

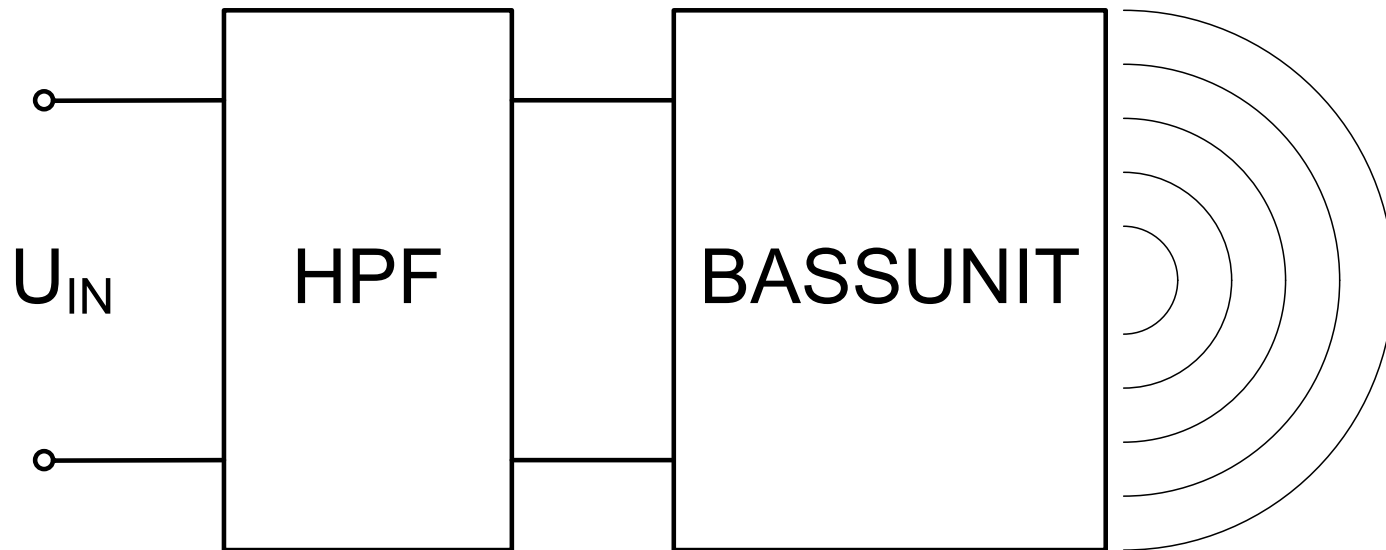


Elektroakustika

L11A: Reproduktorová sústava s predradeným tvarovacím filtrom

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



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

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

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

BassUnit - Dialog

Definition Def_BassUnit / Calculator X

Resonance frequency fs... 25Hz ...Hz...	Electrical quality Qes... 0.3	Mechanical quality Qms... 3.99	Voice coil resistance Re... 6.1ohm ..ohm..	Voice coil inductance Le... 3.08mH H... ExpoLe=0.618	Equ. vol. to compliance Vas... 164L m3,...in3	Diaphragm dimension SD... 350cm2 m2,...in2 Cone
Excursion max. Xms 4mm m,...in	Generator resistance Rg ..ohm..	Mass-load factor mb 1 0.95...1	Enclosure volume Vb 53.18L m3,...in3,L	Quality factor/ frequency Qb/fo 1000	<input type="checkbox"/> Vented	Helmholtz resonance fb... ..Hz..

Closed Box System

fc	Qtc	Directivity frequ. fD	f3	
50.521Hz	0.564	518Hz	42Hz	
Lw max. 4-pi-sr	Pel max.	Uo max. rms	Reverb. -60dB	Ripple
96.11dB	6.03W	6.06V	85.7ms	2.58m dB

<input checked="" type="checkbox"/> HP-Filter	on/off
Quality factor Qe	Pole - frequency fe
1.599	43.002Hz
	..Hz..

Identification

BU2

Alignments...
 Diagram...
 Evaluate
 From script
 Copy to clipboard and close

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

Closed Cabinet Alignments ✕

Alignment table fsb: 25Hz Qtsbg: 0.279 Qb/fo: 1000 CHI 4 k = 0.795

Qtc	fc [Hz]	Vb [L]	f3 [Hz]	Lwmax [dB]	Qe	fe [Hz]	t60 [ms]	Ripple [dB]
0.823	73.7	21.3	35	91	3.843	38.1	242	1.26
0.721	64.6	28.9	34	91.2	3.069	36.6	200	0.59
0.648	58.1	37.3	35	92.2	2.457	37	157	0.21
0.598	53.6	45.6	37	93.9	1.976	39.1	118	0.05
0.564	50.5	53.2	42	96.1	1.599	43	86	
0.541	48.5	59.4	48	98.8	1.307	48.5	61	
0.541	48.5	59.4	48	98.8	1.307	48.5	61	
0.539	48.3	60	50	99.2	1.225	47.7	55	

Query (Select only alignments with...)

Enclosure volume Vb	HP-filter quality factor Qe	Cut-off frequency f3	Max. SPL 1m, 4-pi-sr SPLmax	Enclosure quality/ fb Qb/fo
<input type="text" value="<"/>	<input type="text" value="<"/>	<input type="text" value="<50.0Hz"/>	<input type="text" value="<"/>	<input type="text" value=""/>
<small>m3,...,in3,L</small>		<small>..Hz..</small>	<small>dB</small>	

Alignment list
 Diagram
 Copy alignment to Def_BassUnit Calculator

Lw in a 4-pi-sr. room

Alignment family

- Quasi-Butterworth
- Chebyshev
- Butterworth-Thomson

- High-pass filtered

Skript

| Seas Prestige CA26RE4X H1316
| $Revc=6.1\Omega$; $Levc=3.08mH$; $Bl=11.6N/A$; $Mmd=38.5g$; $Mmrd=3.8g$;
| $Rms=1.66Ns/m$; $Cms=1.1mm/N$; $Sd=350cm^2$
| $Fs=25Hz$; $Qts=0.28$; $Qms=3.99$; $Qes=0.30$; $Vas=164lit.$,
| $y_{max}=4mm$; $sens=91dB$; $Pe(lt)=80W$

Def_BassUnit 'BU2'

$SD=350cm^2$ $dD1=5.5cm$ $tD1=6.5cm$ |Cone

$fs=25Hz$ $Vas=164L$ $Qms=3.99$

$Qes=0.3$ $Re=6.1\Omega$ $Le=3.08mH$ $ExpoLe=0.618$

$Xms=4mm$

$Vb=53.18L$

$Qe=1.599$ $fe=43.0Hz$

|Performance in sealed enclosure:

