

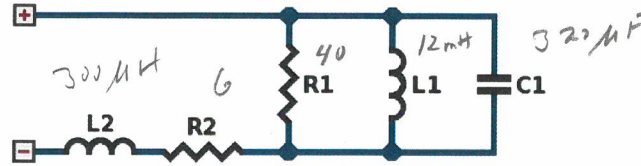
## A more precise model of speaker impedance.

Version of 22 November 2008.

[Home.](#)

Calculations on the home page assumed that speakers exhibit a constant impedance throughout their frequency range. Although this simplification is adequate for many purposes, a finer model is sometimes required. The diagram below illustrates the connections of one popular scheme that uses:

- two [resistors \[w\]](#), labeled  $R_1$  and  $R_2$
- two [inductors \[w\]](#), labeled  $L_1$  and  $L_2$
- one [capacitor \[w\]](#), labeled  $C_1$



A convenient text notation for this wiring is Ser (Par ( $R_1, L_1, C_1$ ),  $R_2, L_2$ ) where Ser stands for series and Par for parallel. In this report, this model is called *RLC-RL*.

With well-chosen values for the five components, this network can fairly well approximate the impedance behavior of a typical dynamic speaker for guitar, as input varies over the range of audio frequencies, 20 Hz to 20 kHz. RLC-RL is most accurate when the speaker is not mounted in any cabinet or on any baffle — the "free air" condition. In practice however, speakers need to be in cabinets for two reasons: (1) to protect the speaker from damage, and (2) to prevent a low-frequency wave originating from the back of the speaker from circling around and cancelling the opposite-phase wave originating from the front of the speaker. For precise modeling of the effects of a cabinet, a model more sophisticated than RLC-RL is required; among other reasons, the enclosure has a resonant frequency depending on its volume.

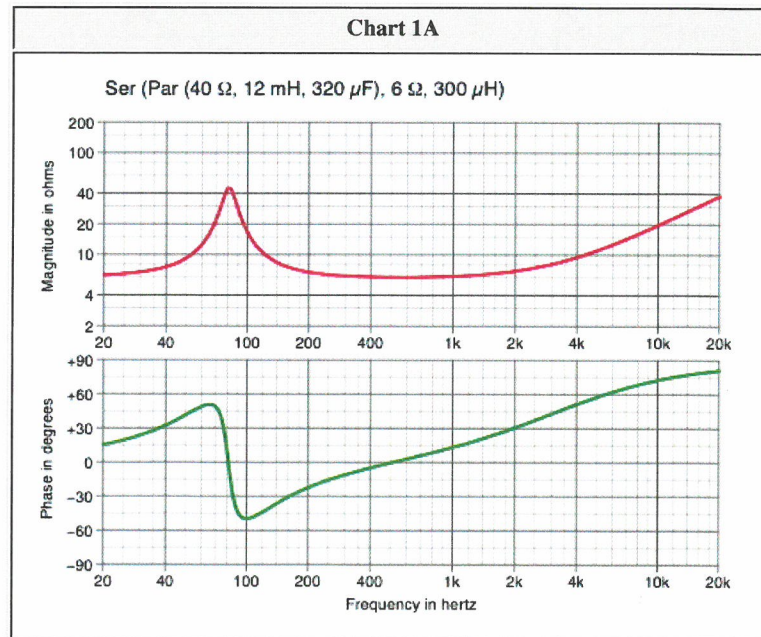
Some manufacturers publish charts showing how impedance of their speakers varies with frequency, for instance:

- [Jensen \(example\)](#)
- [Eminence \(example\)](#)
- [B&C \(example\)](#)

Such charts routinely include the magnitude of the complex impedance, but not the phase. It turns out that for dynamic speakers, the phase is roughly proportional to the [derivative \[w\]](#) of the magnitude, so at least the phase can be estimated. The phase of a dynamic speaker might lie anywhere between  $-90^\circ$  and  $+90^\circ$ , but amplifiers usually perform best when the phase is between  $-45^\circ$  and  $+45^\circ$ . Otherwise, the amplifier can be delivering substantial voltage and current, yet little power.

The network Ser (Par ( $40 \Omega, 12 \text{ mH}, 320 \mu\text{F}$ ),  $6 \Omega, 300 \mu\text{H}$ ) was selected as a benchmark for comparison within this report because it approximates the electrical characteristics of a typical guitar speaker. Its impedance curves are displayed three different ways in charts 1A, 1B and 1C.

Chart 1A contains two graphs pertaining to the impedance of the benchmark: in the upper a red curve for the magnitude, and in the lower a green curve for the phase.



Magnitude is scaled logarithmically in chart 1A, as is the industry custom, although linear scaling is a practicable option. On the other hand, there is little choice but linear scaling for the phase, because it can be positive, zero or negative.

Chart 1B represents the same information in a completely different format. The purple curve represents the impedance of the benchmark speaker at various frequencies, some labeled. Noteworthy is that between 20 Hz and 500 Hz the plot is almost a circle, while above 500 Hz it is almost a straight line.

