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ABOUT LOUDSPEAKER SYSTEM IMPEDANCE WITH TRANSIENT DRIVE

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ABSTRACT

This experimental work deals with the loudspeaker-amplifier interface. The instantaneous input voltage/current relationships of loudspeakers are measured with low-pass filtered square wave at different levels. These preliminary measurement results allow us to assume that power amplifiers intended to drive loudspeakers should be designed to supply several times the current which could be expected directly from the system nominal impedance.

1. INTRODUCTION

The problems of many amplifiers to supply full power at low frequencies to loudspeaker loads led us to investigate, how does the loudspeaker look from the side of an amplifier, what is the peak current absorbed and how these are related to the system's nominal impedance. A series of measurements was performed first with real program signals, with strong LF content (like setting phonograph stylus onto groove, synthesizers etc.) and later with filtered square waves. During the work it was found that the system behaviour itself is independent of frequency.

The amplifier, being basically a voltage source, does not know, whether the current is flowing to a resistance or a reactance, therefore we define the measurement result, instantaneous input voltage divided by instantaneous current, as an Apparent Load (Z_{al}), expressed in ohms. The ratio, nominal impedance (Z_{nom} , manufacturer's spec.) divided by the apparent load gives an indication of the current increase factor when driving this particular system, as compared to driving a purely resistive, "nominal" load.

2. MEASUREMENTS

First input resistance R_{vc} , impedance magnitude $|Z|$ and impedance phase φ measurements were carried out to all systems. Then, with a filtered square wave (1st order low-pass at 20 kHz) having constant amplitude, a frequency was found where load current had a maximum. Z_{al} was measured at this frequency at different levels. The measurement setup is shown in Fig. 1.

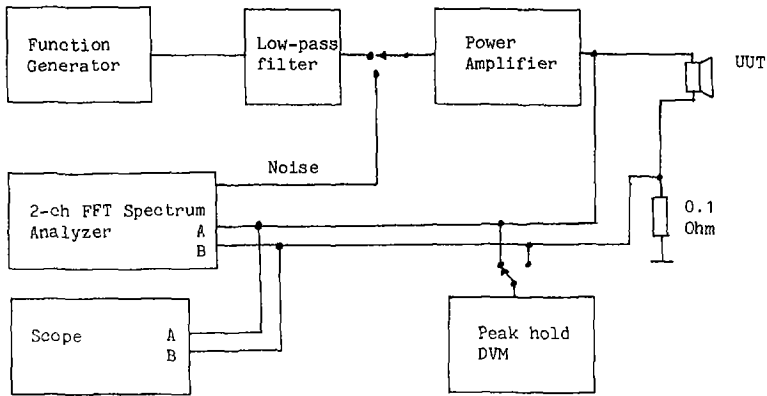


Fig.1. Measuring setup

3. MEASURING RESULTS

Measured systems and their fundamental characteristics are listed in Table 1. Impedance plots and Z_{al} at different levels are presented in Figs. 2...19.

No	Type	Nominal impedance (Mfg.spec.) ohms	R_{vc} ohms	Z_{al} (minimum) ohms
1	Woofer in a closed box	8	6.2	4.8
2	Woofer in a vented box	8	6.2	4.7
3	Closed-box 2-way system	8	7.5	3.4
4	Closed-box 2-way system with a dual voice coil woofer	4	4.0	2.2
5	Closed-box 3-way system with B3 low-frequency response	8	7.1	2.8
6	Vented-box 3-way system	6	7.2	3.0
7	Full-range electrostatic system	4...15	0.6	1.8

Table 1. The characteristics of the measured speaker systems

3.1. Woofer in a closed box

The impedance magnitude and phase are shown in Fig.2 and the Z_{al} values in Fig.3. Z_{nom}/Z_{al} is around 1.6, ($R_{vc}/Z_{al} = 1.3$) and peak current occurs at 88 Hz. Z_{al} rises with increasing signal level.

3.2. Woofer in a vented box

The impedance magnitude and phase are shown in Fig.4 and the Z_{al} values in Fig.5. $Z_{nom}/Z_{al} \approx 1.7$, ($R_{vc}/Z_{al} = 1.3$), peak current frequency is 26 Hz. Heat generated during measurement affects the values at higher levels, therefore test time was less than one second.

3.3 2-way closed-box system

The impedance and Z_{al} data are presented in Figs. 6, 7 and 8. Two peak current frequencies are observed, 92 Hz and 1.32 kHz. $Z_{nom}/Z_{al} = 2.4$, ($R_{vc}/Z_{al} \approx 2.2$).

3.4 2-way closed-box system with a dual voice coil in the woofer

The impedance and Z_{al} values are shown in Figs. 9 and 10. The impedance plot is quite flat throughout the frequency range, therefore only LF part is presented. $Z_{nom}/Z_{al} = 1.5$ with low level, but increases to 1.8 at higher level, indicating some form of nonlinearity. Peak current occurs at 64 Hz.

3.5 Three-way closed-box system with B3 low-frequency response

The impedance and Z_{al} characteristics are shown in Figs. 11, 12 and 13. R_{vc} is measured inside the system, after the series capacitor. Z_{nom}/Z_{al} is around 2.6, ($R_{vc}/Z_{al} \approx 2.3$) but higher level causes a drop in Z_{al} and Z_{nom}/Z_{al} rises to 2.9. Current maximum is at 76 Hz with a smaller peak around 2.5 kHz.