| f_c Q_{tc} f_D f_3

| 50.5Hz 0.564 517.6Hz 41.8Hz

| L_{wmax} P_{elmax} U_{oRms} t_{60} Ripple

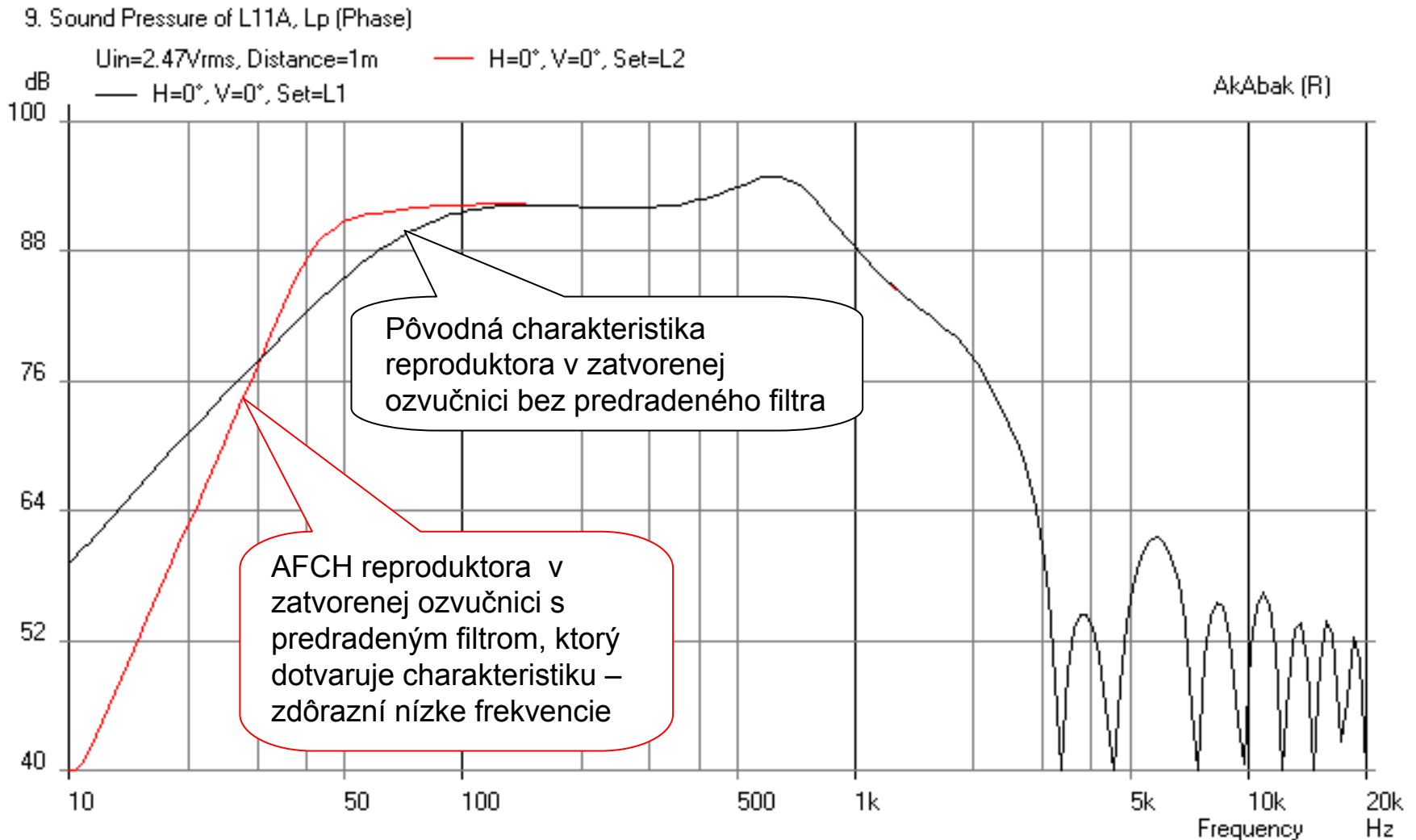
| 96.1dB 6.0W 6.06V 85.7ms 2.6mdB

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; }

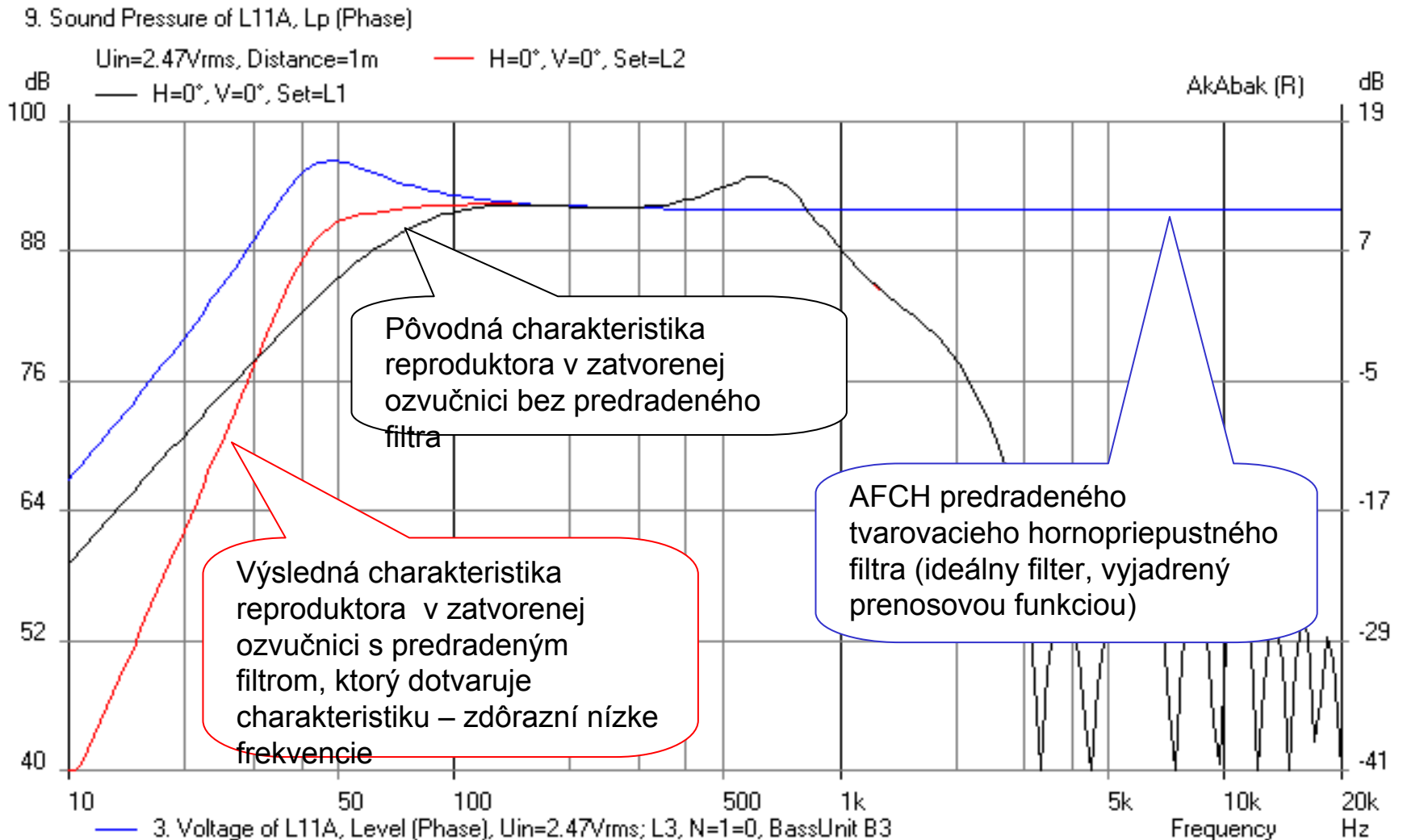
BassUnit 'B3' Def='BU2' Node=1=0

x=0 y=0 z=0 HAngle=0 VAngle=0

$$f_0 = f_e = 43 \text{ Hz}$$

$$a_1 = \frac{1}{Q_e} = \frac{1}{1.599} = 0.625$$

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 85.7ms2.6m dB

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

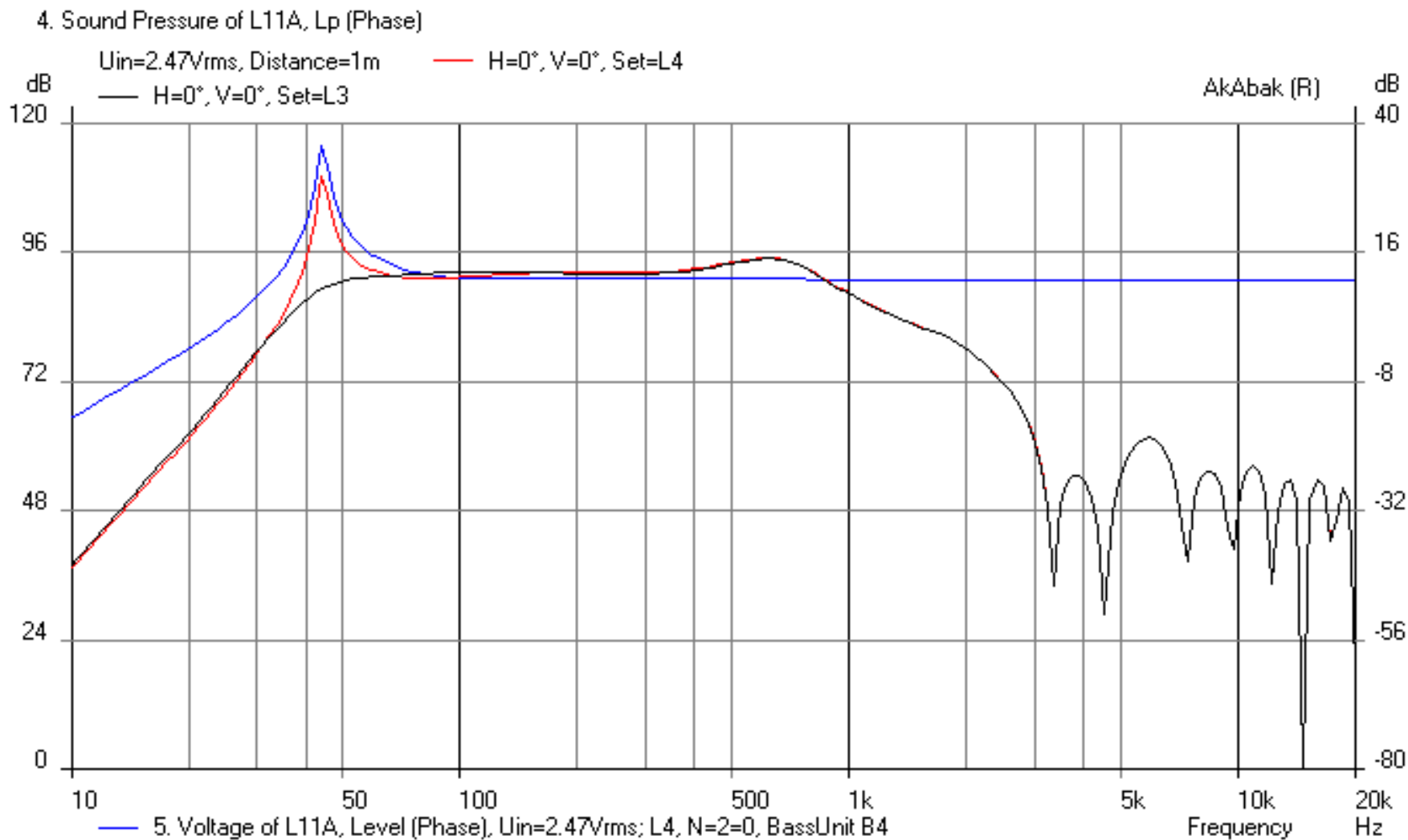
{b2=1;