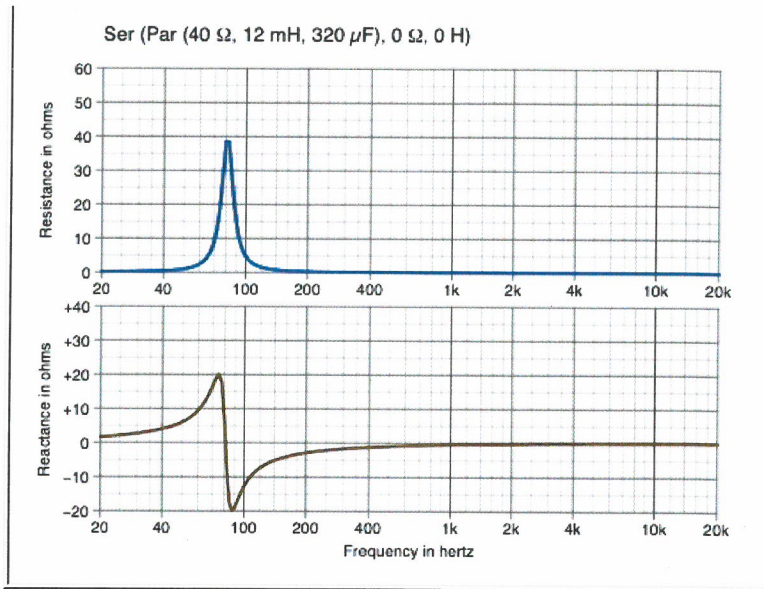
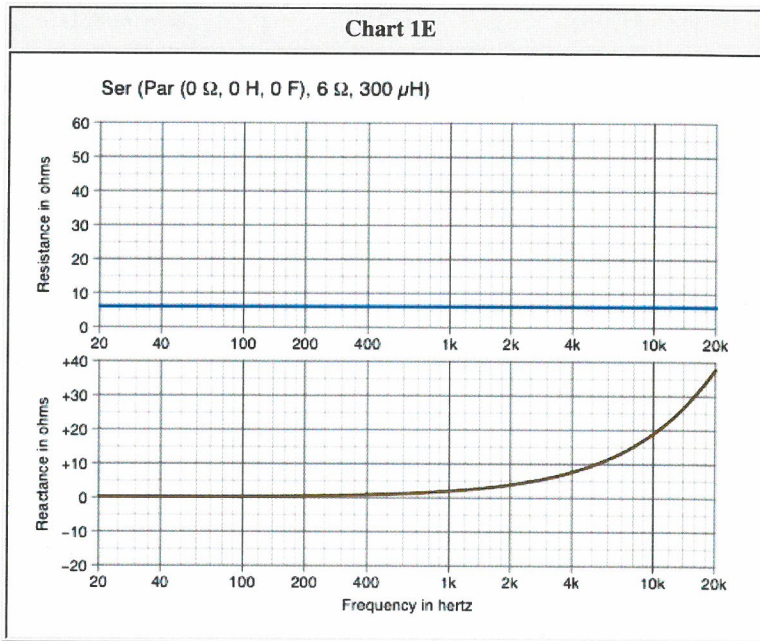


Chart 1E shows that the effect of  $R_2$  is constant throughout the whole range of frequencies (blue curve), and  $L_2$  has little influence below 400 Hz (brown curve). For this chart,  $R_1$ ,  $L_1$  and  $C_1$  have been zeroed.

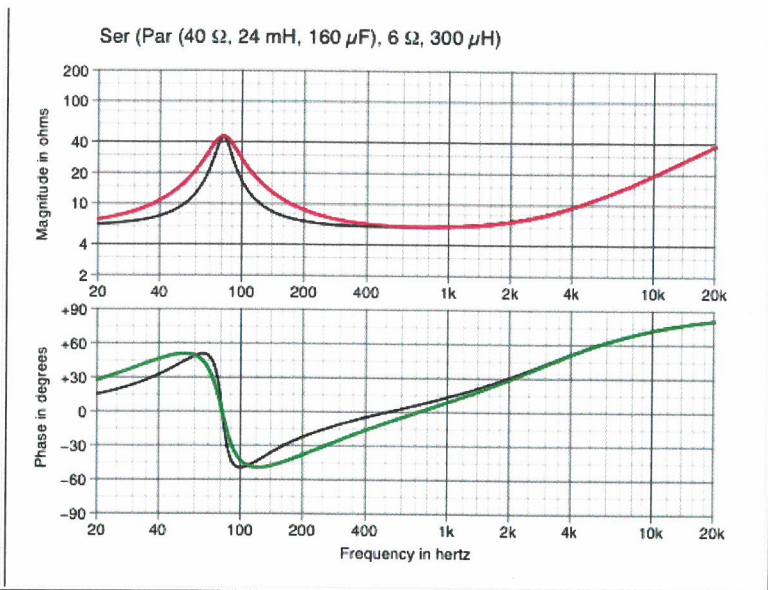
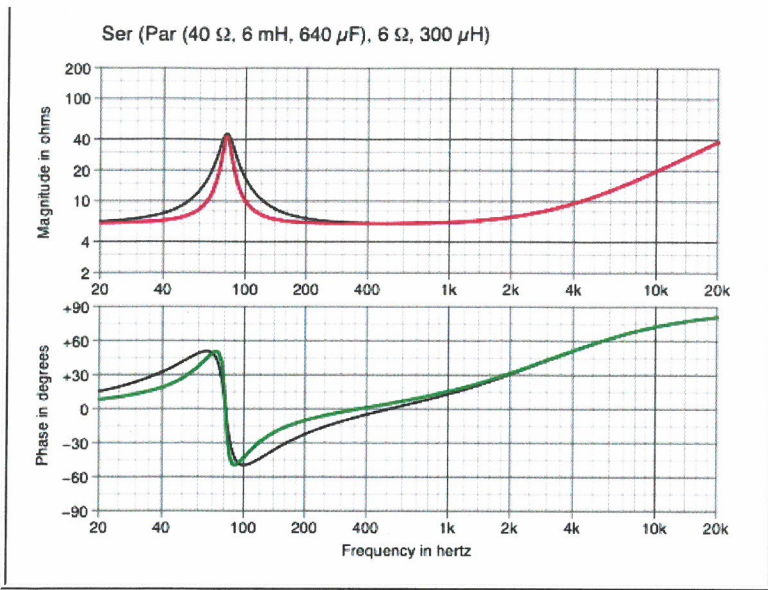