3.6 Three-way vented-box system

The impedance and Z_{al} behaviour are presented in Figs. 14, 15 and 16. The manufacturer has rated the system to 6 ohms although R_{vc} is 7.16 ohms, obviously due to the 4.9 ohm impedance minimum around 120 Hz. Z_{nom}/Z_{al} is 2.0, ($R_{vc}/Z_{al} \approx 2.3$) and at higher level some step-type nonlinearity takes place. Z_{al} rises from 3.13 ohms to 3.85 ohms in 0.2 seconds and increases then slowly due to heating. Peak current is observed at 80 Hz and an almost similar peak at 4.4 kHz.

3.7 Full-range electrostatic speaker system

The impedance and Z_{al} characteristics are presented in Figs 17, 18 and 19. At 1.6 kHz, where $|Z| \approx 13$ ohms, $|Z|/Z_{al} = 4.9$ and at 20 kHz the ratio is 1.13. Peak current frequency is 20 kHz but the peak value is fairly flat over the entire frequency range. This speaker system is commonly regarded as a difficult load, but mainly because of amplifier instability it has caused.

4. DISCUSSION

In the impedance plots also phase response is shown. The peak current frequency appears to be near to the frequency (frequencies) where the capacitive reactance has a maximum. To refresh the basics, a simplified electrical equivalent circuit of a loudspeaker (at resonance) is shown in Fig.20.

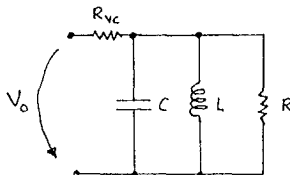


Fig.20. A simplified electrical equivalent circuit of a speaker

Above resonance the capacitance mainly defines the circuit current and assuming the parallel impedances to be high compared to R_{vc} , the capacitor voltage approaches V_o . Changing the source voltage to $-V_o$ causes an instantaneous current of $2V_o/R_{vc}$ through the circuit. Looked from the electrical side a multiway system with passive crossover means basically a group of parallel-coupled equivalents of Fig.20, isolated with filters. However, it is unimportant, whether the capacitive reactance originates from mechanical (driver) or from purely electrical (filter) side, see for example system No 5 at 2 kHz in Fig.12, and thus current ratios greater than 2 are possible with appropriate excitation. (Although the filters isolate the driver fundamental resonance from the amplifier, they exhibit capacitive reactance themselves). It is thus easy to see that high current peaks are not a speciality of woofers only, the peak energy is naturally frequency dependent.

In terms of required amplifier current the systems can be divided into two groups. Types 1 and 2 where the driver is directly connected to amplifier (active low-level crossovers) have greatest Z_{al} values and are thus easier to drive. This is also true for type 4 (Z_{nom}/Z_{al} about 1.5) due to its low reactive content. The other systems with passive crossovers form an other group requiring significantly more linear current from the amplifier. A simple numerical example will clarify: a 200 W into 8 ohms amplifier provides 56.6 V peak output voltage. When driving 8 ohms resistance, 7.1 A peak output current is required. The same signal to system No 1 causes 11.1 A peak output current and when driving system No 5, 20.5 A peak output current is necessary. It should be noted, however, that the test signal used now may not be the worst possible, and certainly there are speaker systems with greater Z_{nom}/Z_{al} than the ones measured so far.

With the speakers tested the Z_{al} value varies between 55 % (system 5) and 86 % (system 7) of the impedance magnitude minimum which, in turn, should be at least 83 % of the nominal impedance according to IEC. It should be noted however, that very few speakers in the market fulfil this IEC requirement. To be on the safe side, let us take the impedance minimum as 70 % of the nominal impedance as specified by the manufacturer and the Z_{al} value 40 % of that, so the design load should be not more than 28 % of the rated load. In pure numbers, an amplifier for 8 ohms "nominal" load should be able to deliver full output voltage swing down to 2.2 ohms. We would like to emphasize again, that these figures are based on the present measurement data, there may be loudspeaker systems and test signals which exhibit Z_{al} values outside the range presented now and will so change the rule of thumb outlined above.

5. CONCLUSIONS

Seven loudspeaker systems representing different design were measured in terms of their instantaneous input voltage/current characteristics. At certain frequencies they absorb significantly more, in some cases with passive crossover filters several times more current than what could be expected from the specified, "nominal" impedance. Obviously amplifiers dimensioned for nominal resistive loads cannot deliver full output power to loudspeakers and thus a different power amplifier design approach is necessary.

6. ACKNOWLEDGMENT

The authors wish to thank Dr. Matti Otala for valuable discussions during this work.