a2=1; a1=0.625; a0=1; }

BassUnit 'B4' Def='BU2' Node=2=0

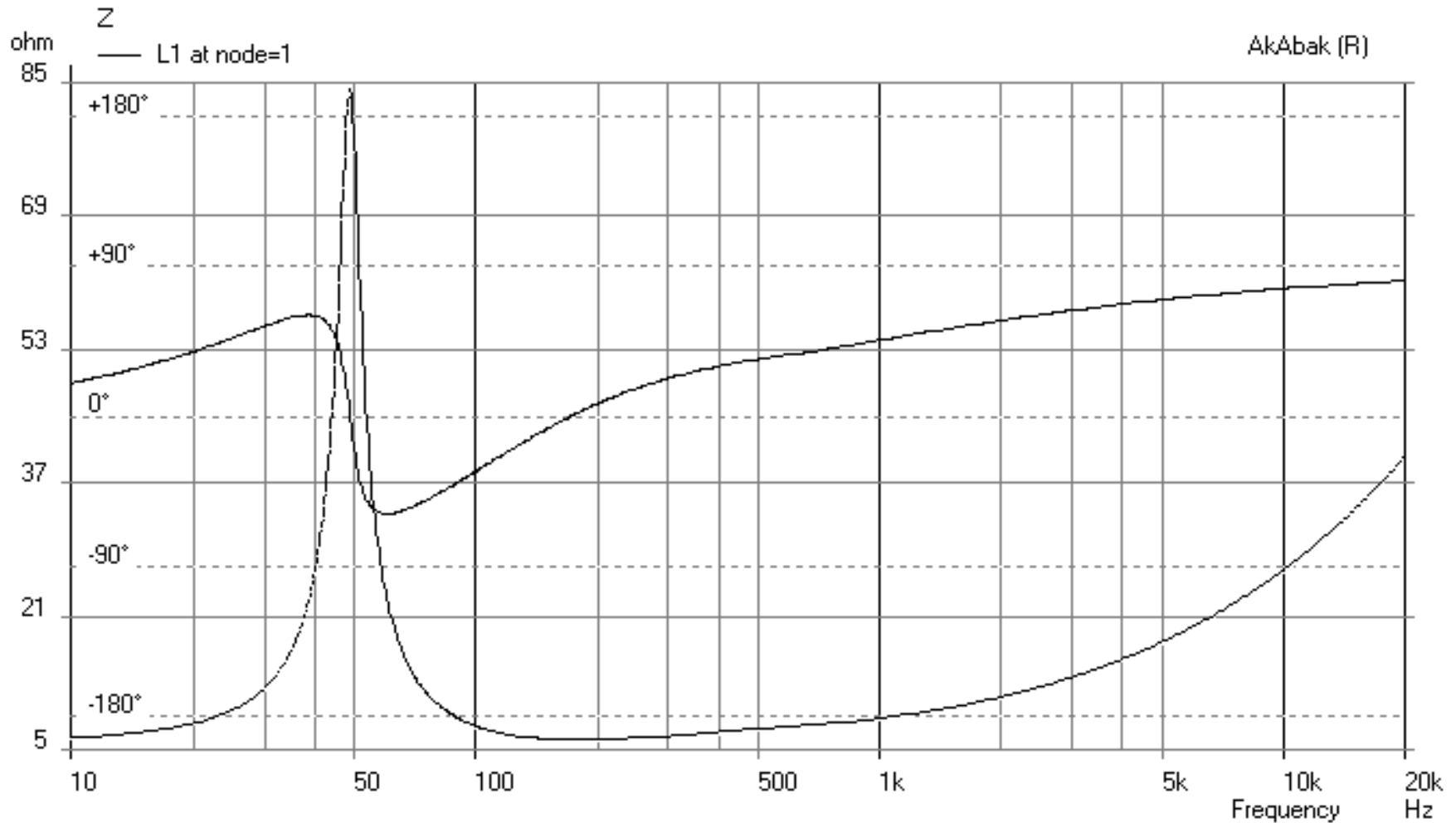
x=0 y=0 z=0 HAngle=0 VAngle=0

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

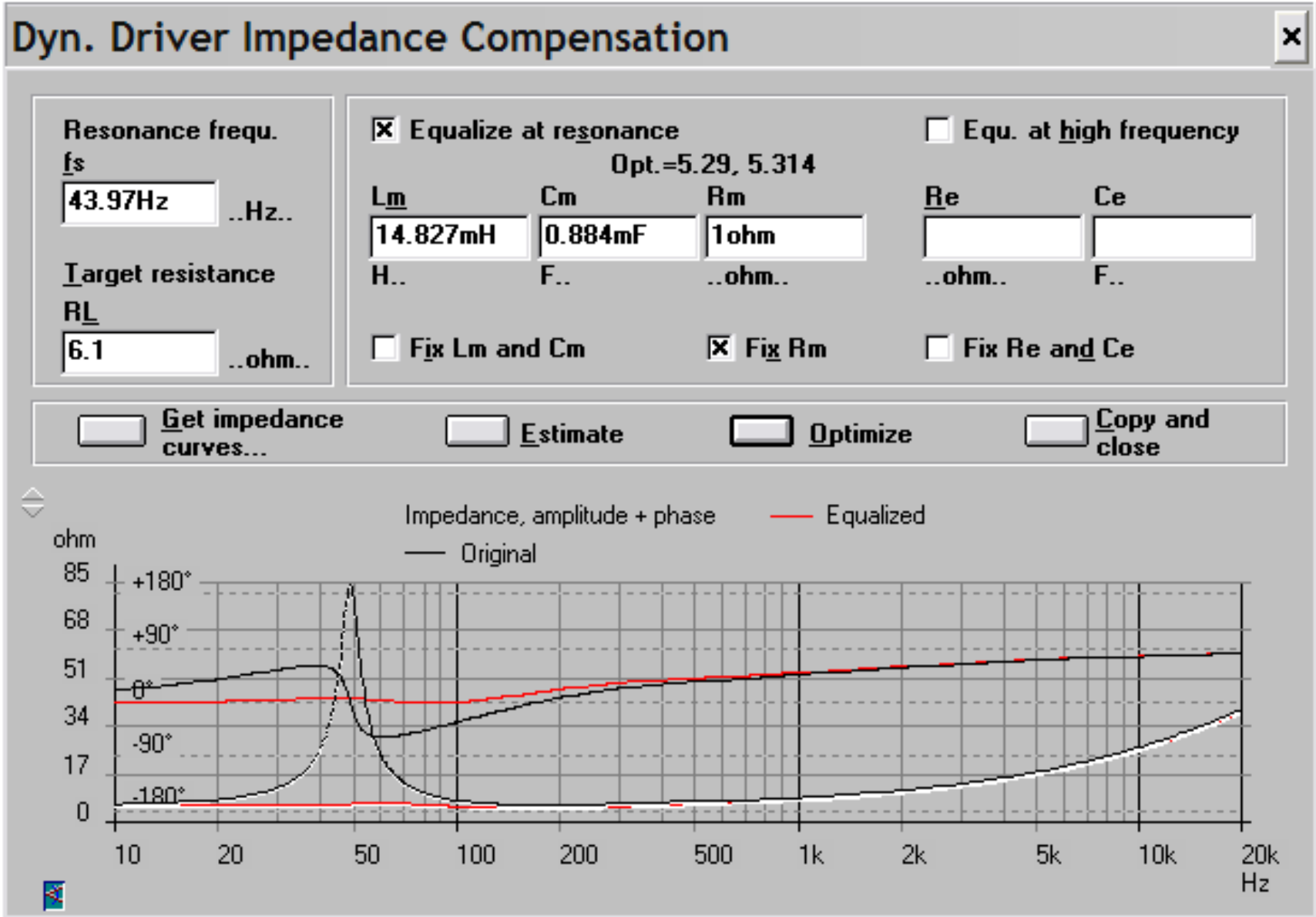


Impedancia reproduktora v zatvorenej ozvučnici

6. Impedance of L11A, Amplitude (Phase)



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 85.7ms 2.6m dB

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

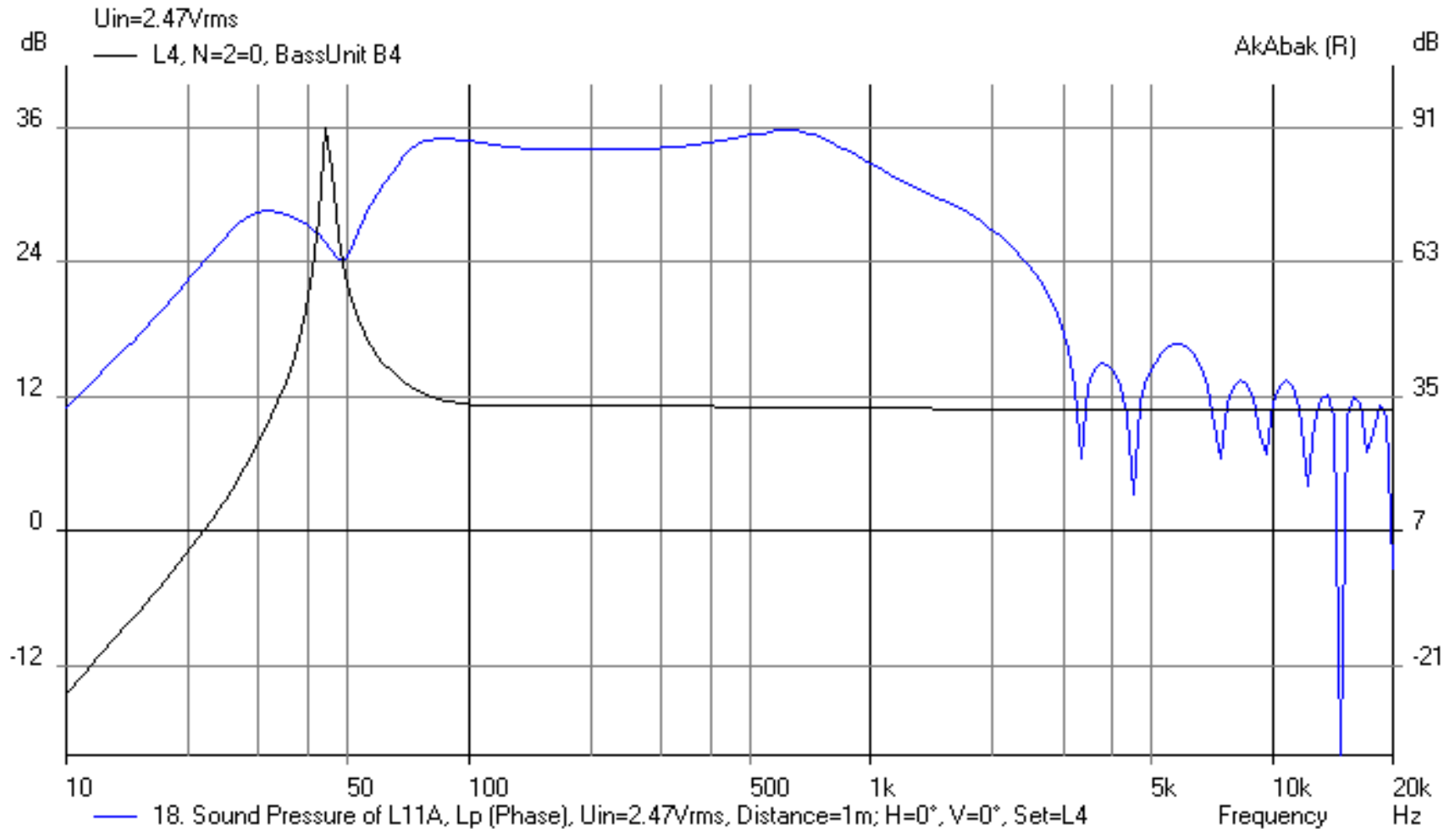
Capacitor Node=2=0 C=0.884mF Rs=7.1ohm Ls=14.82mH

