
Skript: Impedance compensation

```
Def_BassUnit  'BU2'
 SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
 fs=25Hz  Vas=164L  Qms=3.99
 Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
 Xms=4mm
 Vb=53.18L
 |Qe=1.599  fe=43.0Hz
 |Performance in sealed enclosure:
 |  fc    Qtc      fD       f3
 |  50.5Hz      0.564   517.6Hz        41.8Hz
 |  Lwmax       Pelmax          UoRms          t60      Ripple
 |  96.1dB      6.0W   6.06V  85.7ms2.6mdB

System 'L4'
 Capacitor  Node=1=2  C=0.971mF
 Coil       Node=2=0  L=14.111mH
 SynthesisInfo
  Passive  FirstNode=1  RL=6.1ohm  QL=0
  fo=43Hz  vo=1
  {b2=1;
   a2=1;  a1=0.625;  a0=1;  }

  |Impedance compensation
 Capacitor  Node=2=0  C=0.884mF  Rs=7.1ohm  Ls=14.82mH

BassUnit   'B4'  Def='BU2'  Node=2=0
  x=0  y=0  z=0  HAngle=0  VAngle=0
```

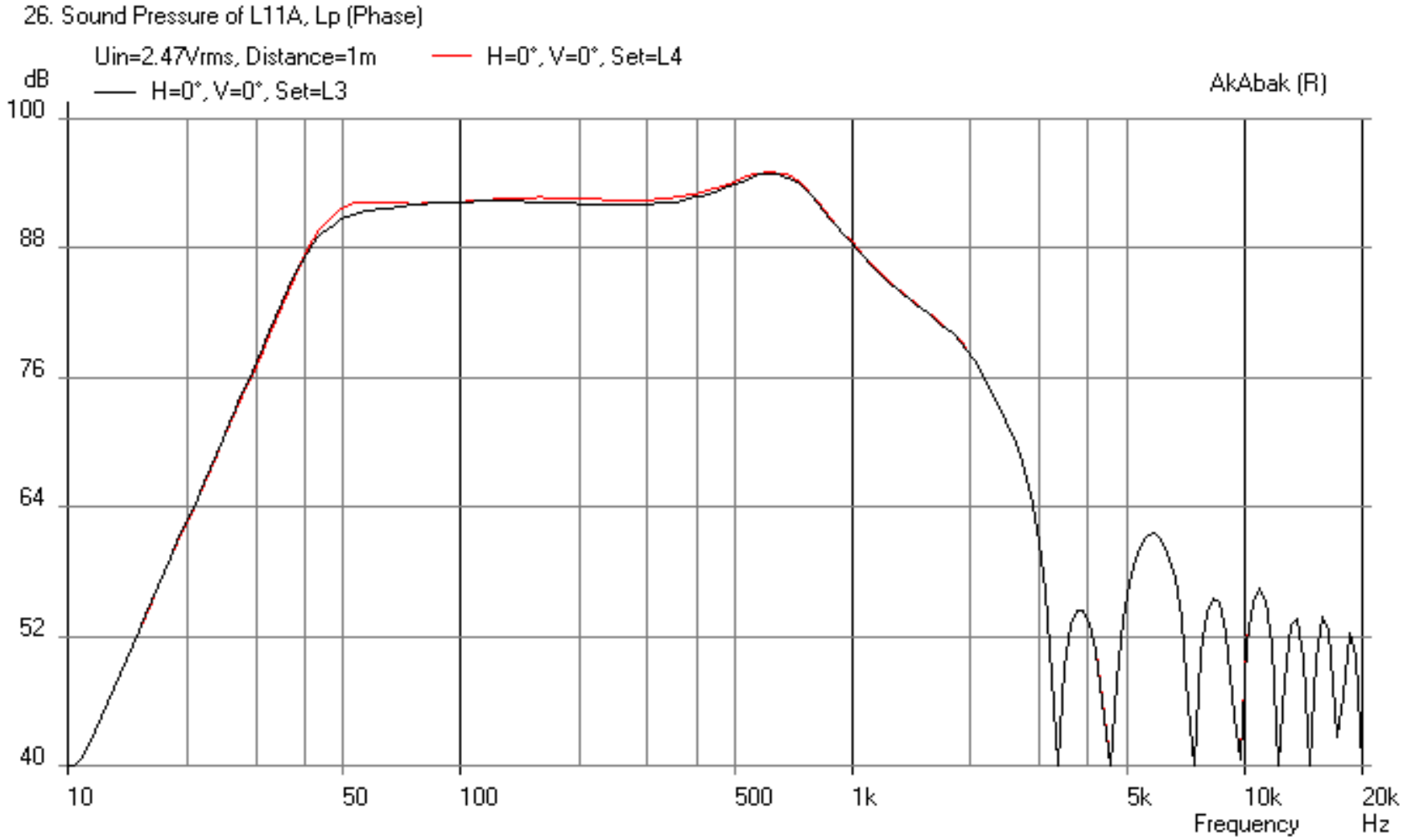
Ak je kompenzačný obvod naladený na frekvenciu impedancie



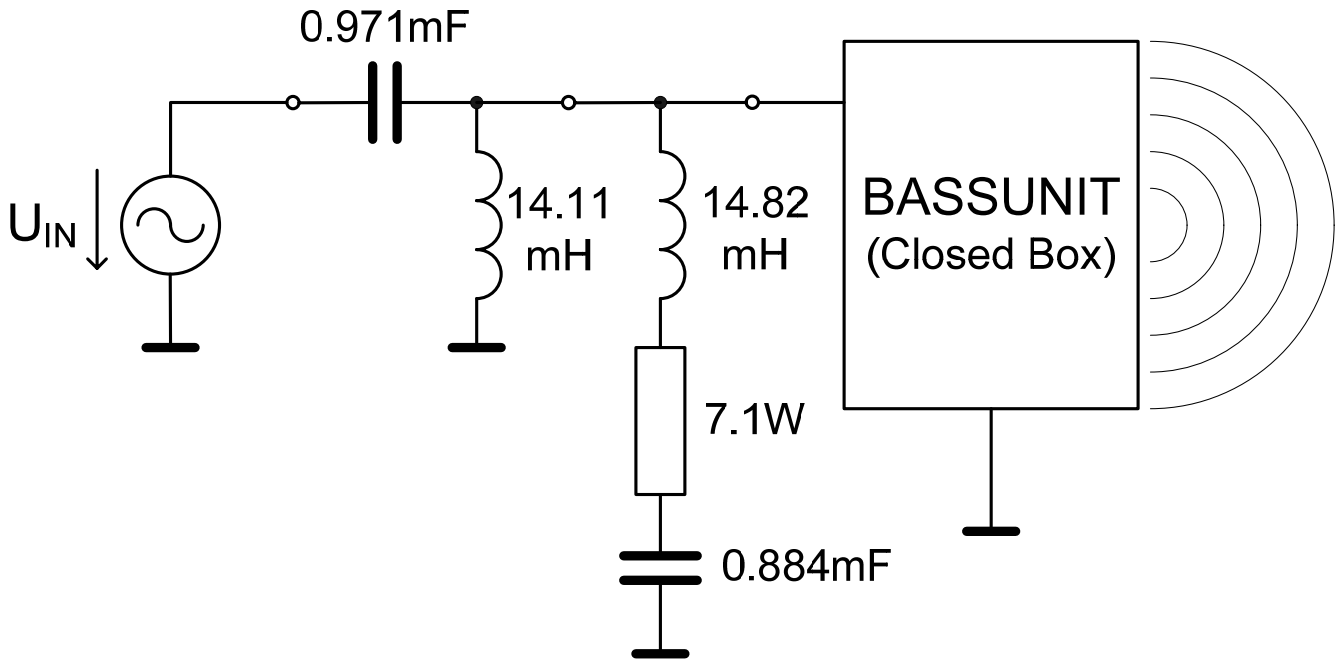
Ak je kompenzačný obvod naladený na frekvenciu predradeného filtra



Ideálny versus reálny filter s kompenzačným obvodom: porovnanie



Schématické zapojenie tvarovacieho filtra s kompenzačným obvodom pre reproduktor v zatvorenej ozvučnici