Most dynamic speakers have impedance curves that allow the separation of roles illustrated in charts 1D and 1E, although the exact numbers will vary.

Charts 2 through 7 double and halve the values of various components to illustrate how the impedance curve can be adjusted to more closely match laboratory measurements of a real-world speaker. The ratio 2.0 was selected merely because it yields convenient examples; any other nonnegative real number is also eligible.

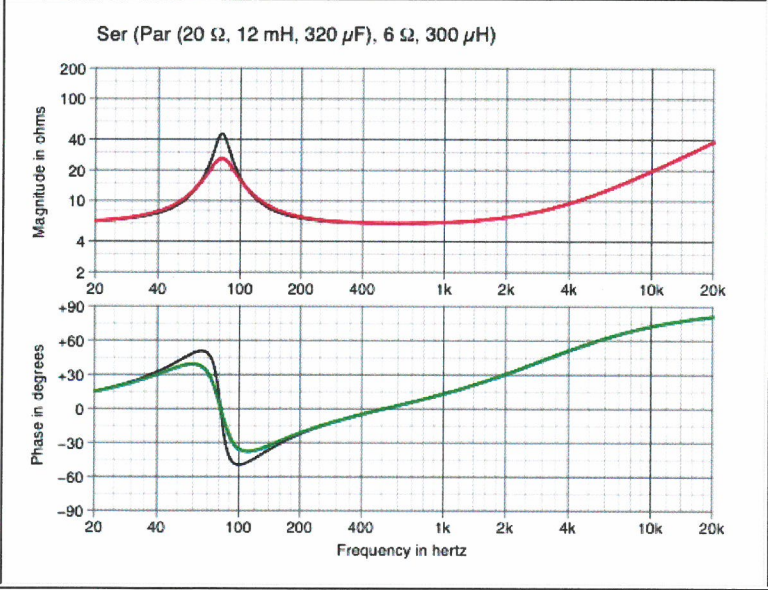
Drawn for comparison are black curves representing the magnitude or phase of the impedance of the benchmark speaker (chart 1A). When lying at the same ordinate as the red or green curves, the black curves will be eclipsed.

<b>Scale the overall impedance</b>	
<p style="text-align: center;"><b>Chart 2A</b></p> <p style="text-align: center;">double <math>C_1</math> and halve all other components — to decrease impedance</p>	<p style="text-align: center;"><b>Chart 2B</b></p> <p style="text-align: center;">halve <math>C_1</math> and double all other components — to increase impedance</p>