BassUnit 'B4' Def='BU2' Node=2=0

x=0 y=0 z=0 HAngle=0 VAngle=0

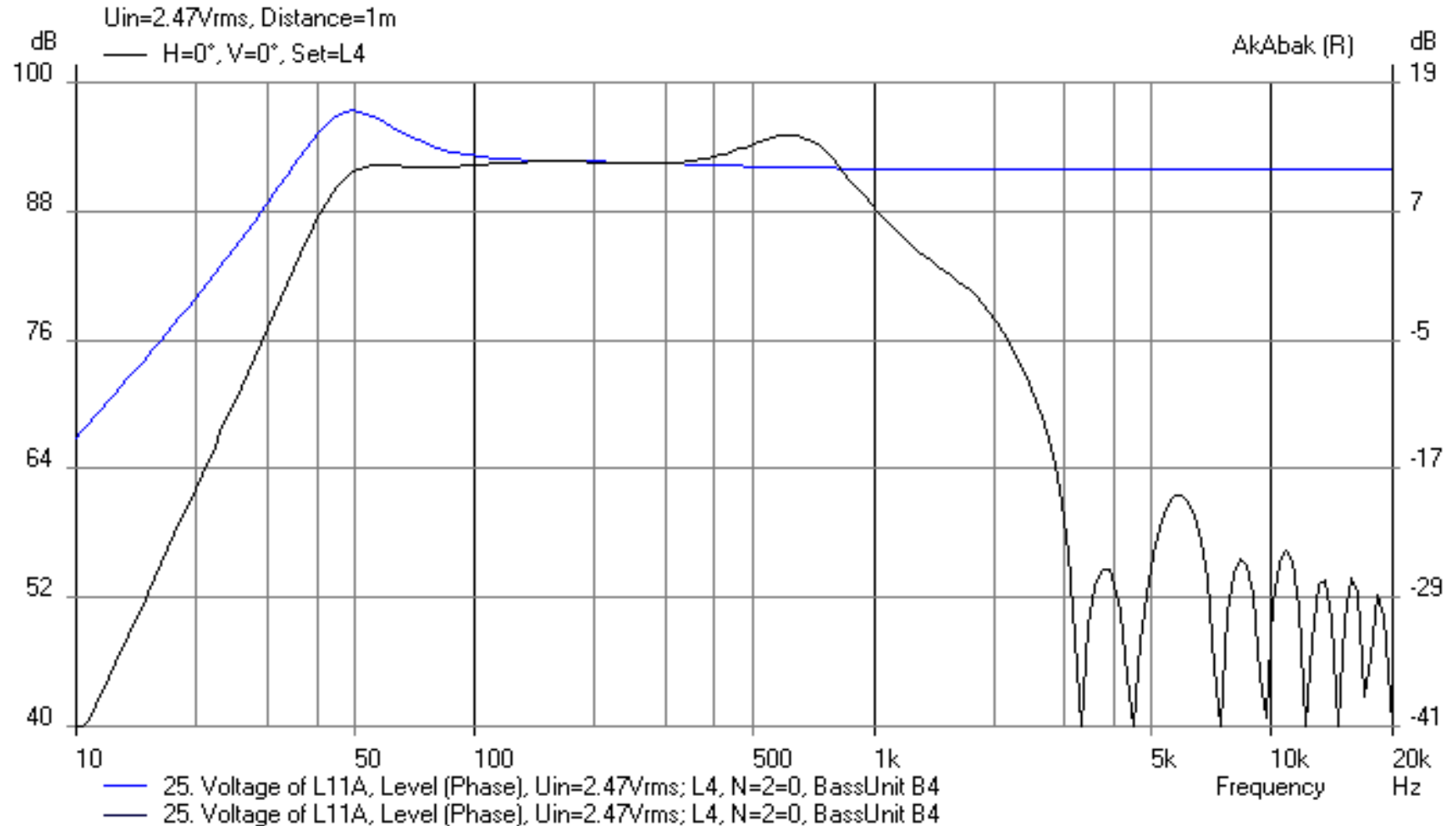
Ak je kompenzačný obvod naladený na frekvenciu impedancie

5. Voltage of L11A, Level (Phase)



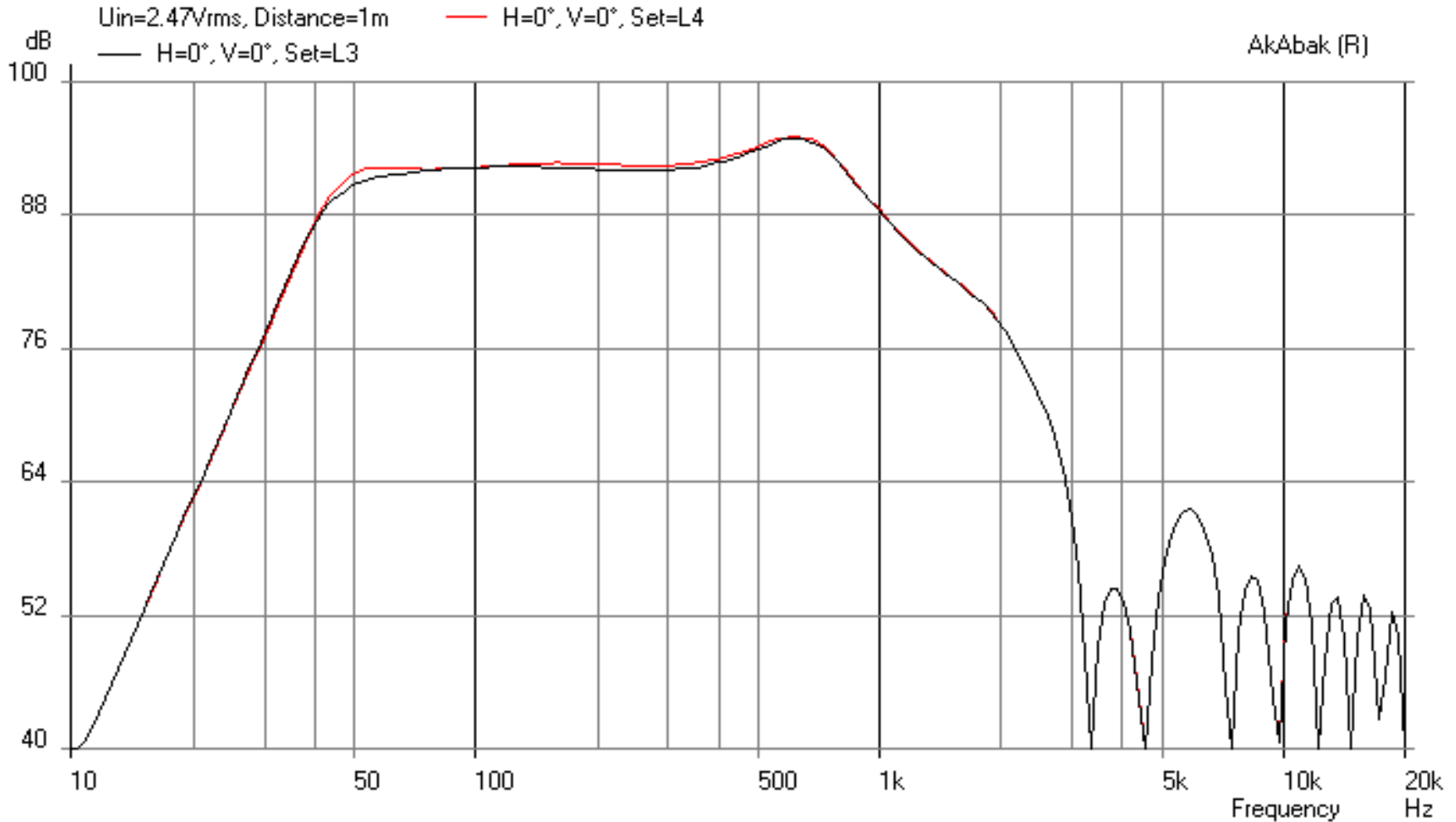
Ak je kompenzačný obvod naladený na frekvenciu predradeného filtra