Prenosová funkcia reproduktora v basreflexovej ozvučnici

$$G_{VB}(s) = \frac{{s_0}^4}{{s_0}^4 + a_1{s_0}^3 + a_2{s_0}^2 + a_3 s_0 + 1} \qquad s_0 = \frac{s}{\omega_0}$$

$$a_1 = \frac{Q_L + h \cdot Q_T}{\sqrt{h} \cdot Q_L \cdot Q_T} \qquad \omega_0 = \sqrt{\omega_B \omega_S}$$

$$a_2 = \frac{h + \left(\alpha + 1 + h^2\right) \cdot Q_L \cdot Q_T}{\sqrt{h} \cdot Q_L \cdot Q_T}$$

$$a_3 = \frac{h \cdot Q_L + Q_T}{\sqrt{h} \cdot Q_L \cdot Q_T}$$

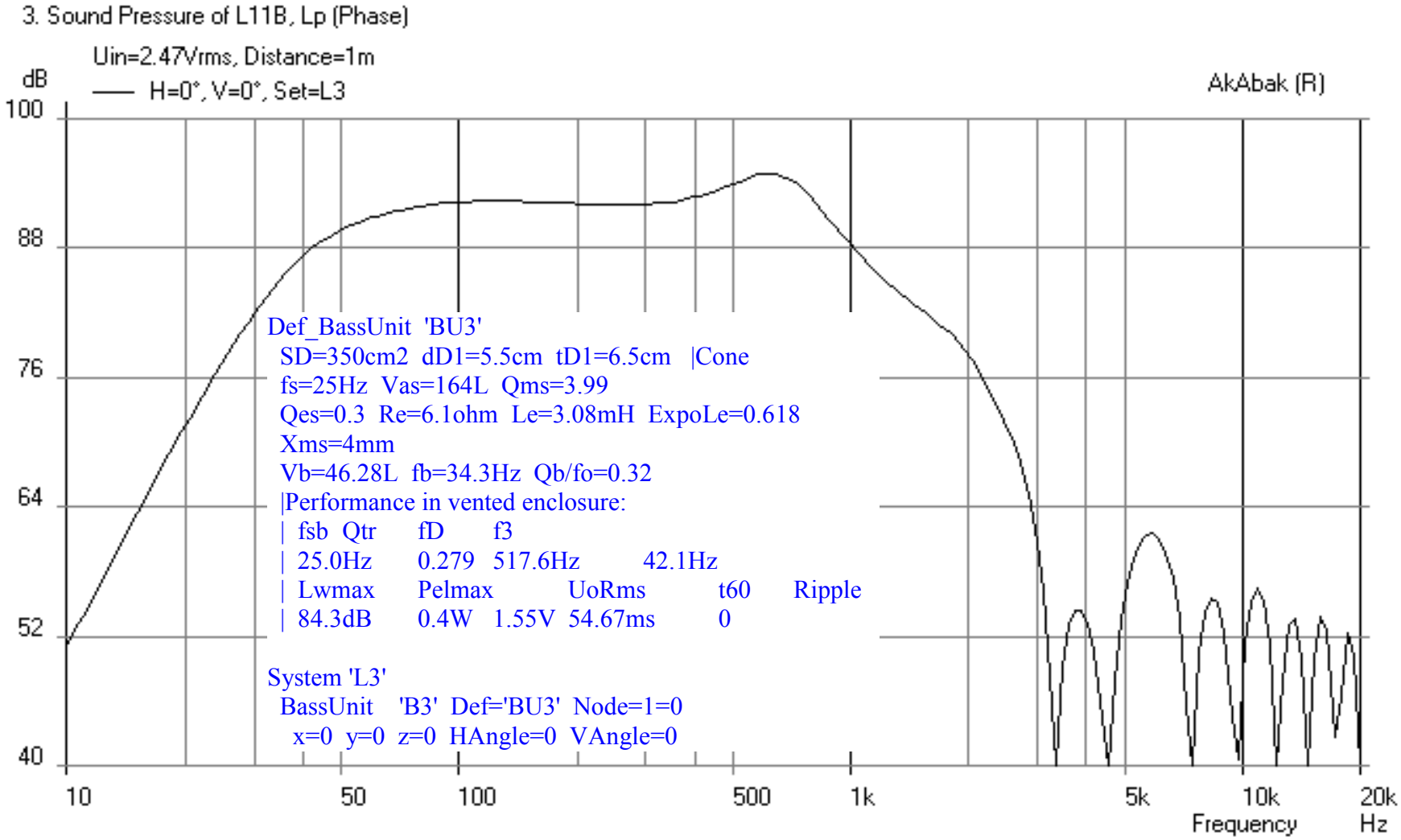
Prenosová funkcia sústavy s basreflexovou ozvučniciu a predradeným filtrom: hornopriepustný filter 6. rádu

$$H_{BP6}(s) = H_{HPF}(s) G_{VB}(s) = \frac{s_e^{\,2}}{s_e^{\,2} + s_e / Q_e + 1} \frac{s_0^{\,4}}{s_0^{\,4} + a_1 s_0^{\,3} + a_2 s_0^{\,2} + a_3 s_0 + 1}$$

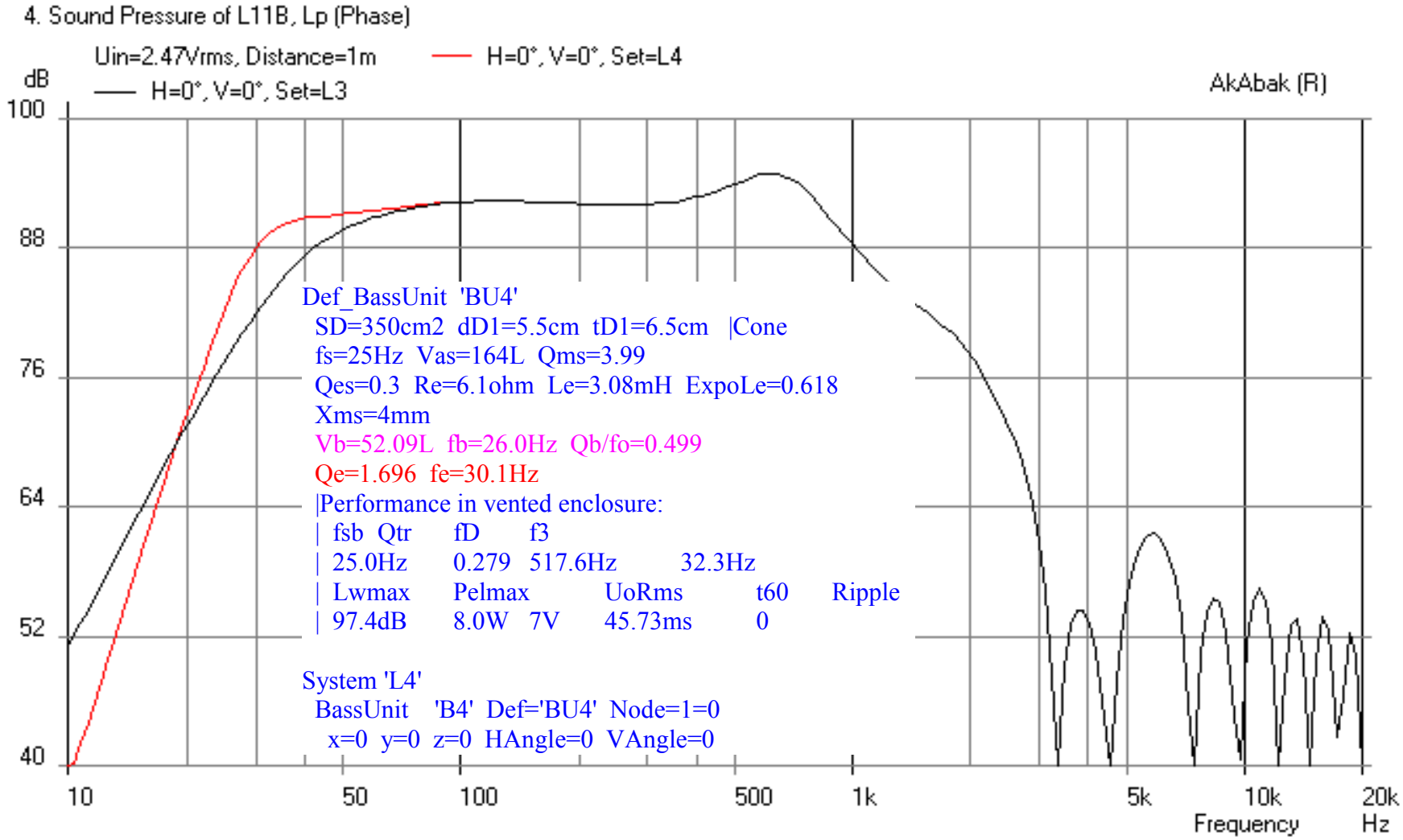
$$H_{BP6}(s) = \frac{c_6 s_1^{\,6}}{d_6 s_1^{\,6} + d_5 s_1^{\,5} + d_4 s_1^{\,4} + d_3 s_1^{\,3} + d_2 s_1^{\,2} + d_1 s_1 + 1}$$