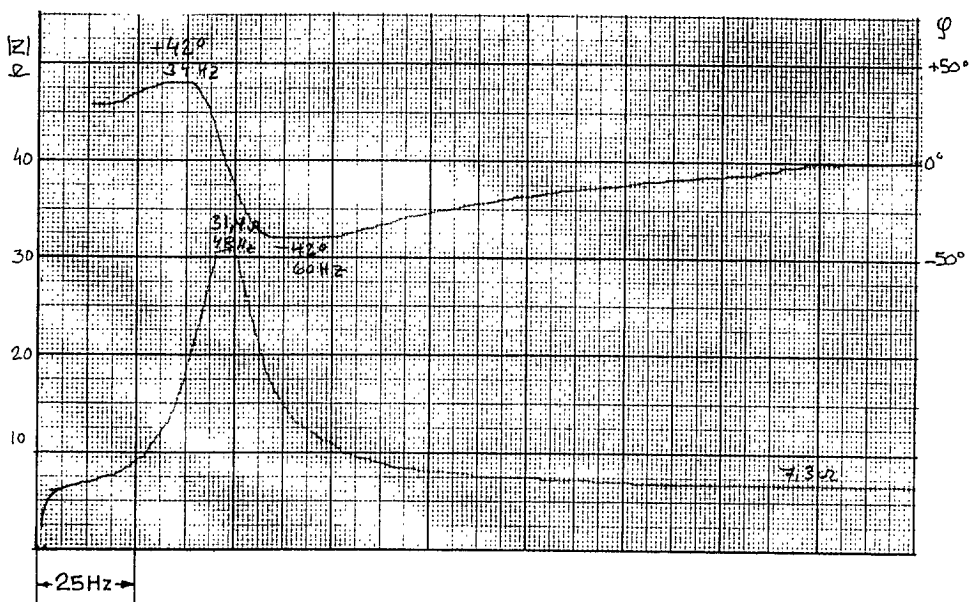


Fig.2. Impedance plot of woofer in a closed box.

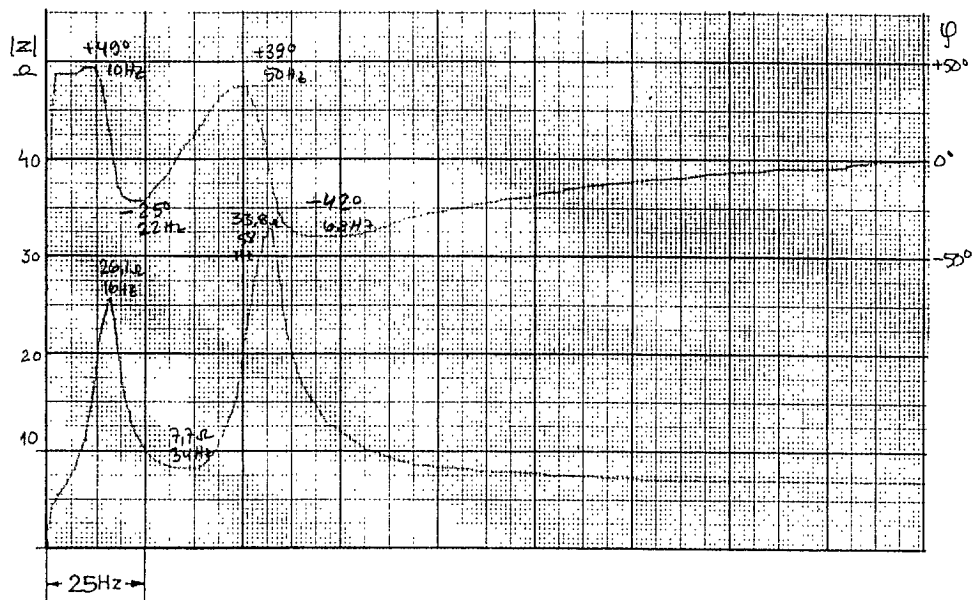


Fig.4. Impedance plot of woofer in a vented box.

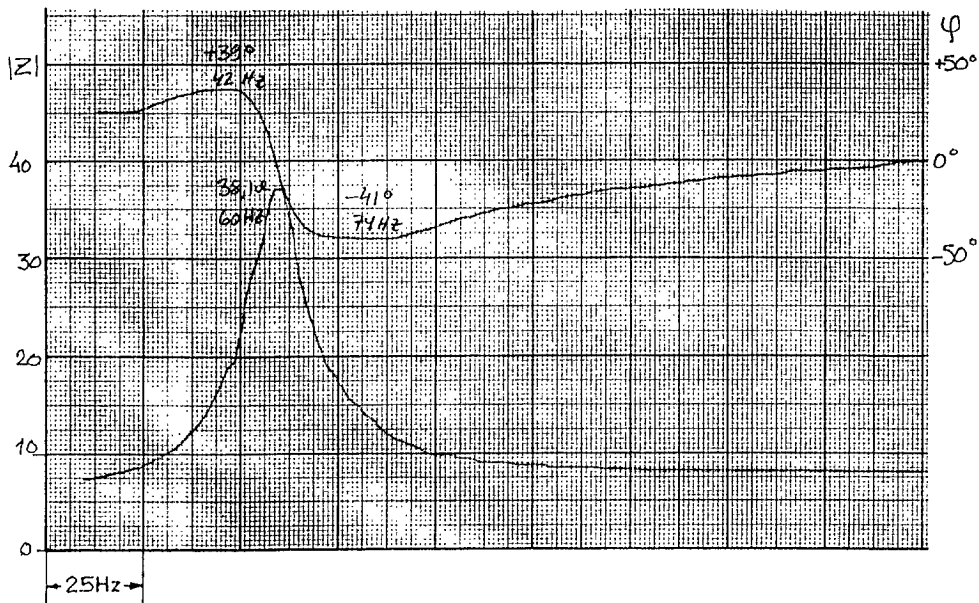


Fig.6. LF impedance plot of 2-way closed-box system.