23. Sound Pressure of L11A, Lp (Phase)

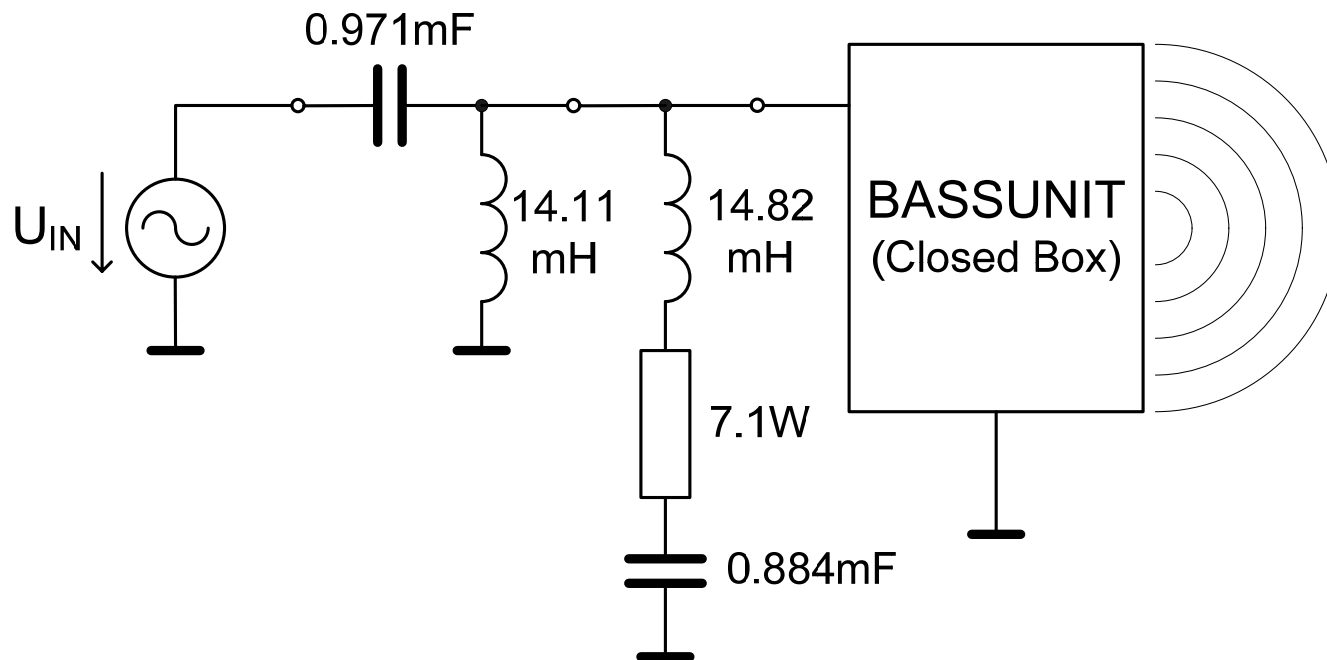


Ideálny versus reálny filter s kompenzačným obvodom: porovnanie

26. Sound Pressure of L11A, Lp (Phase)



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



Prenosová funkcia reproduktora v basreflexovej ozvučnici

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

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

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

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

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

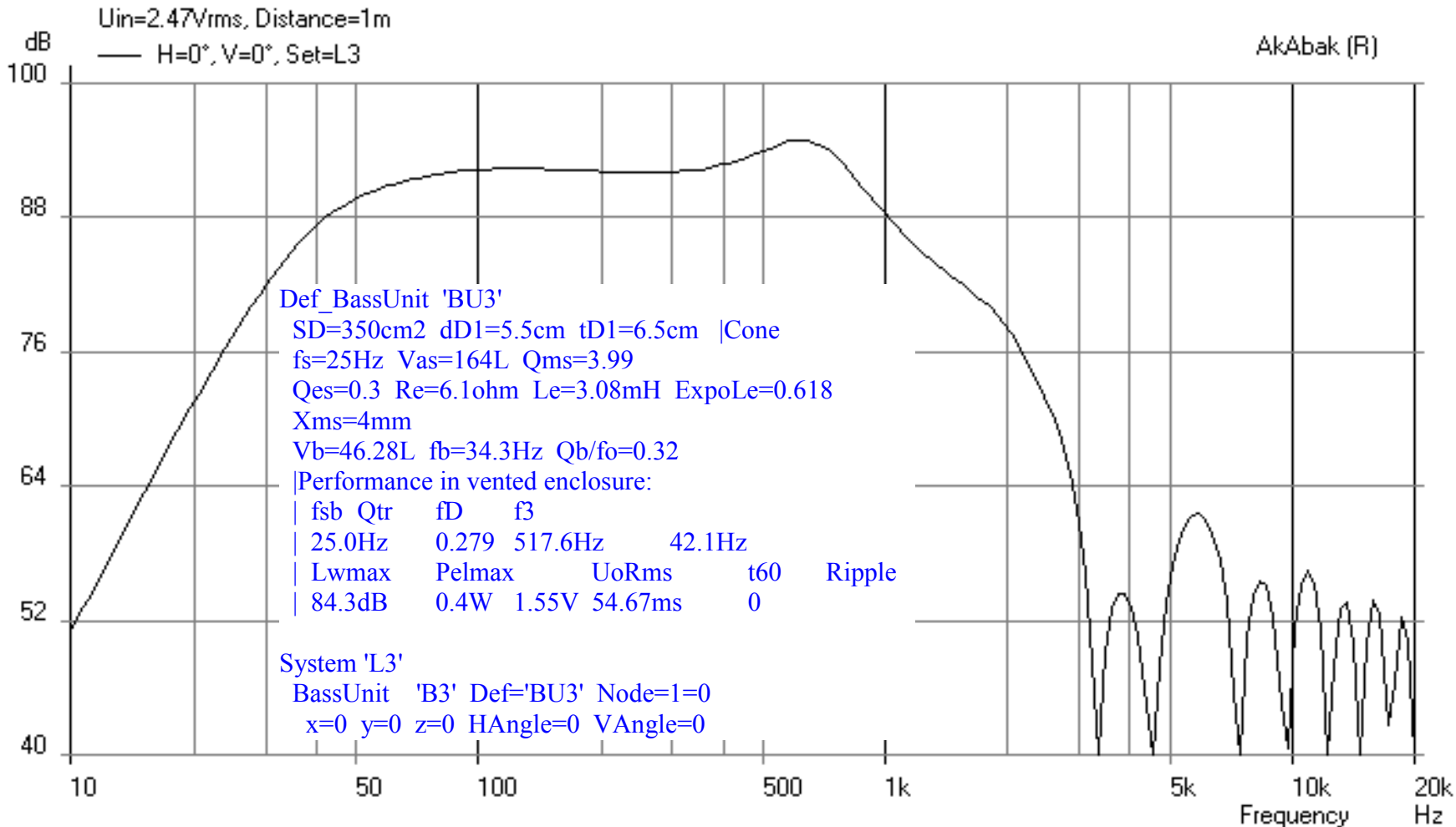
$$H_{BP6}(s) = H_{HPF}(s)G_{VB}(s) = \frac{s_e^2}{s_e^2 + s_e/Q_e + 1} \frac{s_0^4}{s_0^4 + a_1s_0^3 + a_2s_0^2 + a_3s_0 + 1}$$

$$H_{BP6}(s) = \frac{c_6s_1^6}{d_6s_1^6 + d_5s_1^5 + d_4s_1^4 + d_3s_1^3 + d_2s_1^2 + d_1s_1 + 1}$$

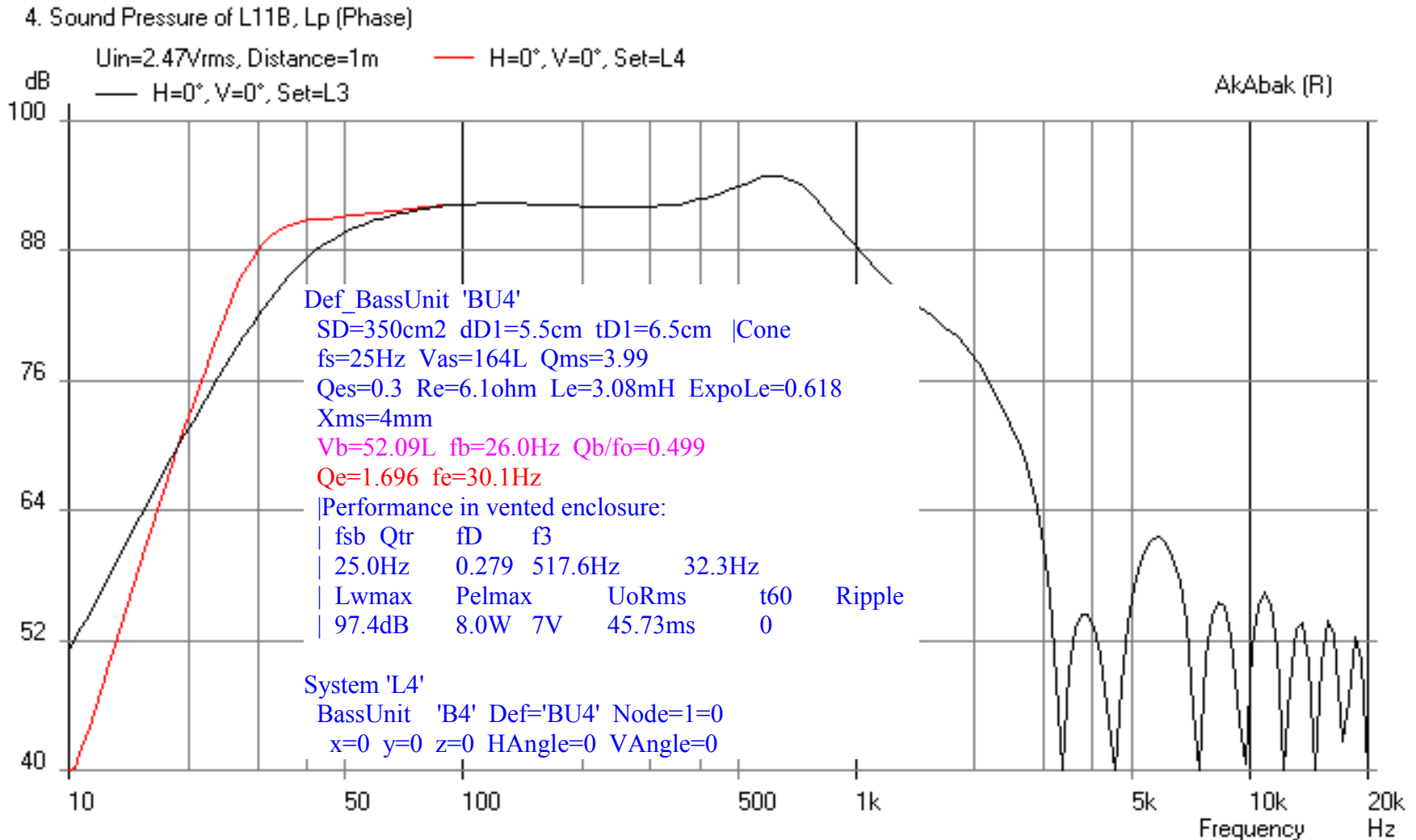
$$s_1 = \frac{s}{\omega_1}$$

Sústava s basreflexovou ozvučnicou bez predradeného filtra

3. Sound Pressure of L11B, Lp (Phase)



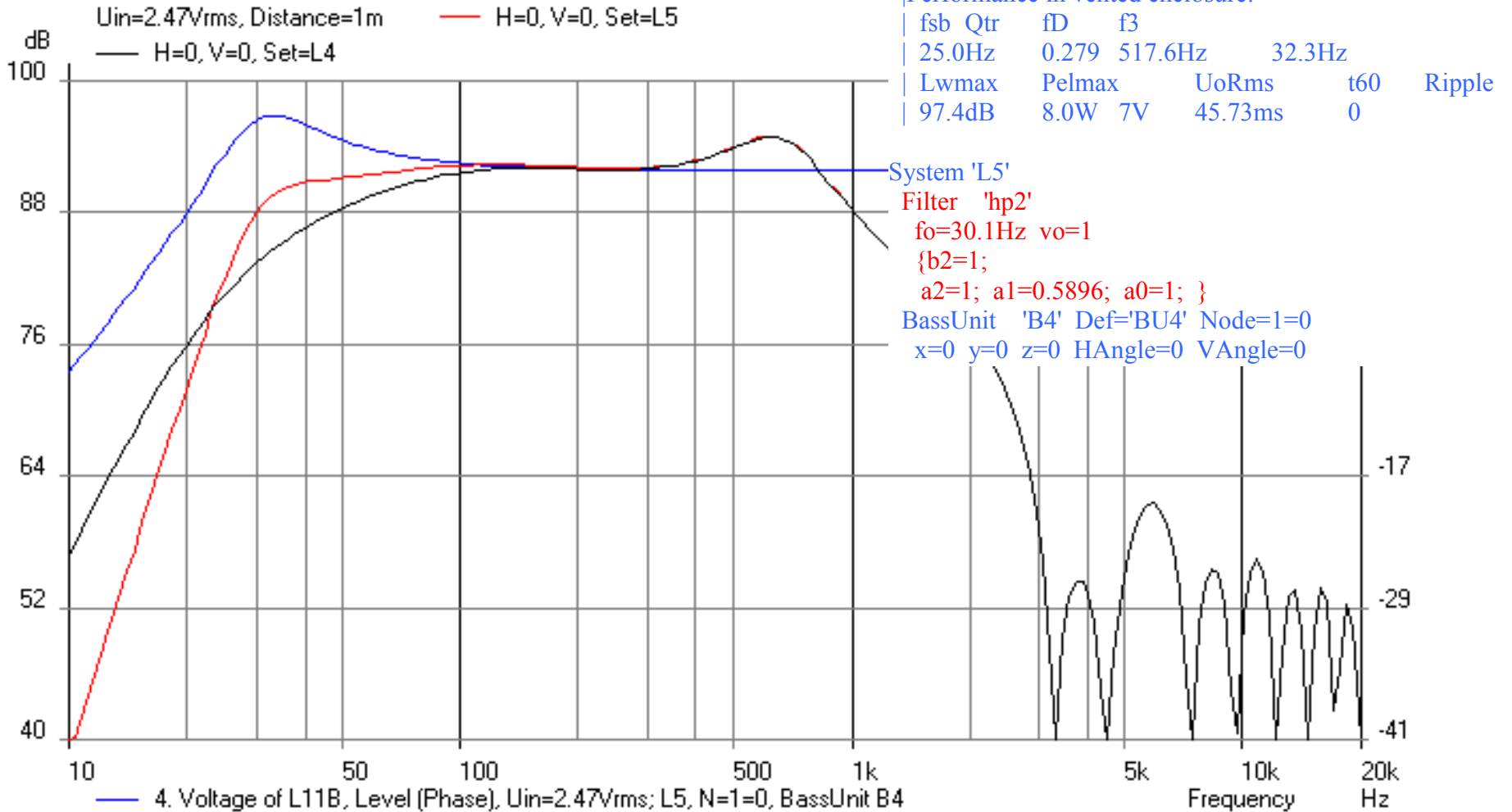
Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (v definičnej časti skriptu)