$$s_1 = \frac{s}{\omega_1}$$

Sústava s basreflexovou ozvučnicou bez predradeného filtra

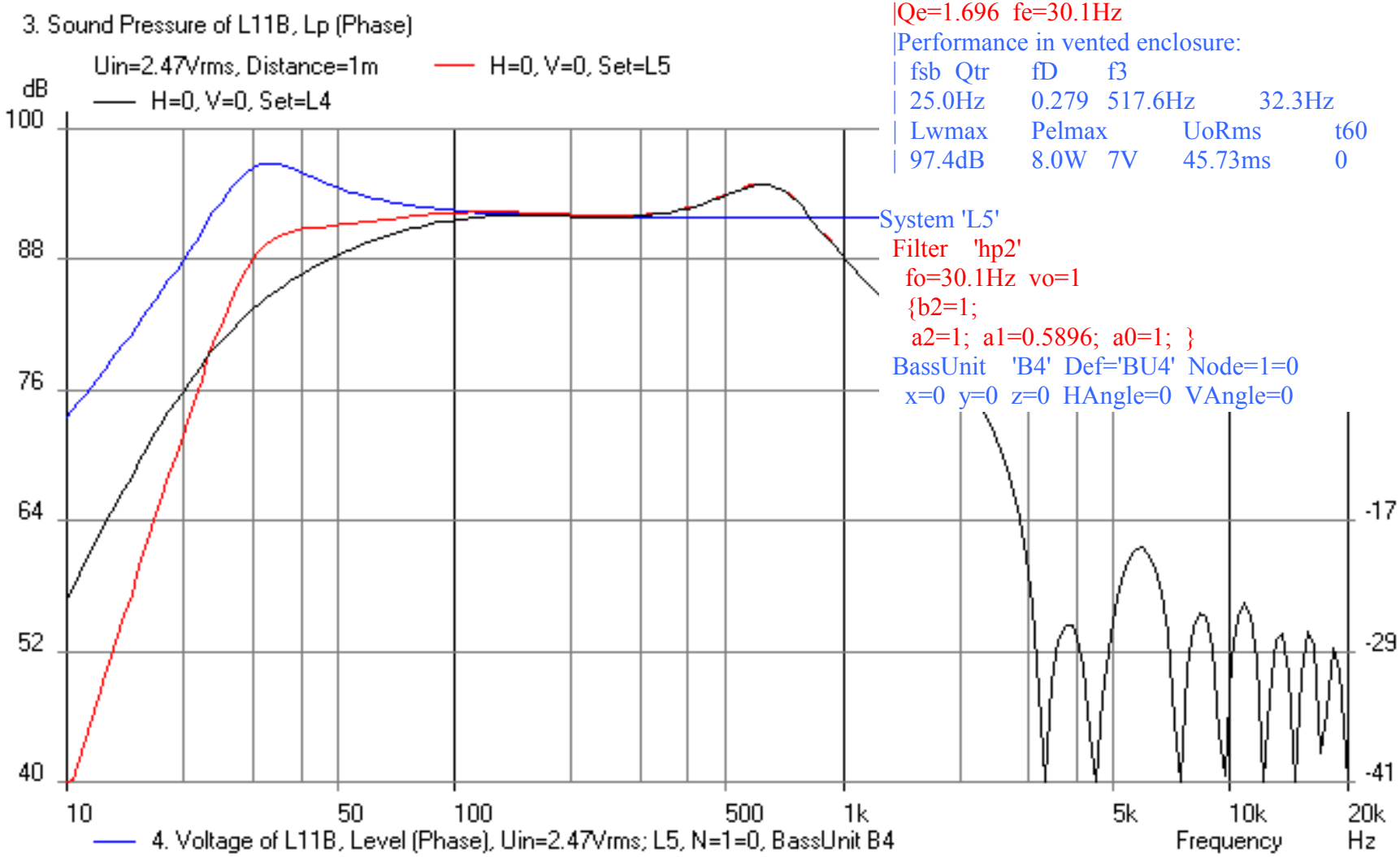


Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (v definičnej časti skriptu)



Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (samostatný filter v hlavnej časti skriptu)