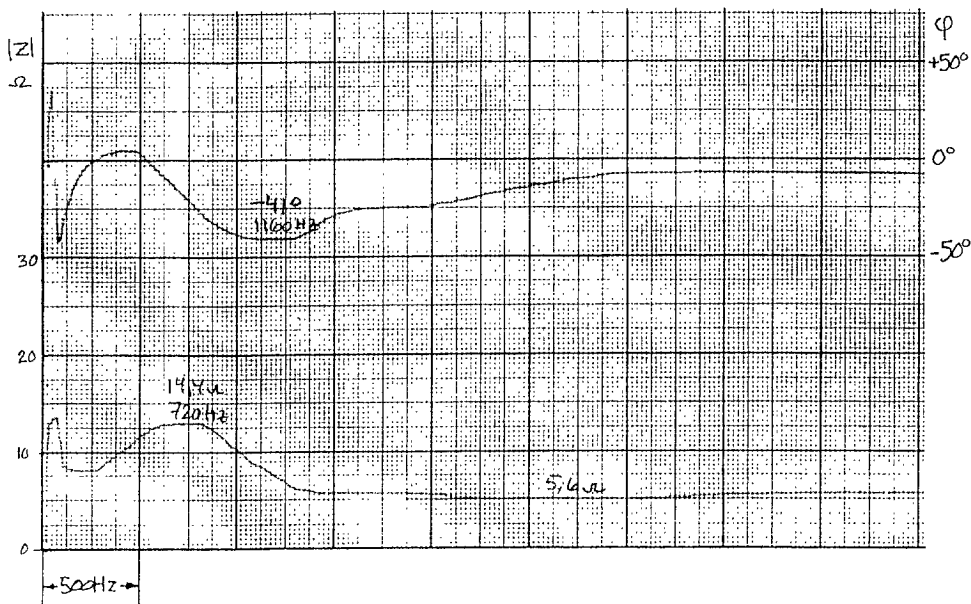


Fig.7. Mid-frequency impedance plot of 2-way closed-box system.

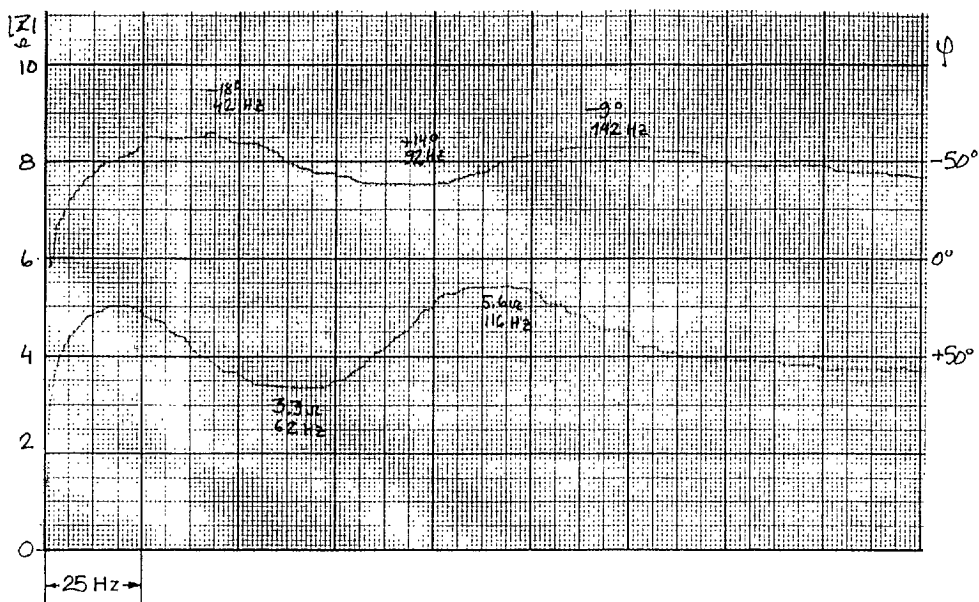


Fig.9. LF impedance plot of closed-box 2-way system with dual voice coil woofer. Note the different scales.

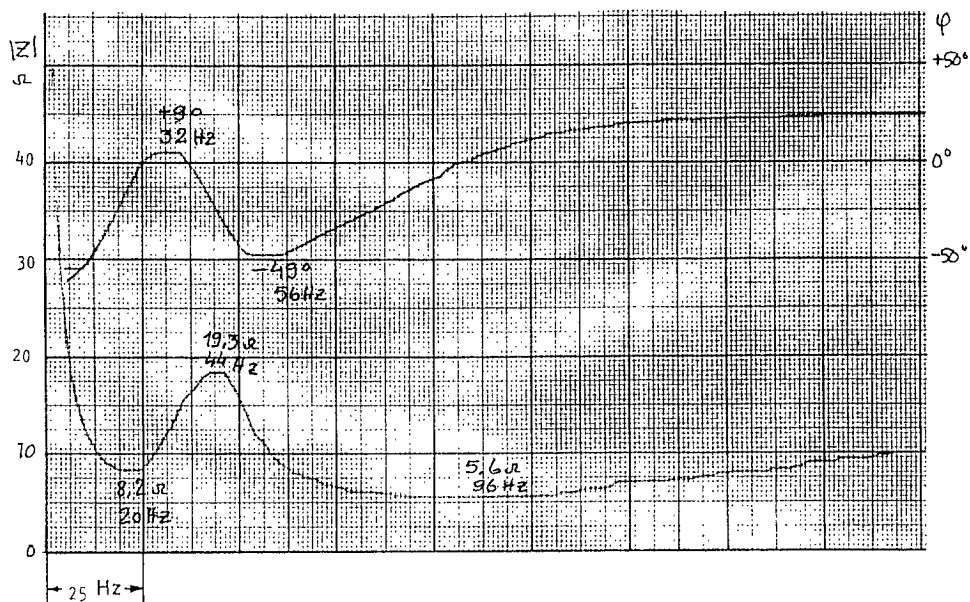


Fig.11. LF impedance plot of three-way closed-box system with B3 LF response.