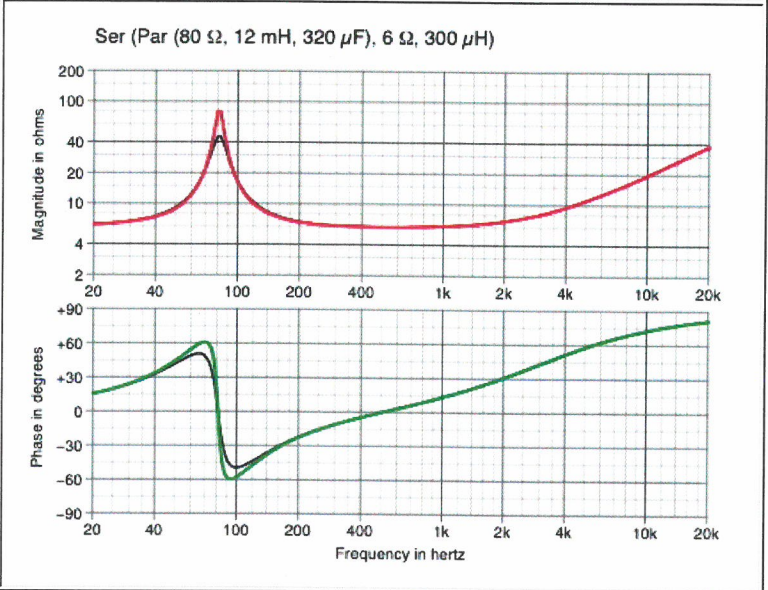


**Change peak impedance at primary resonance**

**Chart 5A**  
halve  $R_1$  — to decrease impedance



**Chart 5B**  
double  $R_1$  — to increase impedance

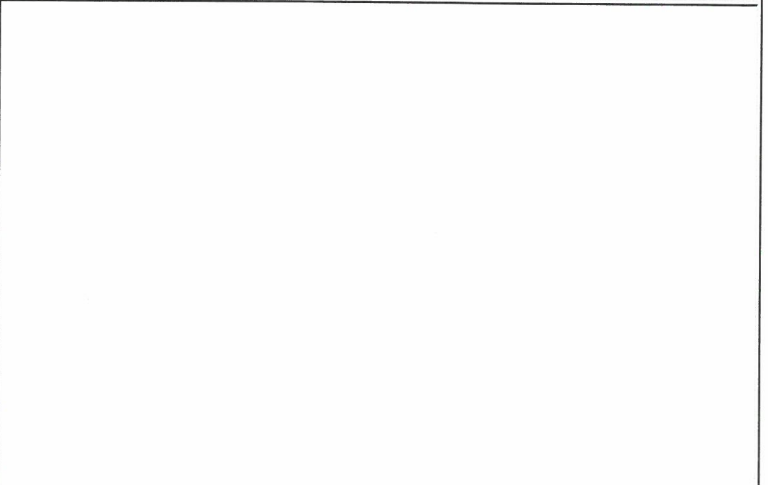


**Change minimum impedance**

**Chart 6A**  
halve  $R_2$  — to decrease impedance



**Chart 6B**  
double  $R_2$  — to increase impedance



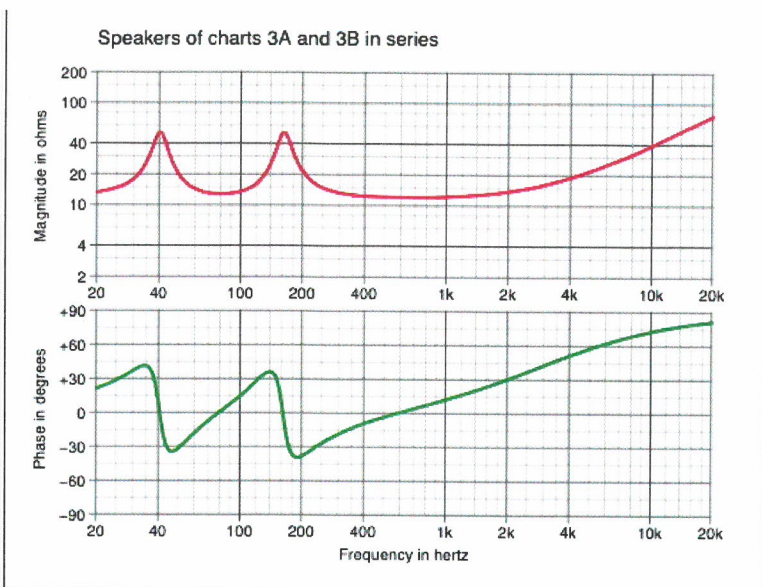
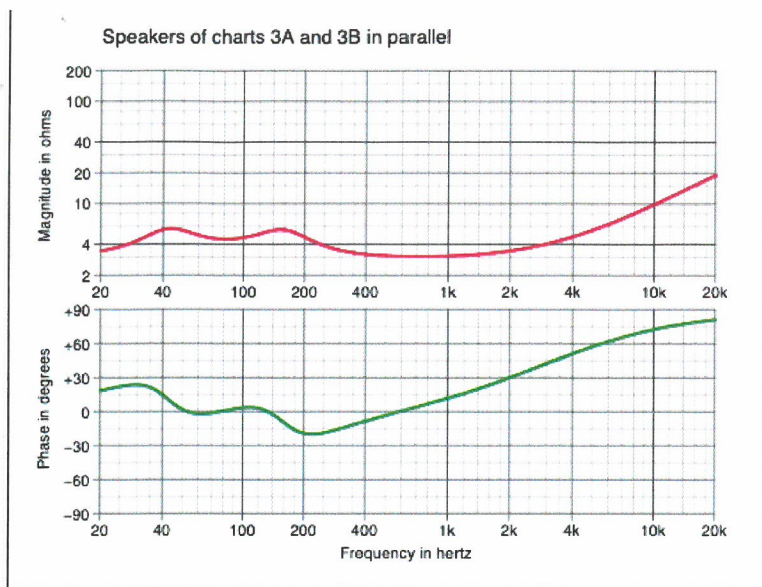


Chart 8A displays how the parallel connection largely eliminates any impedance spike at primary resonance, and reduces the phase angle in that region of frequencies. This results in a load that may be easier for an amplifier to drive. Still, caution must be observed with power handling, because at 40Hz speaker 3A presents an impedance magnitude of about 40  $\Omega$  and speaker 3B presents only about 6  $\Omega$ . Thus at this frequency 13% of current passes through speaker 3A, and 87% of current passes through speaker 3B. A similar phenomenon occurs at 160 Hz. With such uneven distribution of current, hence power, the overall power handling is little more than that of one speaker.

Chart 8B shows how series connection preserves both of the spikes, giving a clue how to model a speaker with more than one resonance peak — regard it as two RLC-RL speakers in series. Although multiple peaks are not common with guitar speakers, they are more likely with midrange and tweeter devices.