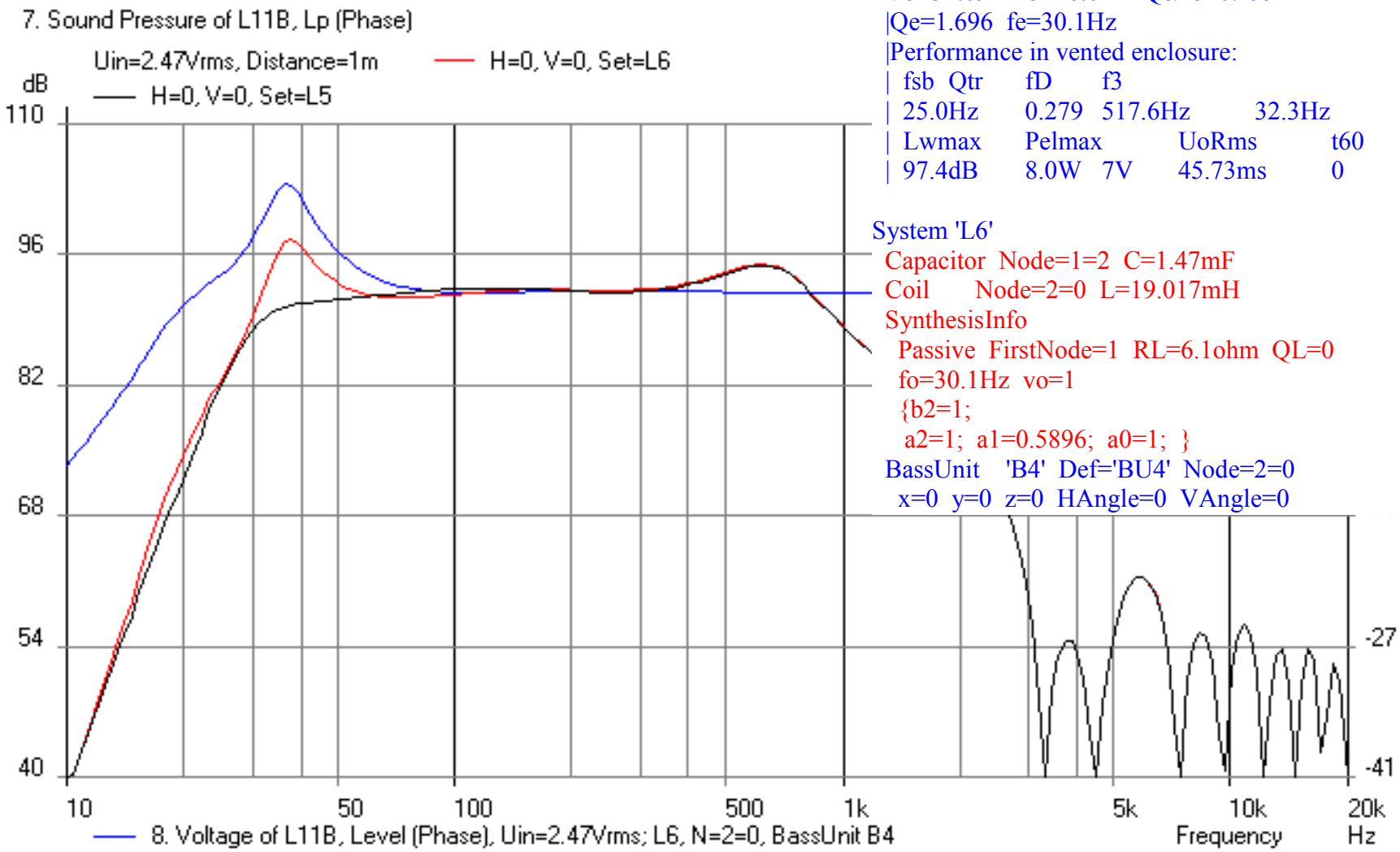
```
Def_BassUnit  'BU4'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=52.09L  fb=26.0Hz  Qb/fo=0.499
  |Qe=1.696  fe=30.1Hz
  |Performance in vented enclosure:
  |  fsb  Qtr      fD       f3
  |  25.0Hz      0.279   517.6Hz        32.3Hz
  |  Lwmax       Pelmax          UoRms          t60       Ripple
  |  97.4dB      8.0W   7V       45.73ms        0

System 'L5'
  Filter    'hp2'
    fo=30.1Hz  vo=1
    {b2=1;
     a2=1;  a1=0.5896;  a0=1;  }
  BassUnit    'B4'  Def='BU4'  Node=1=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```



Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (samostatný filter v hlavnej časti skriptu vo forme obvodovej realizácie)

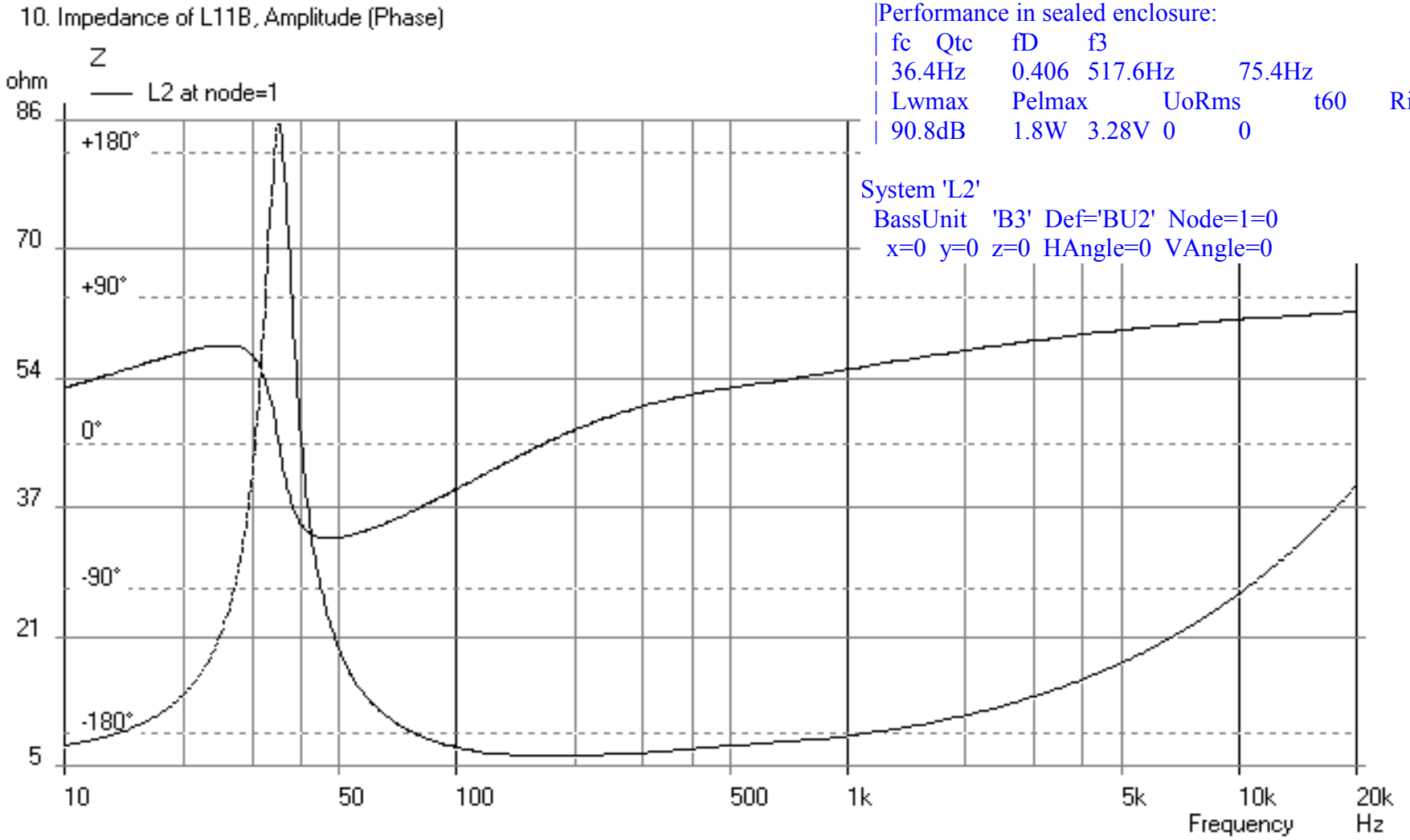
```
Def_BassUnit 'BU4'
 SD=350cm2 dD1=5.5cm tD1=6.5cm |Cone
 fs=25Hz Vas=164L Qms=3.99
 Qes=0.3 Re=6.1ohm Le=3.08mH ExpoLe=0.618
 Xms=4mm
 Vb=52.09L fb=26.0Hz Qb/fo=0.499
 |Qe=1.696 fe=30.1Hz
 |Performance in vented enclosure:
 | fsb  Qtr     fD      f3
 | 25.0Hz    0.279  517.6Hz      32.3Hz
 | Lwmax     Pelmax        UoRms       t60     Ripple
 | 97.4dB    8.0W  7V      45.73ms     0
```