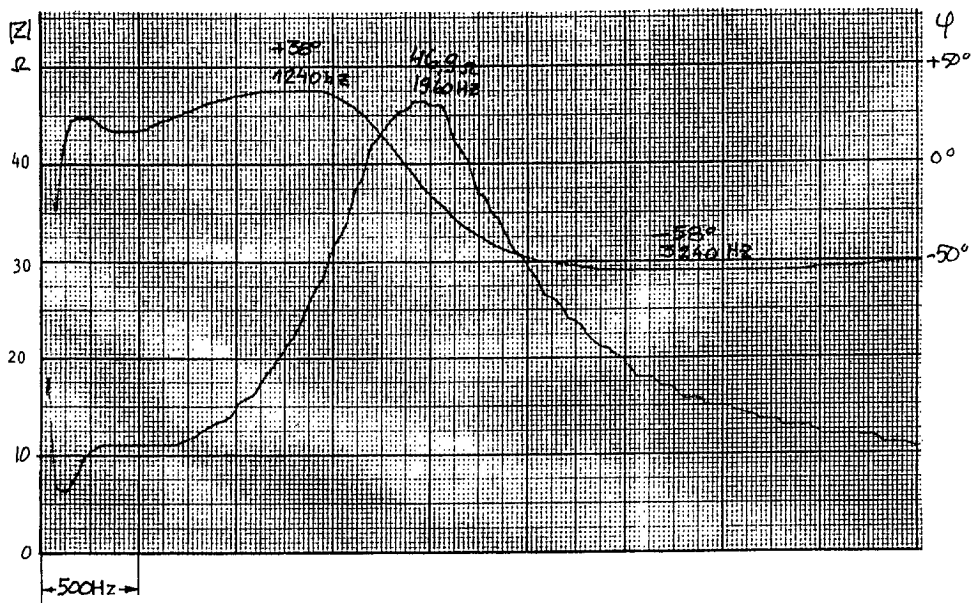


Fig.12. MF impedance plot of three-way closed-box system with B3 LF response

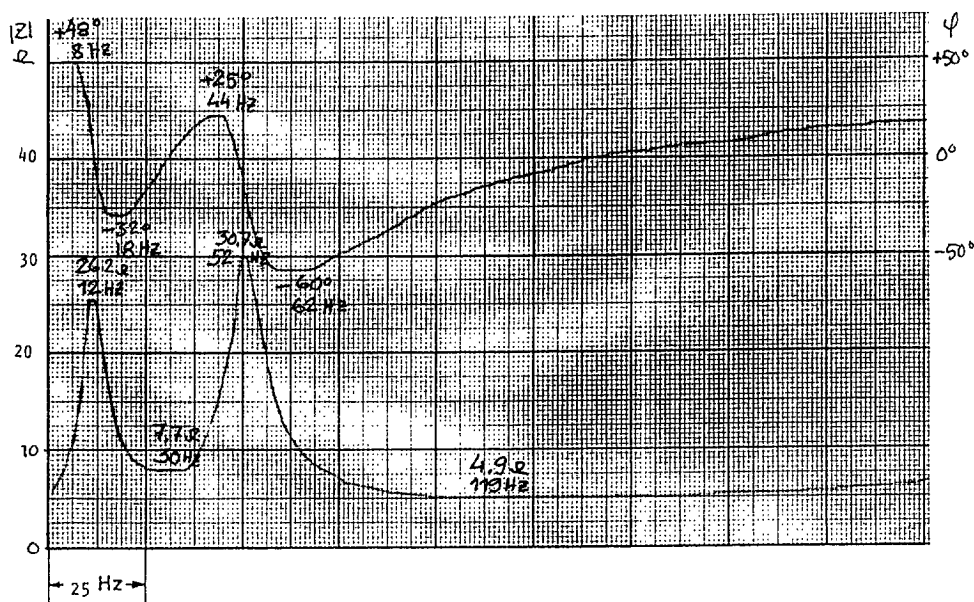


Fig.14. LF impedance plot of three-way vented-box system.