Recall these specifications from:

- Chart 3A: Ser (Par (40  $\Omega$ , 24 mH, 640  $\mu$ F), 6  $\Omega$ , 300  $\mu$ H)
- Chart 3B: Ser (Par (40  $\Omega$ , 6 mH, 160  $\mu$ F), 6  $\Omega$ , 300  $\mu$ H)

Combined in series, and simplified, these become an *RLC-RLC-RL* circuit equivalent to what is found in chart 8B:

- Ser (Par (40  $\Omega$ , 24 mH, 640  $\mu$ F), Par (40  $\Omega$ , 6 mH, 160  $\mu$ F), 12  $\Omega$ , 600  $\mu$ H)

In short, adding another RLC yields another peak.

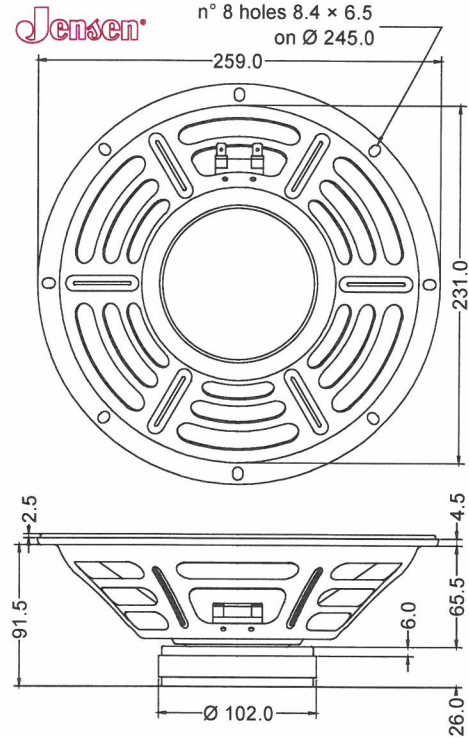
10" - 50 W Mod Series  
Loudspeaker  
Mod 10-50 - 4Ω / 8Ω / 16Ω / 32Ω

General Characteristics		
Nominal Overall Diameter	259 mm	10 in
Nominal Voice Coil Diameter	32 mm	1.26 in
Magnet Weight	426 g	15 oz
Overall Weight	1.68 kg	3.7 lbs
Flux Density		1.1 T

Thiele-Small Parameters		4Ω	8Ω	16Ω	32Ω	
Voice Coil DC Resistance	$R_E$	3.08	6.2	12	24.52	Ω
Resonance Frequency	$f_s$	101.6	107	101	110.6	Hz
Mechanical Q Factor	$Q_{MS}$	16.16	16.84	18.07	16.22	
Total Q Factor	$Q_{TS}$	1.24	1.2	1.53	2.47	
Mechanical Moving Mass	$M_{MS}$	18.1	16.5	18.5	20.6	g
Mechanical Compliance	$C_{MS}$	135	136	134	94	μm/N
Force Factor	$B_{XL}$	5.16	7.28	9.31	11.18	Wb/m
Equivalent Acoustic Volume	$V_{AS}$	2078	20.8	20.4	14.4	lt.
Maximum Linear Displacement	$X_{MAX}$	±2	±1.5	±1.5	±2	mm
Reference Efficiency	$\eta_0$	1.56	1.87	1.22	0.71	%
Diaphragm Area	$S_D$	330.1	330	330	330.1	cm <sup>2</sup>
Losses Electrical Resistance	$R_{ES}$	37.2	81	135	136.5	Ω
Voice Coil Inductance @ 1kHz	$L_E$	0.39	0.62	1.08	1.6	mH
Electrical Q Factor	$Q_{ES}$	1.34	1.29	1.67	2.91	

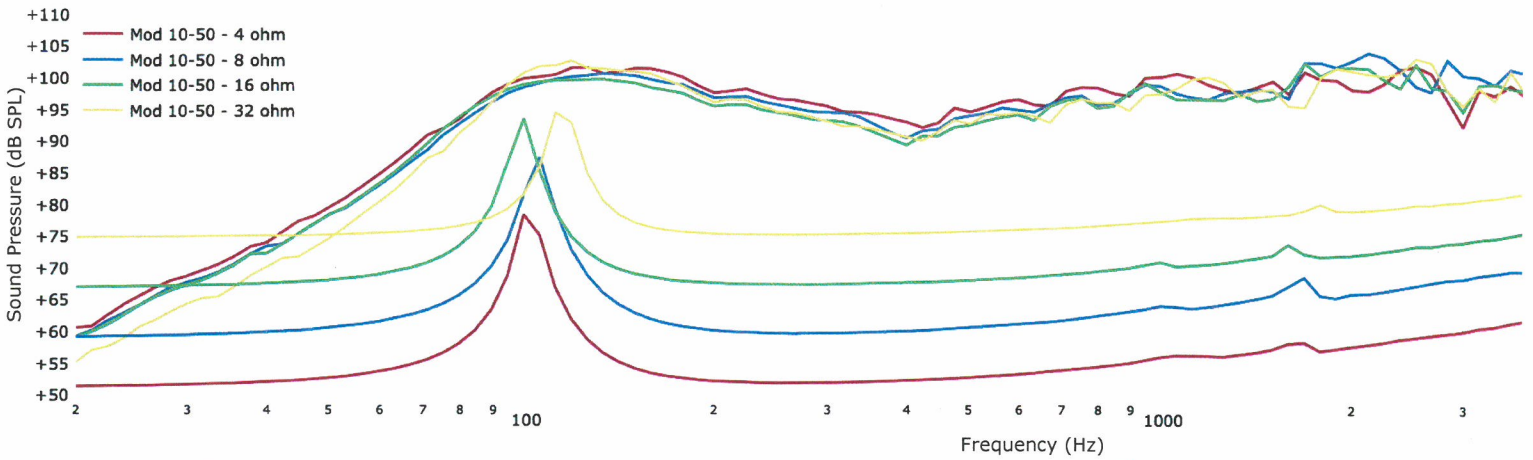
Constructive Characteristics	
Magnet	Ferrite
Voice Coil Winding	Copper
Voice Coil Former	Epotex
Cone Material	Paper
Surround Material	Integrated Paper
Dust Dome Material	Non-treated Cloth
Basket Material	Pressed Sheet Steel