```
System 'L6'
 Capacitor Node=1=2 C=1.47mF
 Coil      Node=2=0 L=19.017mH
 SynthesisInfo
  Passive FirstNode=1 RL=6.1ohm QL=0
  fo=30.1Hz vo=1
  {b2=1;
   a2=1; a1=0.5896; a0=1; }
 BassUnit  'B4' Def='BU4' Node=2=0
  x=0 y=0 z=0 HAngle=0 VAngle=0
```

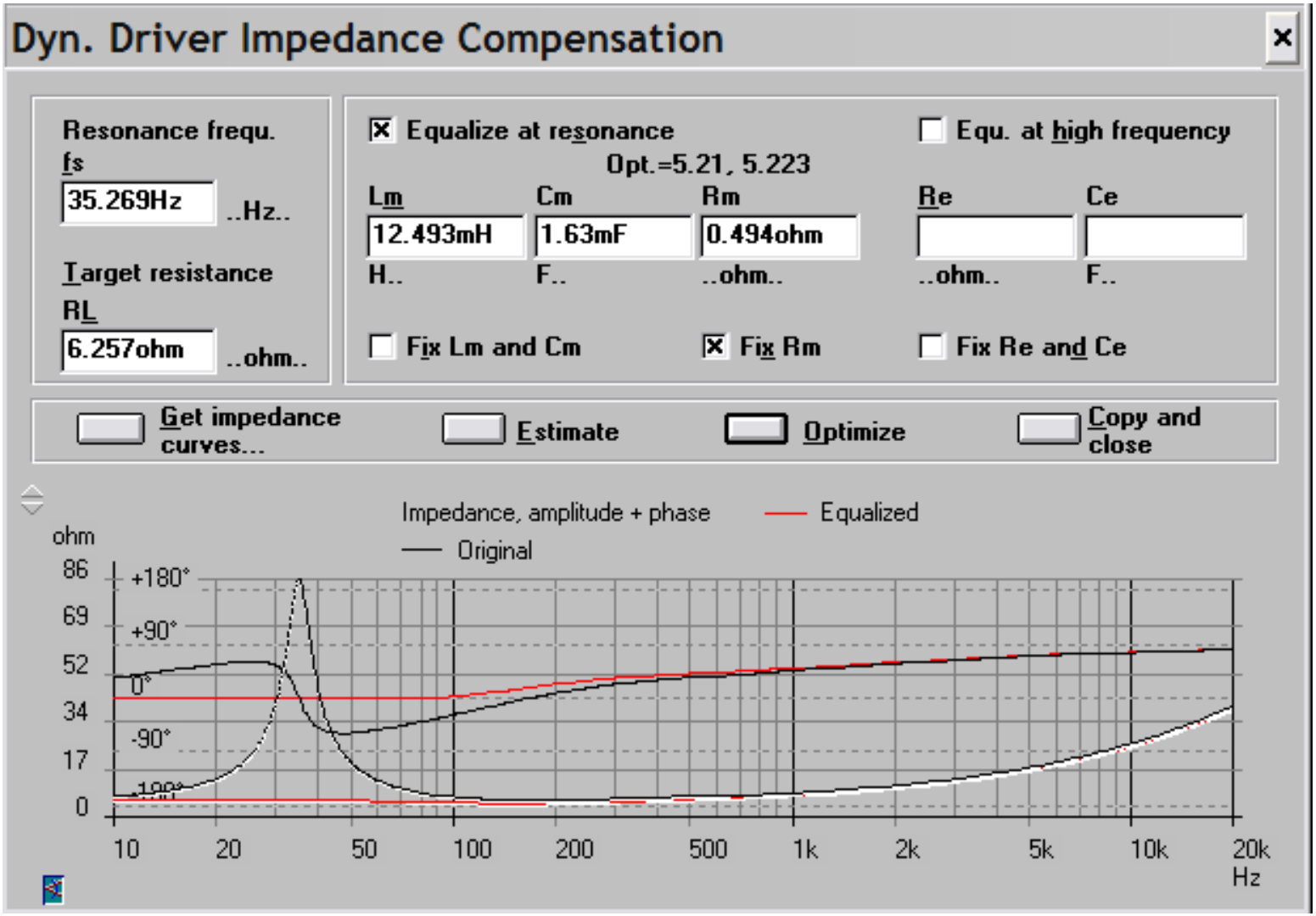


Impedančná krivka

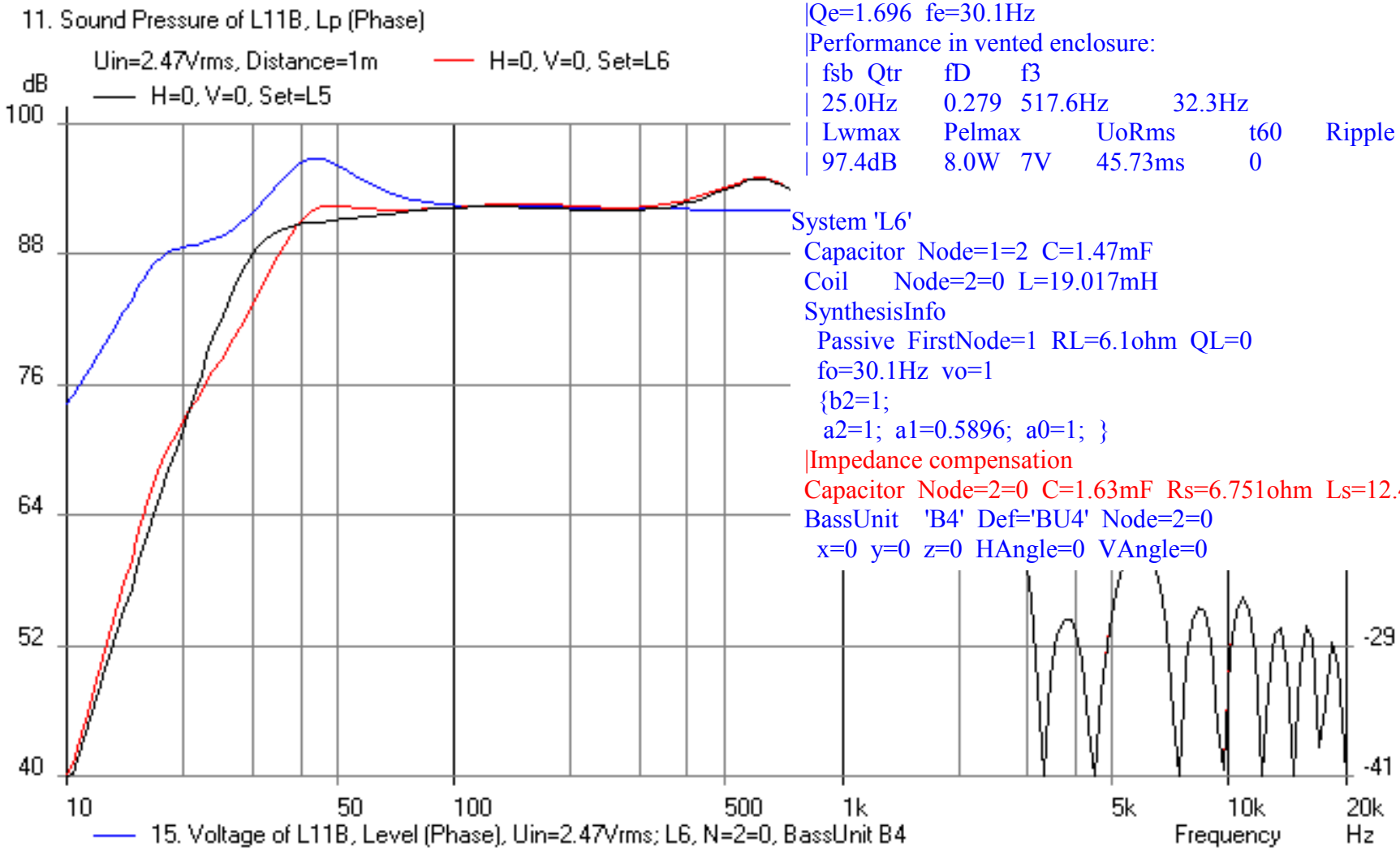
```
Def_BassUnit  'BU2'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=147L
  |Performance in sealed enclosure:
  | fc    Qtc      fD       f3
  | 36.4Hz       0.406   517.6Hz         75.4Hz
  | Lwmax        Pelmax          UoRms          t60       Ripple
  | 90.8dB       1.8W   3.28V  0         0

System 'L2'
  BassUnit    'B3'  Def='BU2'  Node=1=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```