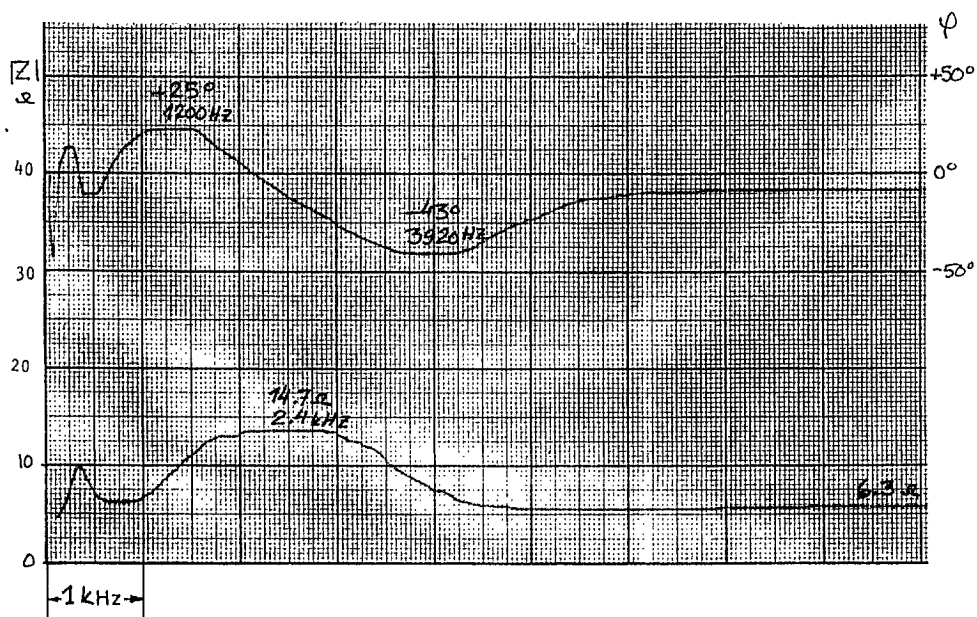


Fig.15, MF/HF impedance plot of three-way vented-box system.

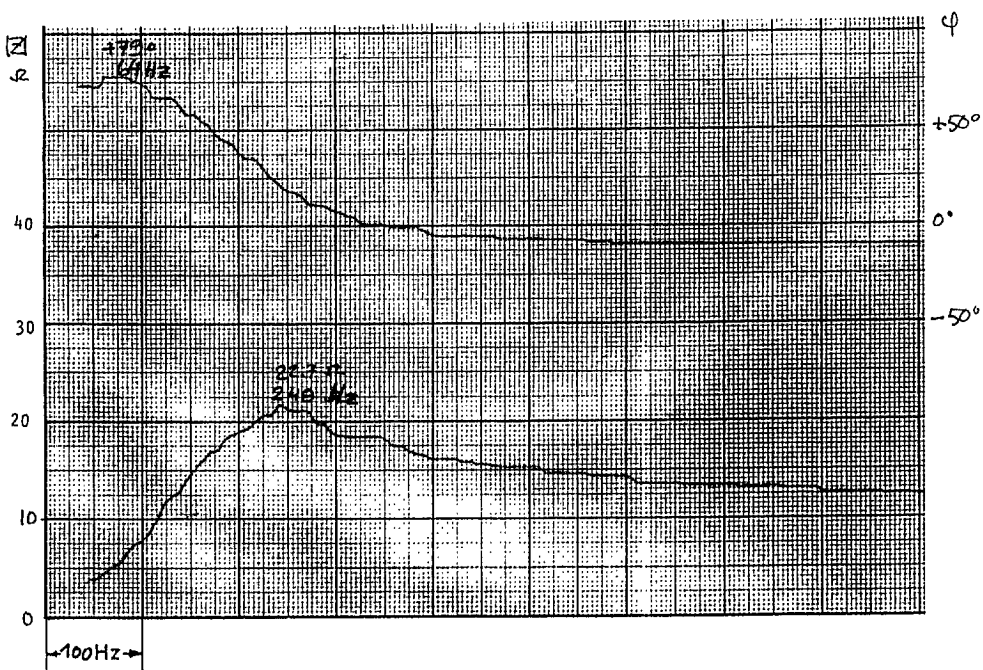


Fig.17. LF/MF impedance plot of full-range electrostatic system.

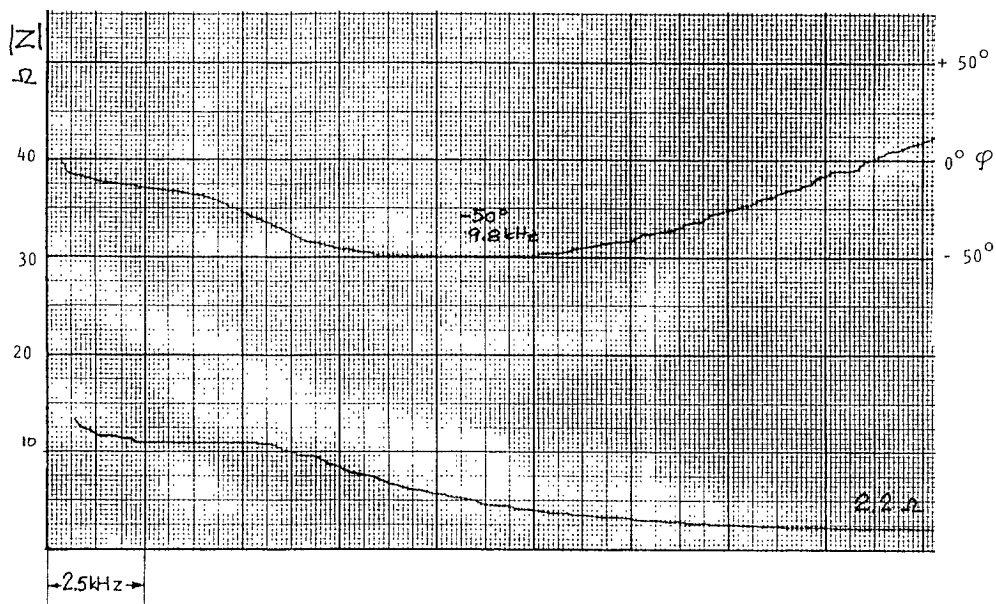


Fig.18. MF/HF impedance plot of full-range electrostatic system.