Electrical Characteristics	4Ω	8Ω	16Ω	32Ω	
Nominal Impedance	4	8	16	32	Ω
Rated Power	50	50	50	50	W
Musical Power	100	100	100	100	W
Sensitivity@1W,1m	95.1	95.8	94	91.9	dB



Note: all dimensions are in mm.

Frequency Response on IEC Baffle (DIN45575) @ 1W, 1 m - Free Air Impedance



Due to continuing product improvement, the features and the design are subject to change without notice.

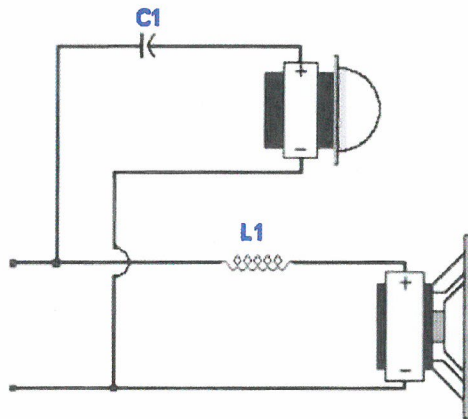
Jensen Loudspeakers · website: [www.jensentone.com](http://www.jensentone.com)

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# 1st Order Butterworth

800 Hertz

8 Ohm Tweeter / 8 Ohm Woofer



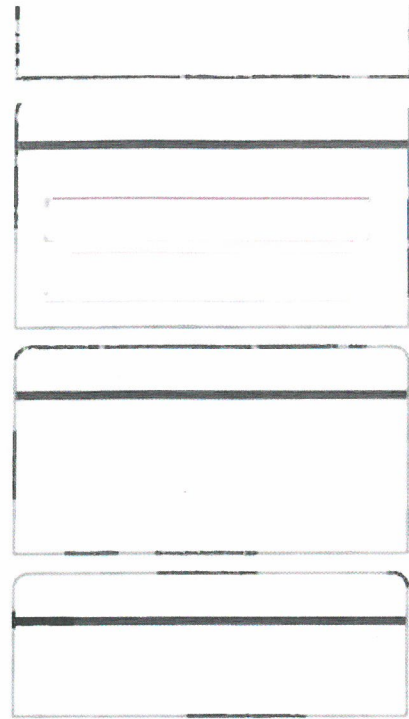
### Parts List

**Capacitors**

**C1** = 24.84  $\mu$ F

**Inductors**

**L1** = 1.59 mH



S.P. 14-E

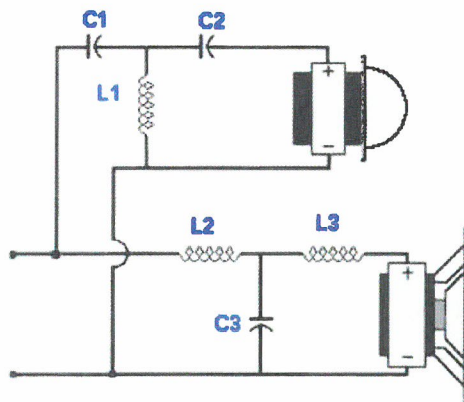
Derive the transfer functions for the the low pass and high pass crossover networks and show that the capacitor and inductor values given make them 3rd order Butterworth filters.

Hint: A simple variable transformation will turn the low pass filter into the high pass filter!