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

3. Sound Pressure of L11B, Lp (Phase)

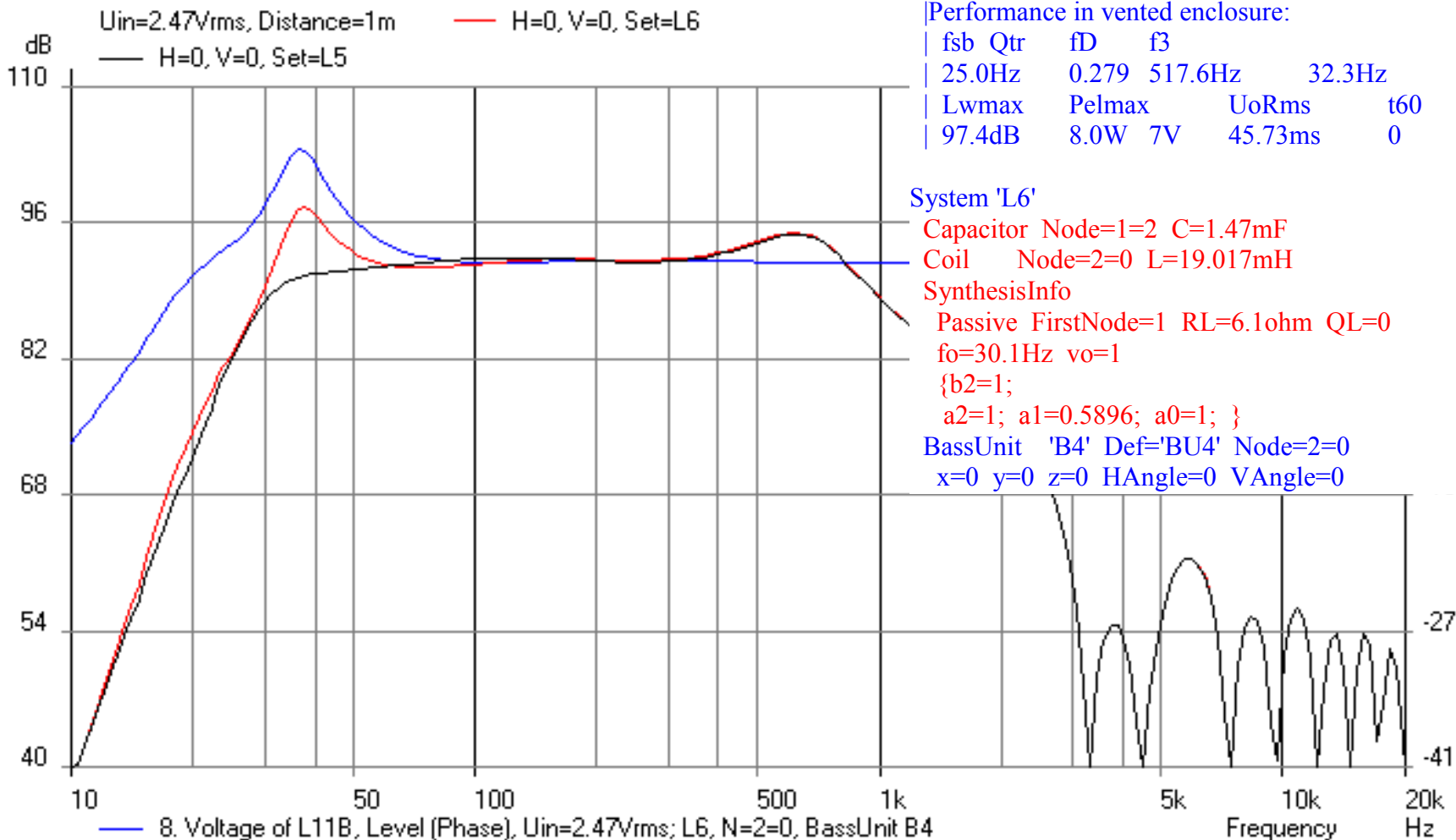


Sústava s basreflexovou ozvučnicou a tvarovacím filtrom (samostatný filter v hlavnej časti skriptu vo forme obvodovej realizácie)

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

7. Sound Pressure of L11B, Lp (Phase)



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

Impedanční křivka

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

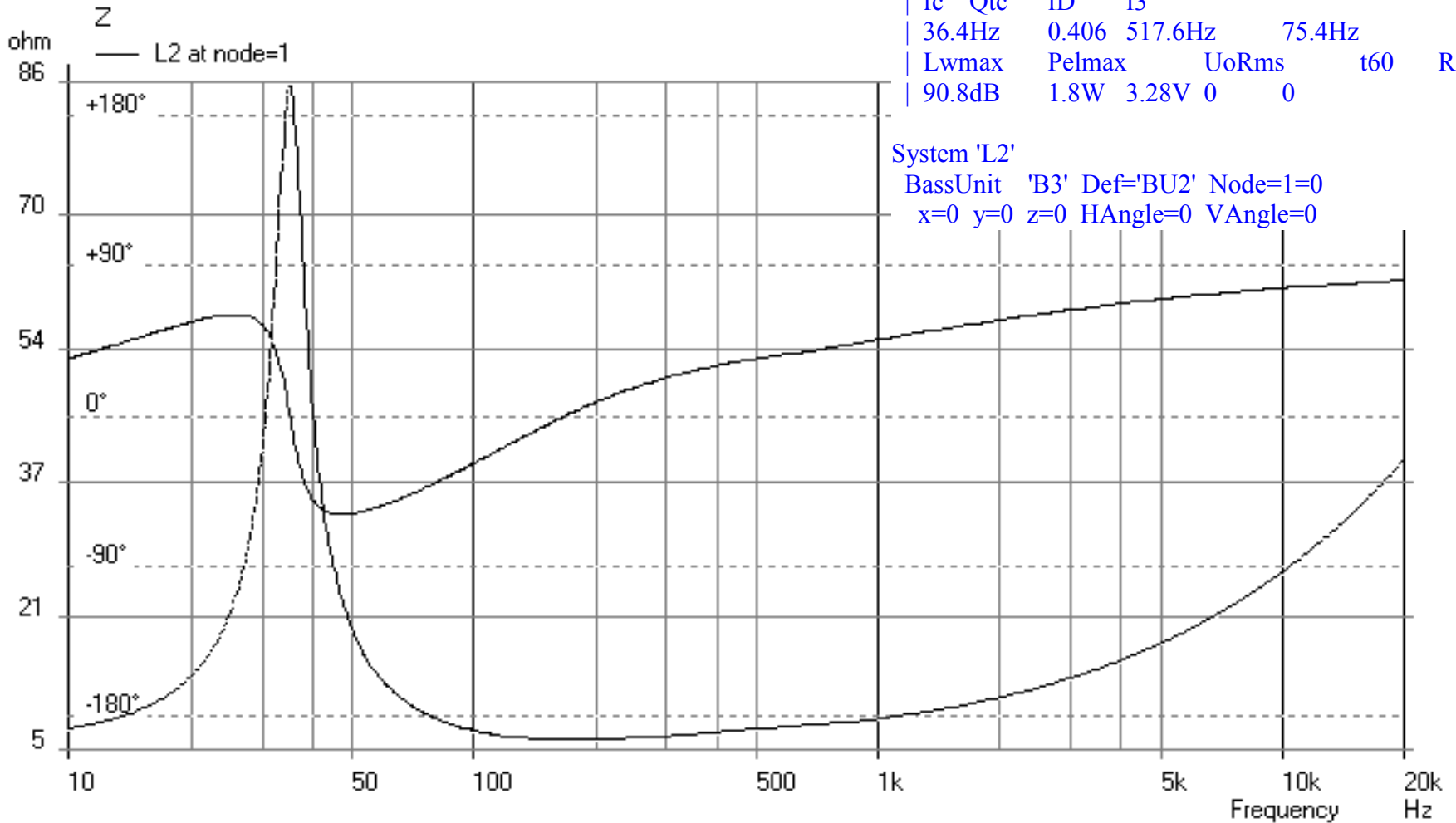
| 90.8dB 1.8W 3.28V 0 0

System 'L2'