Určenie sériového „antirezonančného“ RLC obvodu

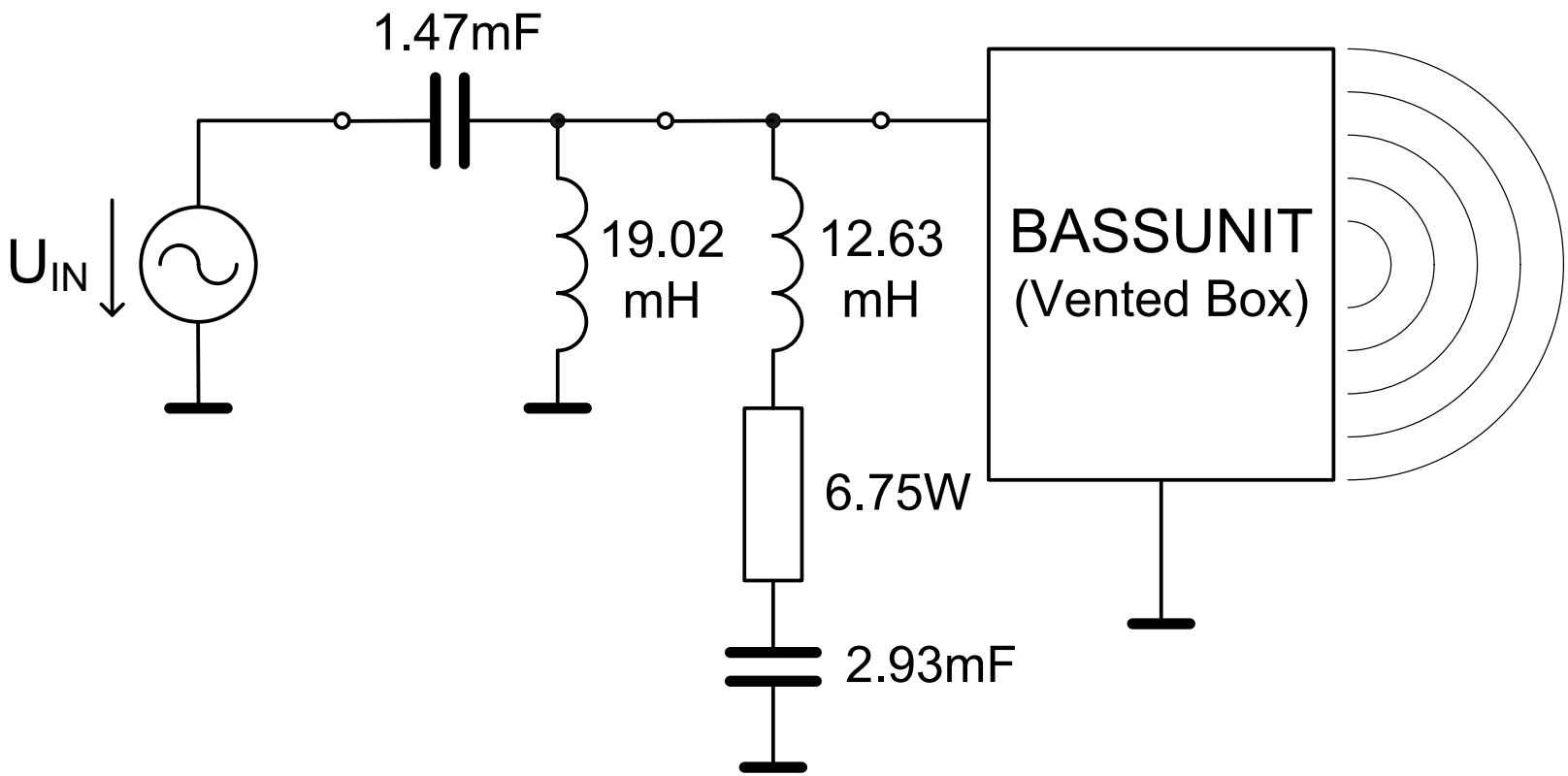


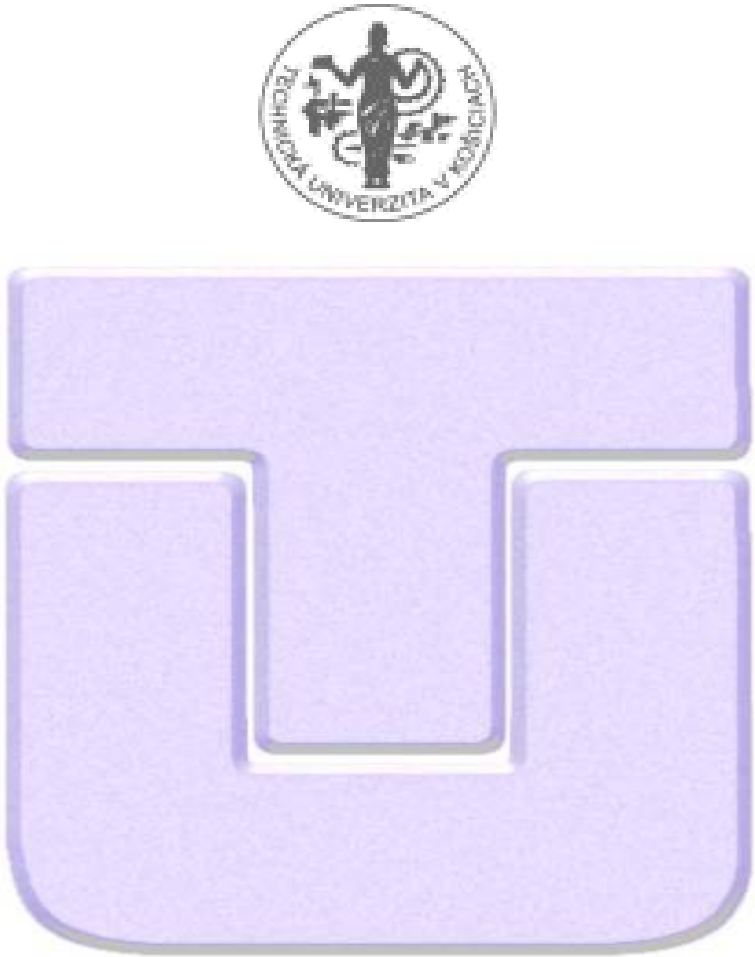
• • •




```
Def_BassUnit  'BU4'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=52.09L  fb=26.0Hz  Qb/fo=0.499
  |Qe=1.696  fe=30.1Hz
  |Performance in vented enclosure:
  |  fsb  Qtr      fD       f3
  |  25.0Hz      0.279   517.6Hz        32.3Hz
  |  Lwmax       Pelmax          UoRms          t60       Ripple
  |  97.4dB      8.0W   7V       45.73ms        0

System 'L6'
  Capacitor  Node=1=2  C=1.47mF
  Coil       Node=2=0  L=19.017mH
  SynthesisInfo
    Passive  FirstNode=1  RL=6.1ohm  QL=0
    fo=30.1Hz  vo=1
    {b2=1;
     a2=1;  a1=0.5896;  a0=1;  }
  |Impedance compensation
  Capacitor  Node=2=0  C=1.63mF  Rs=6.751ohm  Ls=12.494mH
  BassUnit    'B4'  Def='BU4'  Node=2=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```

Schématické zapojenie tvarovacieho filtra s kompenzačným obvodom pre reproduktor v basreflexovej ozvučnici





$$H_{CB}(s) = H_{HPF}(s) \cdot G_{CB}(s) = \frac{s_e^{\,2}}{s_e^{\,2} + s_e/Q_e + 1} \frac{s_C^{\,2}}{s_C^{\,2} + s_C/Q_{TC} + 1} =$$

$$= \frac{s_e^{\,2} s_C^{\,2}}{s_e^{\,2} s_C^{\,2} + s_e s_C^{\,2}/Q_e + s_C s_e^{\,2}/Q_{TC} + s_e^{\,2} + s_C^{\,2} + s_e s_C/Q_{TC} Q_e + s_C/Q_{TC} + s_e/Q_e + 1} =$$

$$= \frac{s_0^{\,4}}{s_0^{\,4} + s_0^{\,3}\sqrt{\frac{\omega_e}{\omega_C}}\frac{1}{Q_e} + s_0^{\,3}\sqrt{\frac{\omega_C}{\omega_e}}\frac{1}{Q_{TC}} + \frac{\omega_C}{\omega_e}s_0^{\,2} + \frac{\omega_e}{\omega_C}s_0^{\,2} + s_0^{\,2}\frac{1}{Q_{TC}Q_e} + s_0\sqrt{\frac{\omega_e}{\omega_C}}\frac{1}{Q_{TC}} + s_0\sqrt{\frac{\omega_C}{\omega_e}}\frac{1}{Q_e} + 1} =$$