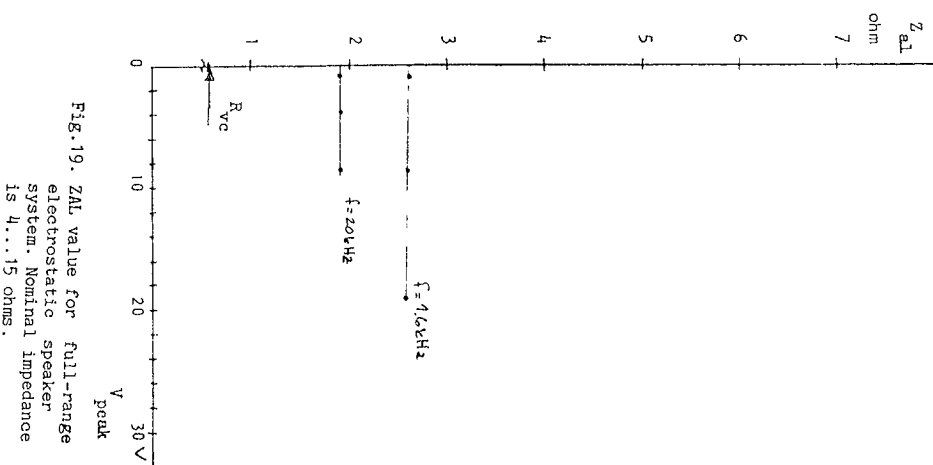


Fig.19. ZAL value for full-range electrostatic speaker system. Nominal impedance is 4...15 ohms.

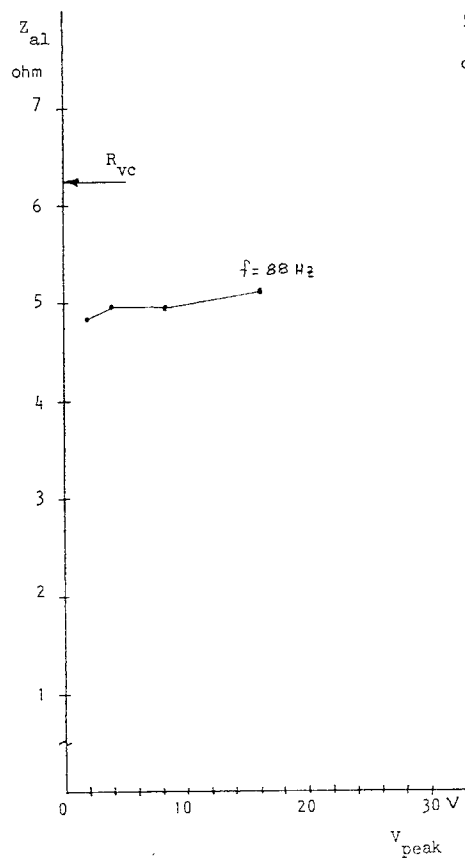


Fig.3. ZAL value for woofer in a closed box. Nominal impedance is 8 ohms.

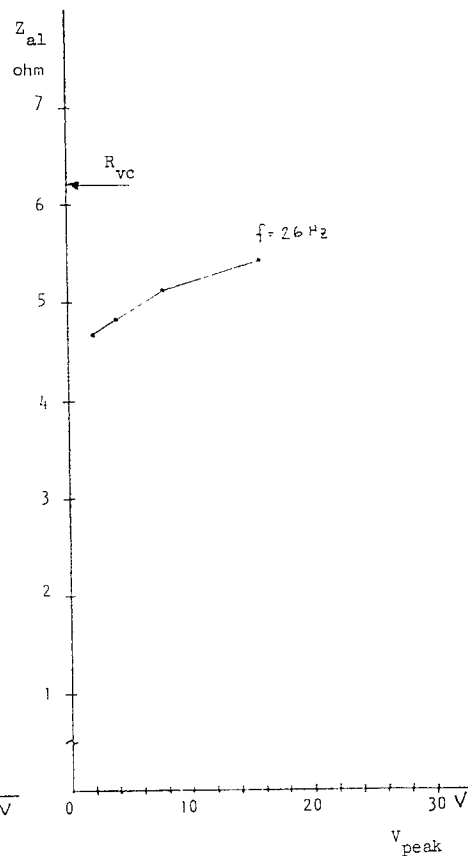


Fig.5. ZAL value for woofer in a vented box. Nominal impedance is 8 ohms.