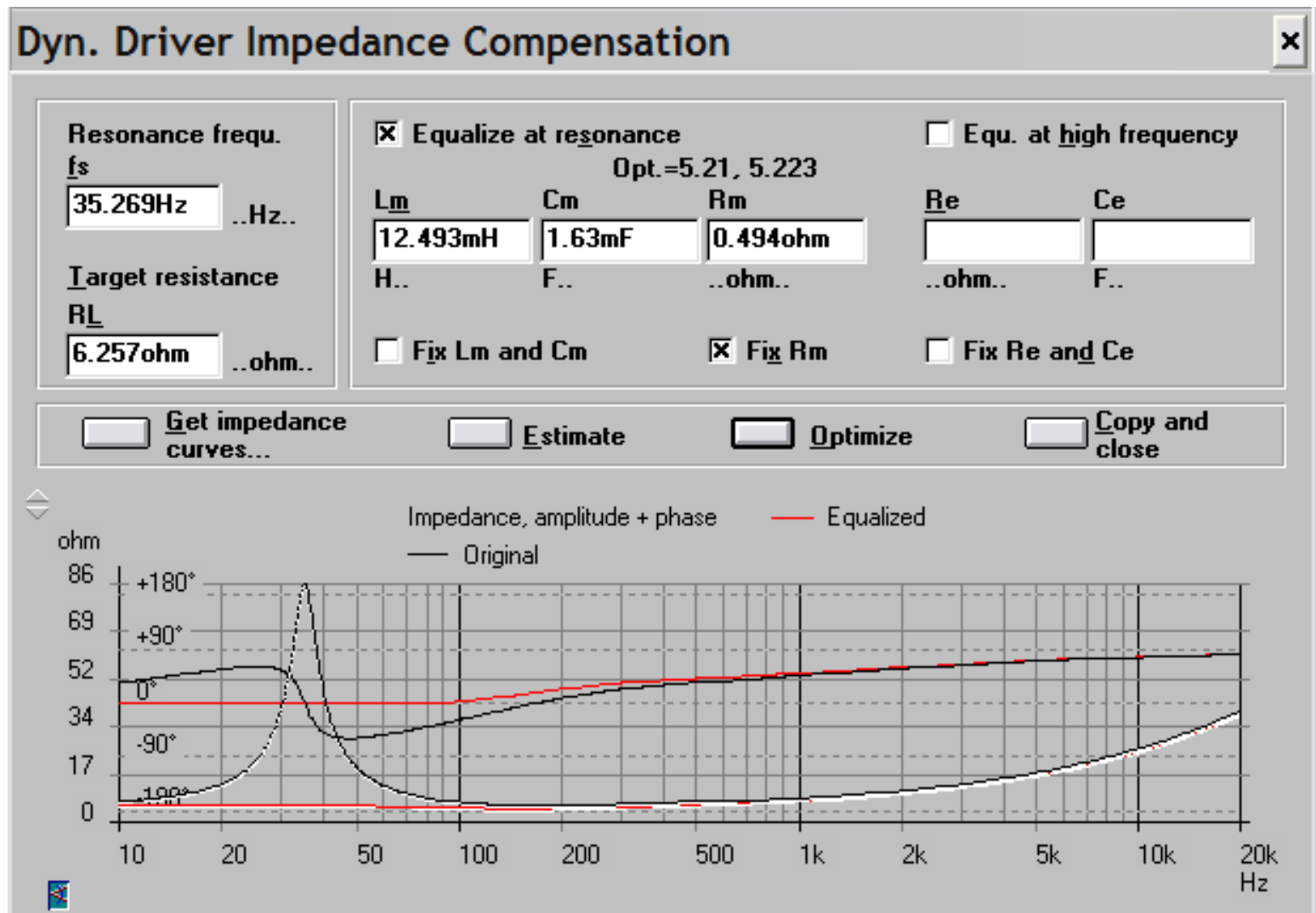
BassUnit 'B3' Def='BU2' Node=1=0

x=0 y=0 z=0 HAngle=0 VAngle=0

10. Impedance of L11B, Amplitude (Phase)



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; }

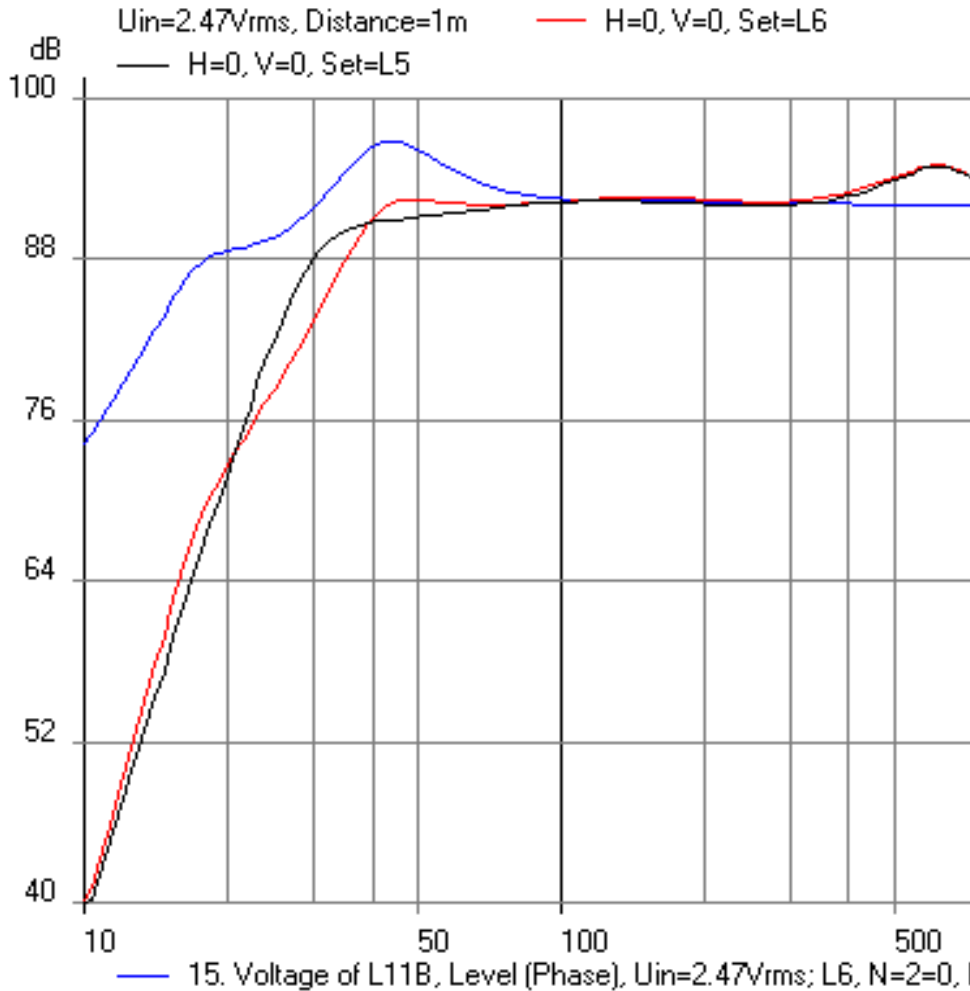
|Impedance compensation

Capacitor Node=2=0 C=1.63mF Rs=6.751ohm Ls=12.494mH

BassUnit 'B4' Def='BU4' Node=2=0

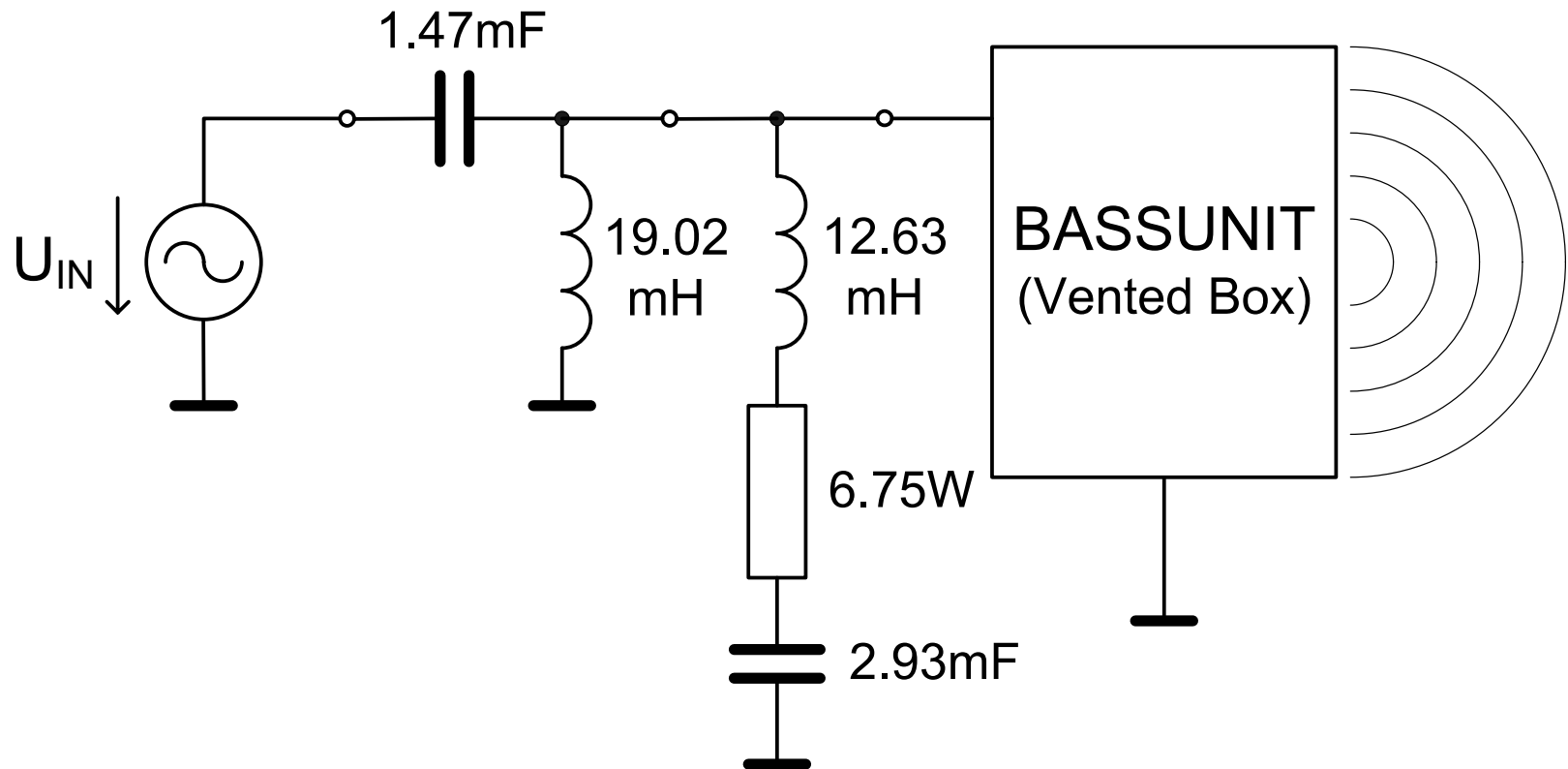
x=0 y=0 z=0 HAngle=0 VAngle=0

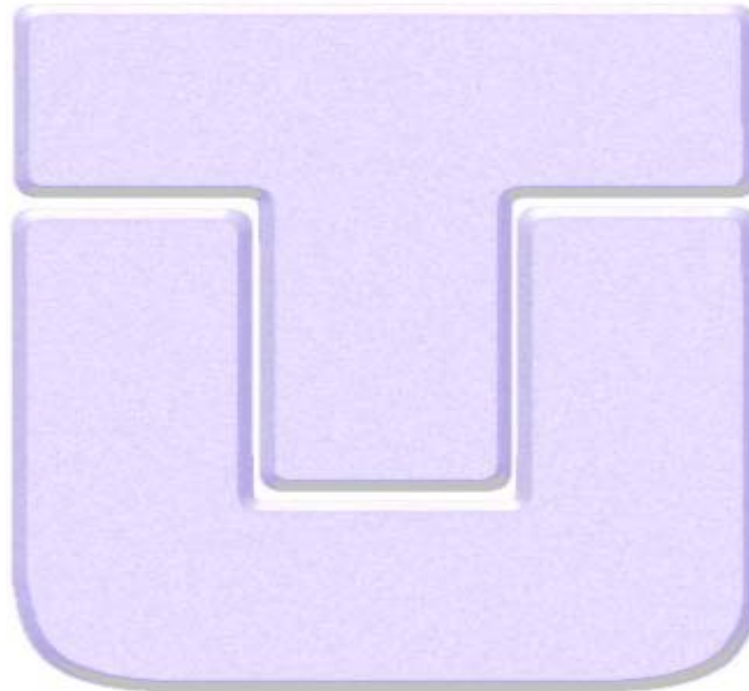
11. Sound Pressure of L11B, Lp (Phase)