$$s_e = \frac{s}{\omega_e} \qquad s_C = \frac{s}{\omega_C} \qquad s_0 = \frac{s}{\omega_0} \qquad \omega_0 = \sqrt{\omega_C \omega_e} = \omega_C \sqrt{h_e} = \frac{\omega_e}{\sqrt{h_e}}$$

$$h_e = \frac{\omega_e}{\omega_C}$$

$$= \frac{s_0^{\,4}}{s_0^{\,4} + \left(\frac{\sqrt{h_e}}{Q_e} + \frac{1}{\sqrt{h_e} Q_{TC}}\right) s_0^{\,3} + \left(\frac{1}{h_e} + h_e + \frac{1}{Q_{TC} Q_e}\right) s_0^{\,2} + \left(\frac{1}{\sqrt{h_e} Q_e} + \frac{\sqrt{h_e}}{Q_{TC}}\right) s_0 + 1} =$$

$$= \frac{s_0^{\,4}}{s_0^{\,4} + a_3 s_0^{\,3} + a_2 s_0^{\,2} + a_1 s_0 + 1}$$

$$a_1 = \frac{1}{\sqrt{h_e} Q_e} + \frac{\sqrt{h_e}}{Q_{TC}}$$

$$a_2 = \frac{1}{h_e} + h_e + \frac{1}{Q_{TC} Q_e}$$

$$a_3 = \frac{\sqrt{h_e}}{Q_e} + \frac{1}{\sqrt{h_e} Q_{TC}}$$

Prenosová funkcia reproduktora v zatvorenej ozvučnici s tvarovacím filtrom

Aproximácia B4 :

$$a_1 = \frac{1}{\sqrt{h_e}Q_e} + \frac{\sqrt{h_e}}{Q_{TC}} = 2.613$$

$$a_2 = \frac{1}{h_e} + h_e + \frac{1}{Q_{TC}Q_e} = 2 + \sqrt{2}$$

$$a_3 = \frac{\sqrt{h_e}}{Q_e} + \frac{1}{\sqrt{h_e}Q_{TC}} = 2.613$$

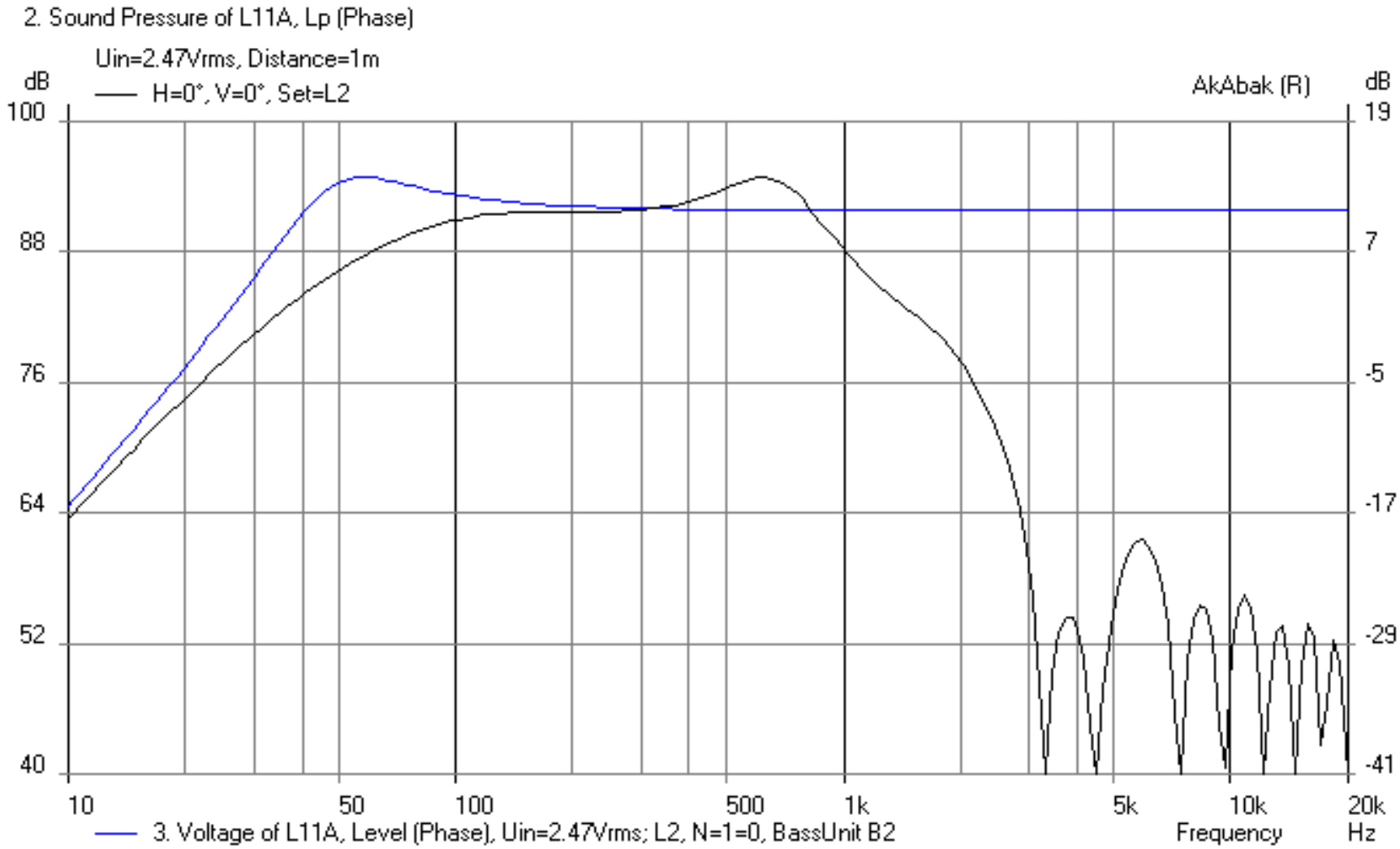
$$a_1 = a_3 \quad \Rightarrow \quad h_e = 1 \quad \Rightarrow \quad f_e = f_C$$

$$\left.\begin{aligned} \frac{1}{Q_{TC}Q_e} &= \sqrt{2} \\ \frac{1}{Q_e} + \frac{1}{Q_{TC}} &= 2.613 \end{aligned}\right\} \Rightarrow \begin{aligned} \sqrt{2}Q_e^{\,2} - 2.613Q_e + 1 &= 0 \\ Q_{e1} = 1.307 \Rightarrow Q_{TC1} &= 1/\sqrt{2}Q_{e1} = 0.541 \\ Q_{e2} = 0.541 \Rightarrow Q_{TC2} &= 1/\sqrt{2}Q_{e2} = 1.307 \end{aligned}$$

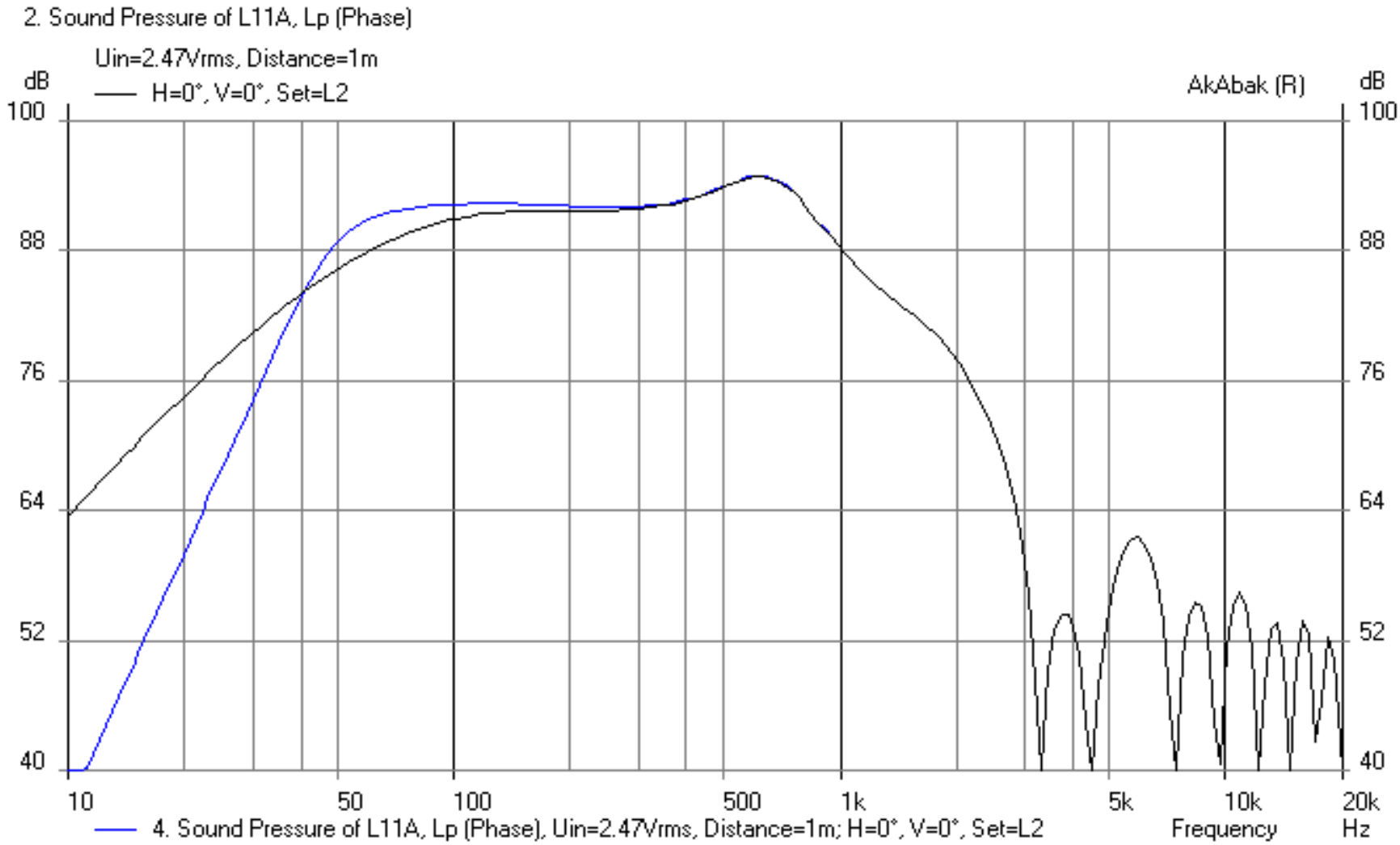
Skript