# 3rd Order Butterworth

3000 Hertz

8 Ohm Tweeter / 8 Ohm Woofer



### Parts List

**Capacitors**

**C1** = 4.42  $\mu$ F

**C2** = 13.26  $\mu$ F

**C3** = 8.84  $\mu$ F

**Inductors**

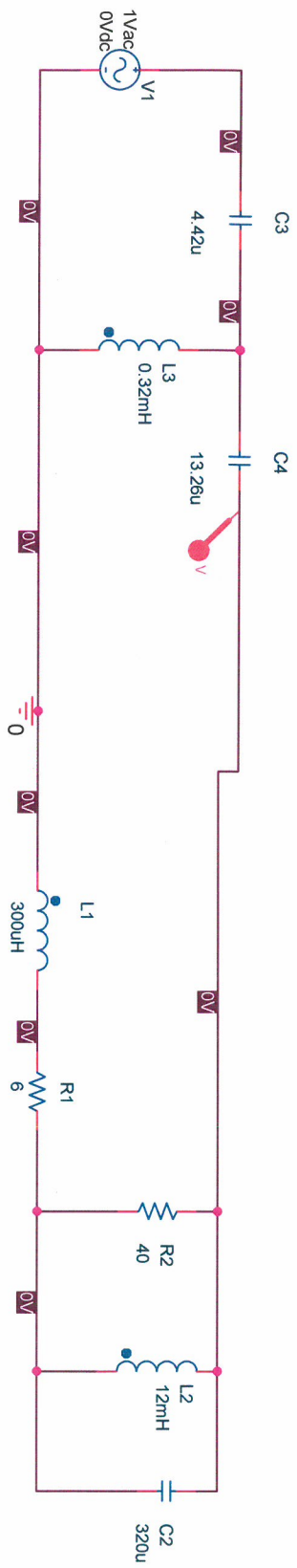
**L1** = 0.32 mH

**L2** = 0.64 mH

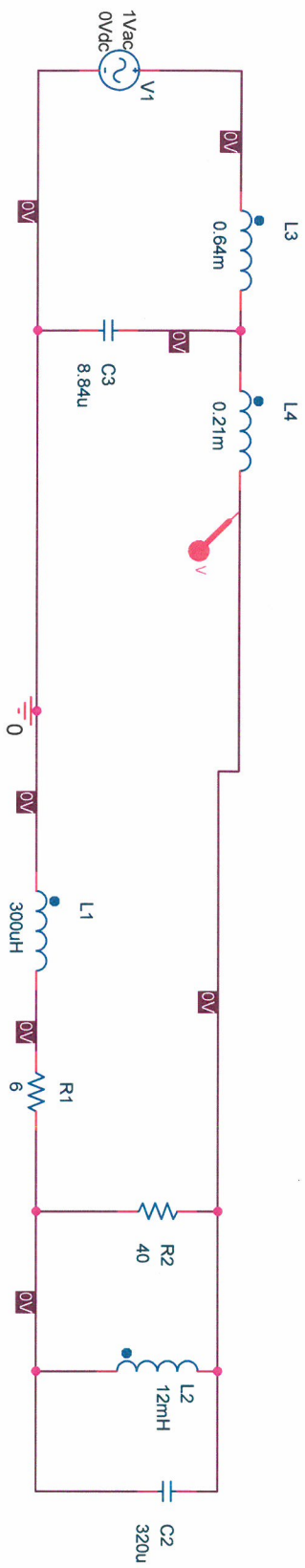
**L3** = 0.21 mH

Now, these two diagrams must be combined into a 3-way diagram. When working with 3 or more speakers, at least one speaker must be bandpass. Bandpass means that the speaker has a high pass filter (HPF) that filters out low frequencies and lets high frequencies pass through, and a low pass filter (LPF) that filters out high frequencies and lets low frequencies pass through. In this system, only the mid will be bandpass. When wiring multiple speakers,

3<sup>rd</sup> order  
H.C.



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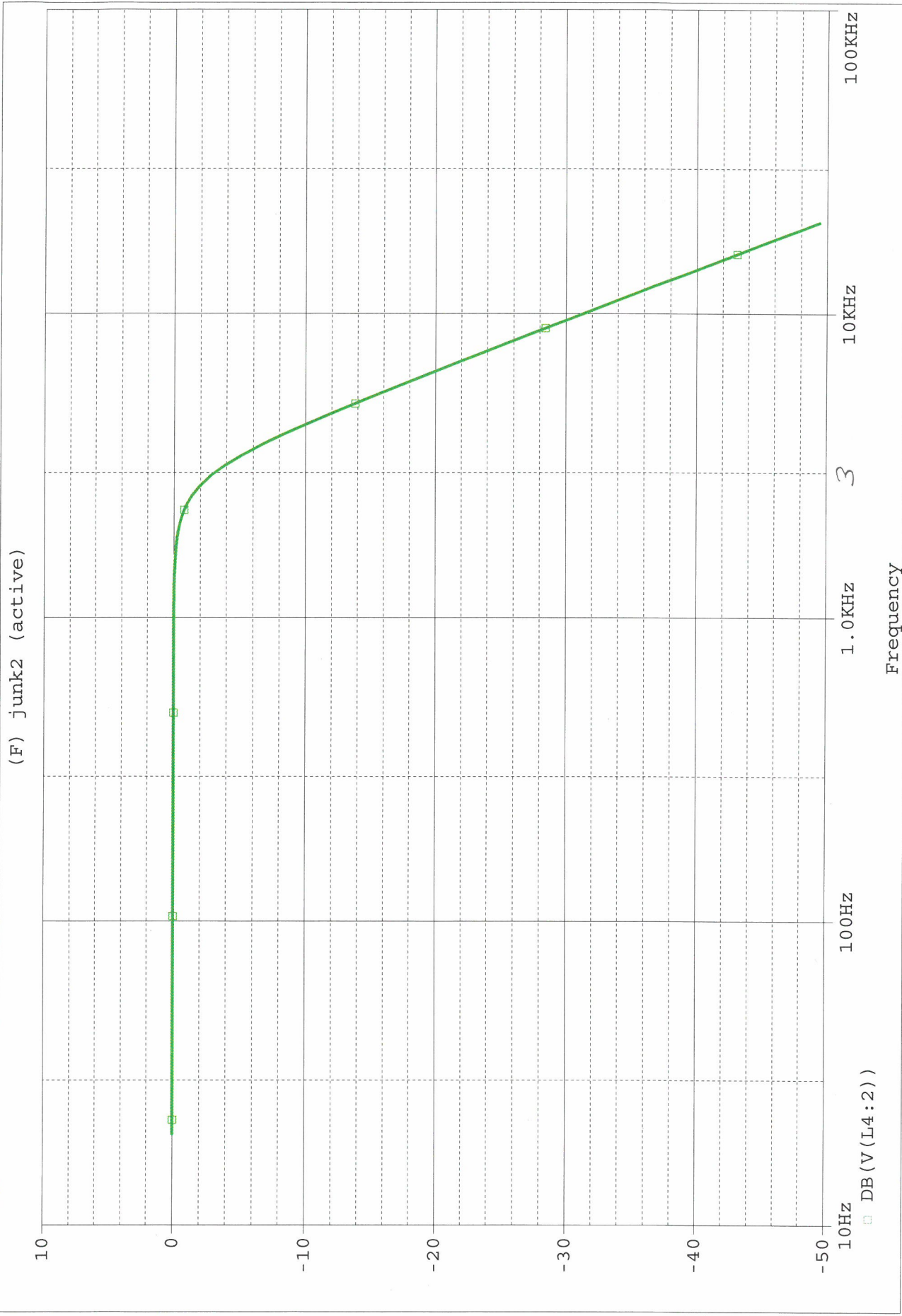