15. Voltage of L11B, Level (Phase), Uin=2.47Vrms; L6, N=2=0, BassUnit B4

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





$$\begin{aligned}
H_{CB}(s) &= H_{HPF}(s) \cdot G_{CB}(s) = \frac{s_e^2}{s_e^2 + s_e/Q_e + 1} \frac{s_C^2}{s_C^2 + s_C/Q_{TC} + 1} = \\
&= \frac{s_e^2 s_C^2}{s_e^2 s_C^2 + s_e s_C^2 / Q_e + s_C s_e^2 / Q_{TC} + s_e^2 + s_C^2 + s_e s_C / Q_{TC} Q_e + s_C / Q_{TC} + s_e / Q_e + 1} = \\
&= \frac{s_0^4}{s_0^4 + s_0^3 \sqrt{\frac{\omega_e}{\omega_C}} \frac{1}{Q_e} + s_0^3 \sqrt{\frac{\omega_C}{\omega_e}} \frac{1}{Q_{TC}} + \frac{\omega_C}{\omega_e} s_0^2 + \frac{\omega_e}{\omega_C} s_0^2 + s_0^2 \frac{1}{Q_{TC} Q_e} + s_0 \sqrt{\frac{\omega_e}{\omega_C}} \frac{1}{Q_{TC}} + s_0 \sqrt{\frac{\omega_C}{\omega_e}} \frac{1}{Q_e} + 1}
\end{aligned}$$

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

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

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

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

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

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

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

**Prenosová funkcia
reproduktora v zatvorenej
ozvučnici s tvarovacím filtrom**

Aproximácia B4:

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

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

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

$$a_1 = a_3 \Rightarrow h_e = 1 \Rightarrow f_e = f_c$$

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

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;

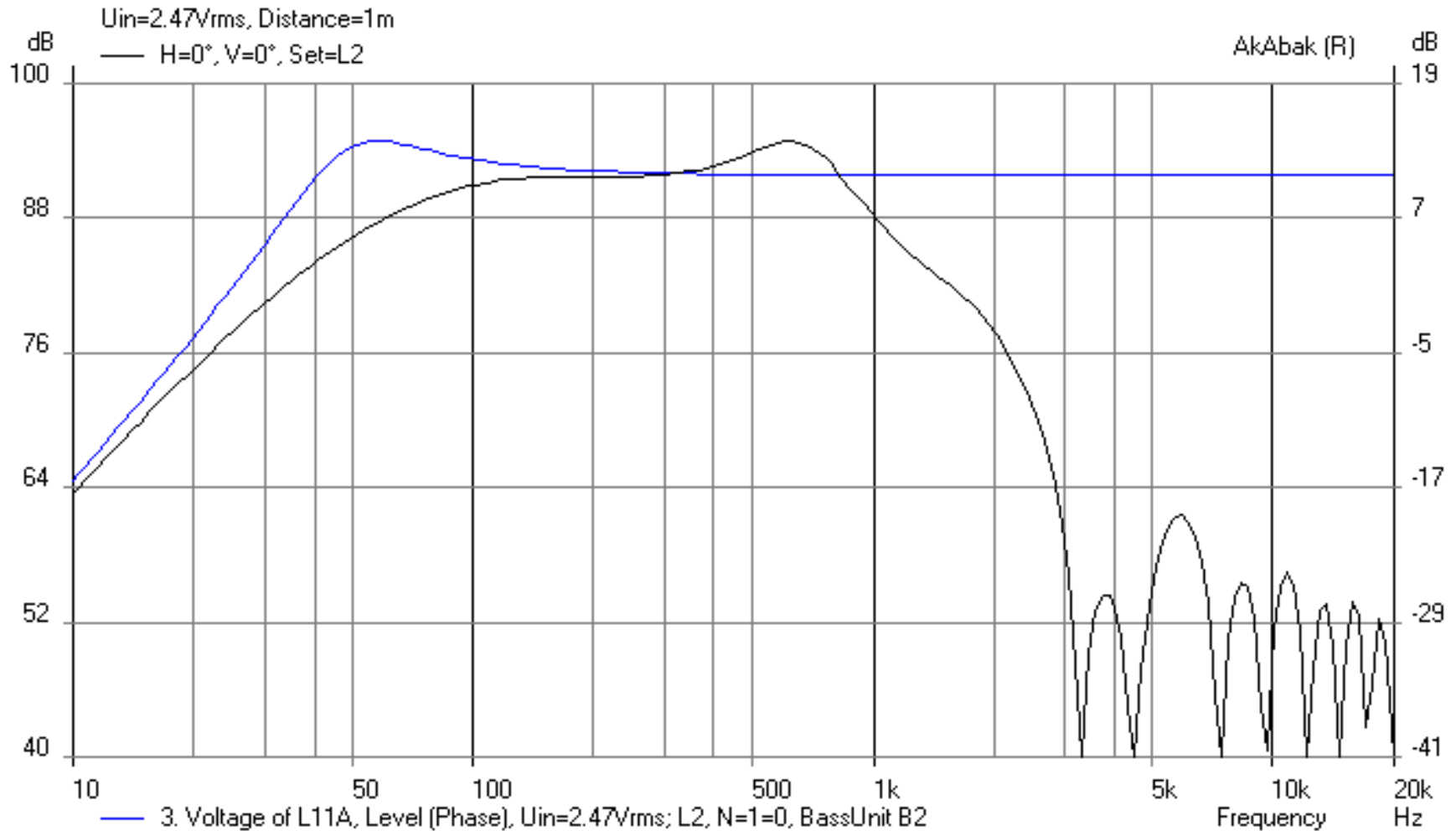
a2=1; **a1=0.765111**; a0=1; }

BassUnit 'B2' Def='BU1' Node=1=0

x=0 y=0 z=0 HAngle=0 VAngle=0

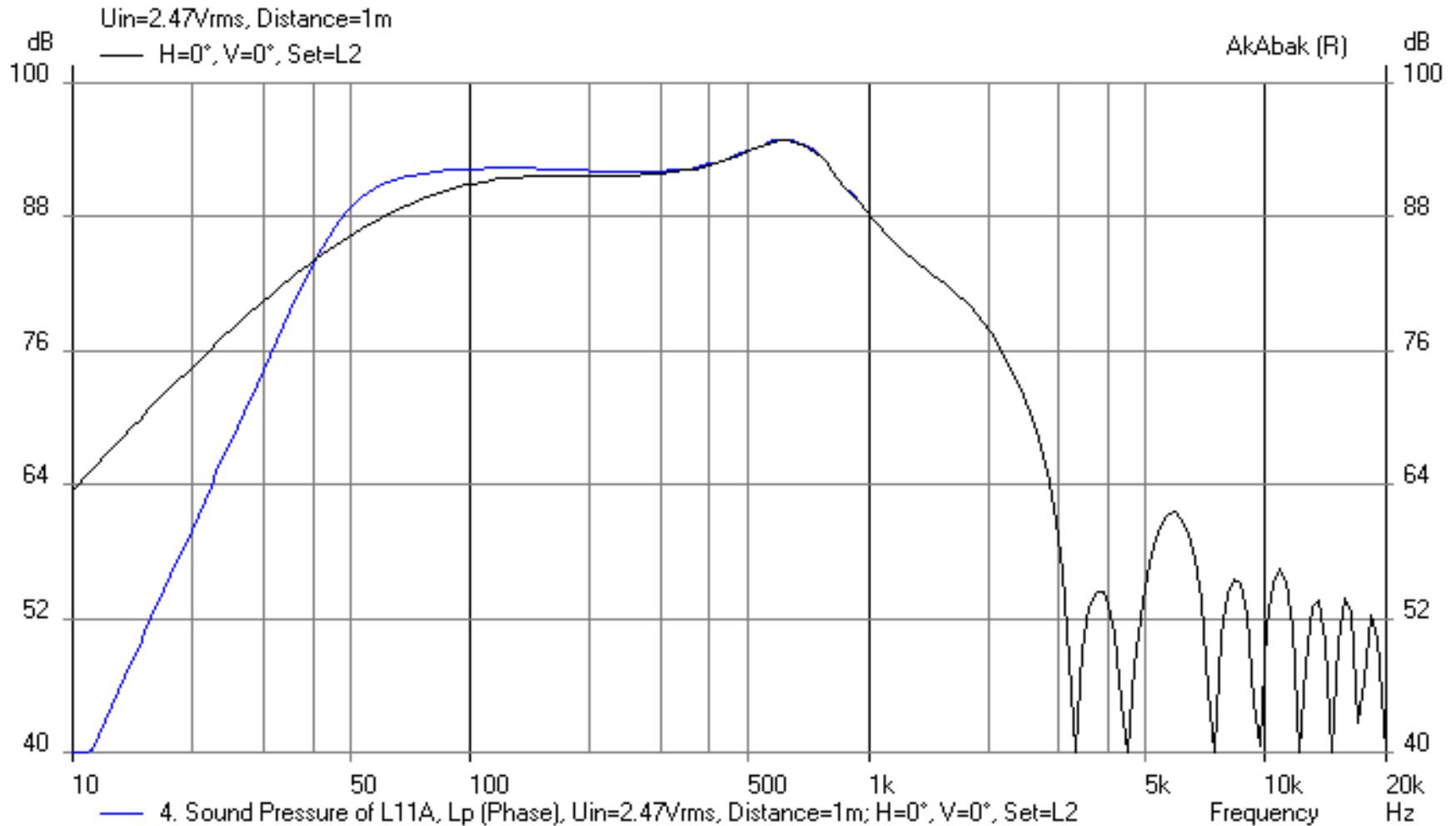
AFCH reproduktora (CB) bez filtra a AFCH filtra

2. Sound Pressure of L11A, Lp (Phase)



AFCH reproduktora (CB) bez filtra a s filtrom

2. Sound Pressure of L11A, Lp (Phase)



Aproximácia LR4:

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

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

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

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

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