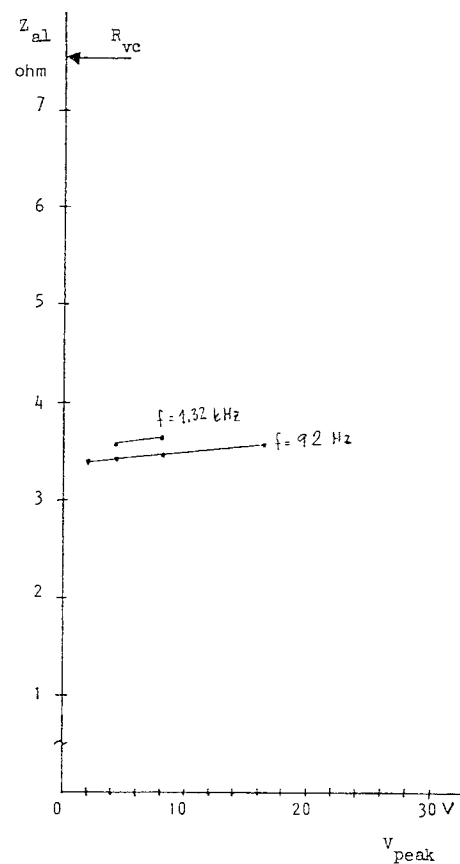


Fig.8. ZAL value for 2-way closed-box system. Nominal impedance is 8 ohms.

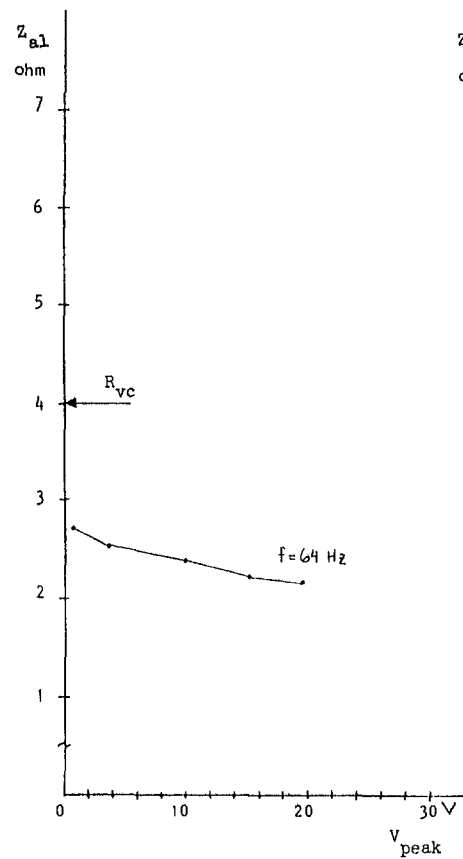


Fig.10. ZAL value for closed-box 2-way system with a dual voice coil woofer. Nominal impedance is 4 ohms.

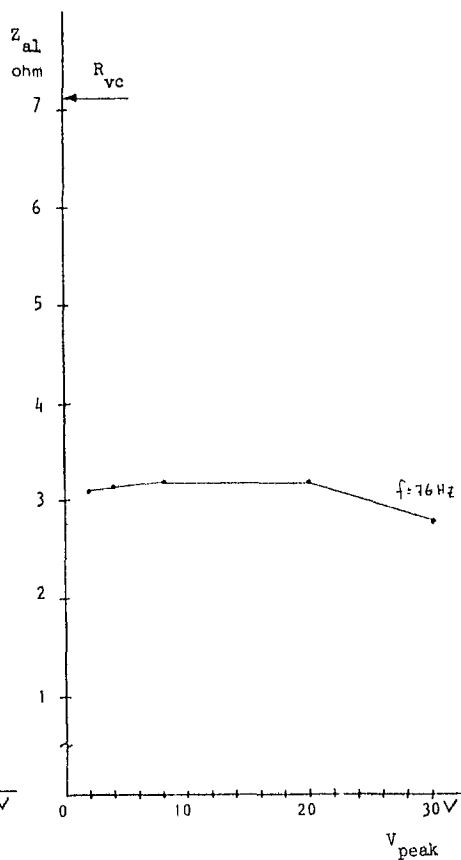


Fig.13. ZAL value for closed-box 3-way system with B3 LF response. Nominal impedance is 8 ohms.

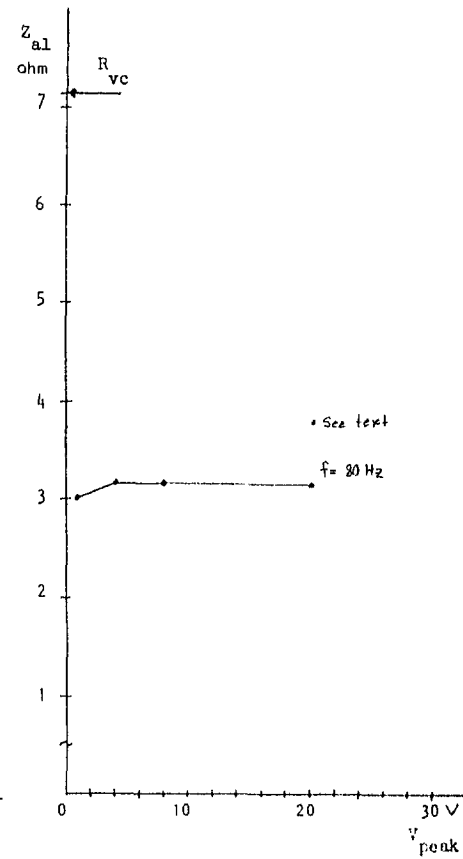


Fig.16. ZAL value for vented-box 3-way system. Nominal impedance is 6 ohms.