*3rd order L.P.*

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3<sup>rd</sup> order L.P. R = 85 - 100d

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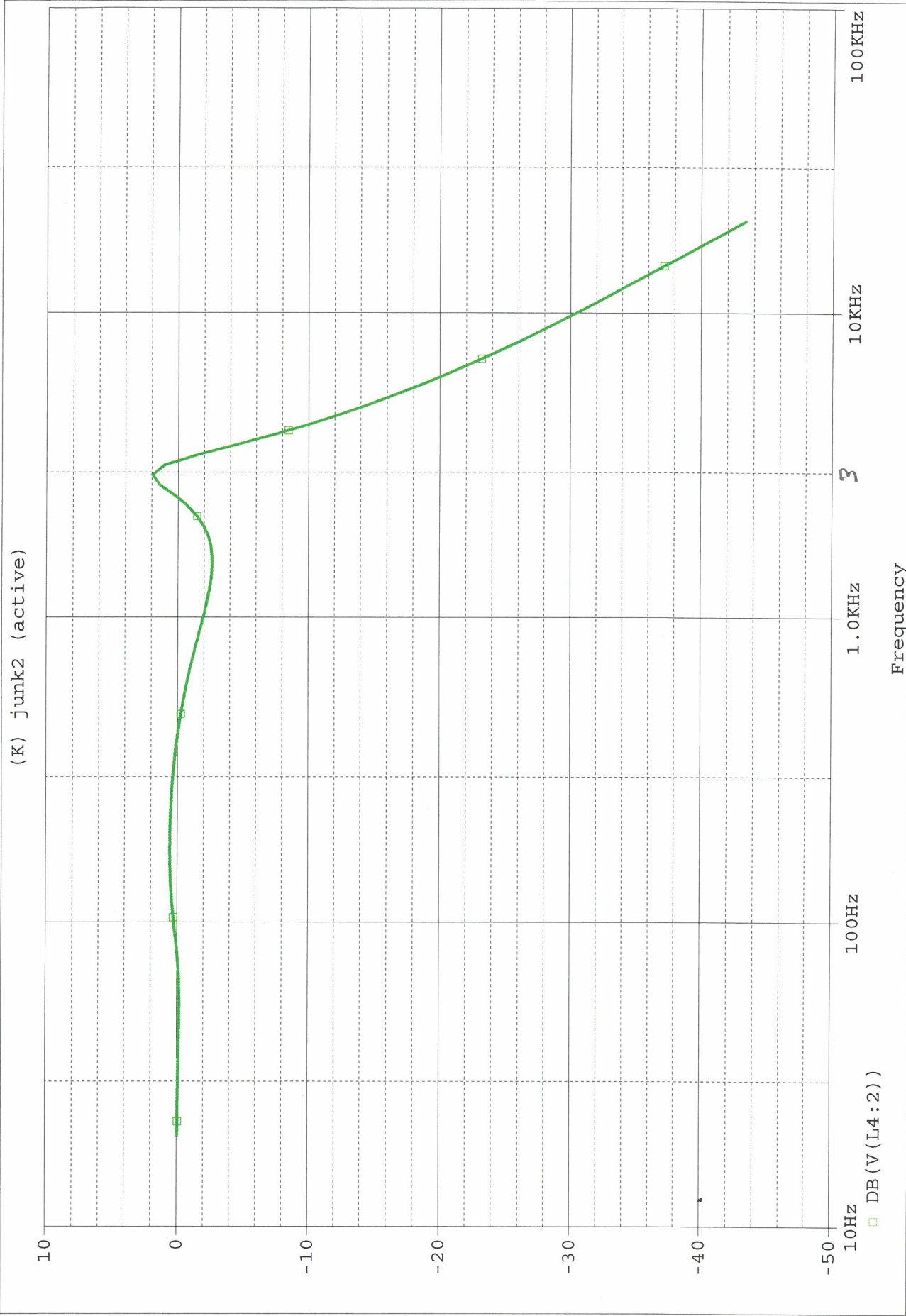
3<sup>rd</sup> order H.P. - R = 8Ω Termination

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3rd order LP  Speaker

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3<sup>rd</sup> order H.P.



Speaker

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