```
Def_BassUnit  'BU1'
  SD=350cm2  dD1=5.5cm  tD1=6.5cm   |Cone
  fs=25Hz  Vas=164L  Qms=3.99
  Qes=0.3  Re=6.1ohm  Le=3.08mH  ExpoLe=0.618
  Xms=4mm
  Vb=59L
  |Performance in sealed enclosure:
  |  fc          Qtc     fD          f3
  |  48.6Hz      0.542   517.6Hz     67.3Hz
  |  Lwmax       Pelmax          UoRms          t60          Ripple
  |  95.8dB      5.6W            5.86V          19.25ms      0

System 'L2'
  Filter    'hpf'
    fo=48.6Hz  vo=1
    {b2=1;
     a2=1;  a1=0.765111;  a0=1;  }
  BassUnit    'B2'  Def='BU1'  Node=1=0
    x=0  y=0  z=0  HAngle=0  VAngle=0
```

AFCH reproduktora (CB) bez filtra a AFCH filtra



AFCH reproduktora (CB) bez filtra a s filtrom



Aproximácia LR4:

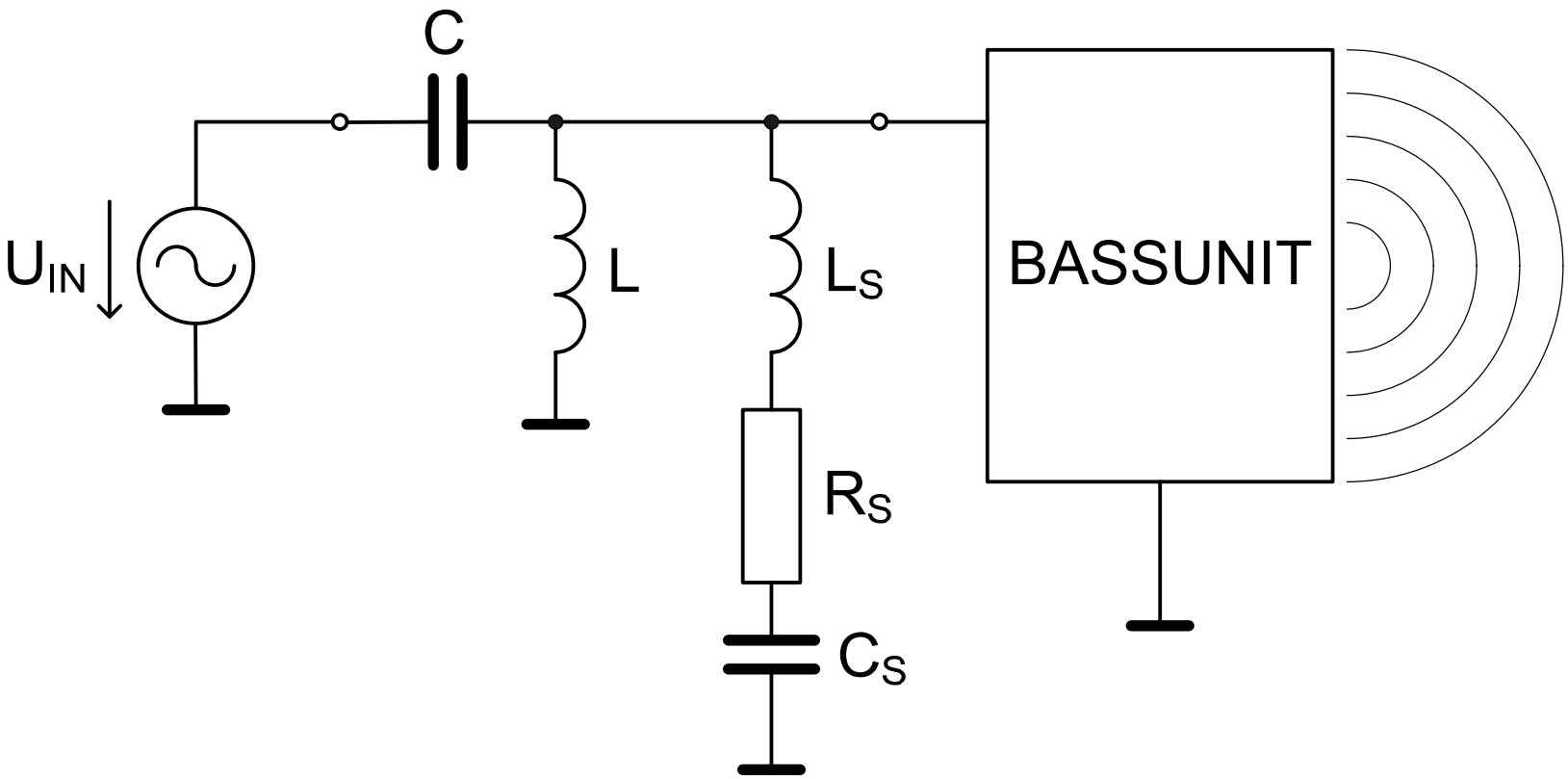
$$a_1 = \frac{1}{\sqrt{h_e}\,Q_e} + \frac{\sqrt{h_e}}{Q_{TC}} = 2.828$$

$$a_2 = \frac{1}{h_e} + h_e + \frac{1}{Q_{TC}Q_e} = 4$$

$$a_3 = \frac{\sqrt{h_e}}{Q_e} + \frac{1}{\sqrt{h_e}\,Q_{TC}} = 2.828$$

$$a_1 = a_3 \quad \Rightarrow \quad h_e = 1 \quad \Rightarrow \quad f_e = f_C$$

$$\left.\begin{aligned} \frac{1}{Q_{TC}Q_e} &= 2 \\ \frac{1}{Q_e} + \frac{1}{Q_{TC}} &= 2.828 \end{aligned}\right\} \Rightarrow \begin{aligned} & 2Q_e^{\,2} - 2.828Q_e + 1 = 0 \\ & Q_e = 0.707 \Rightarrow Q_{TC} = \frac{1}{2Q_{e1}} = 0.707 \end{aligned}$$


C
U_{IN}
L
L_S
BASSUNIT
R_S
C_S