# LR-n Models for Voice Coil of the Loudspeaker Part I: Small Signal Analysis

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*Abstract* –**This paper presents LR-n models for voice coil of the electrodynamics direct radiating loudspeaker. The results from the measured impedance response (magnitude and phase curve, nyquist plot) of a loudspeaker and the math expressions which describe the equivalent circuits are shown graphically.**

*Keywords* – **Loudspeaker, voice coil, equivalent circuit, LR-n model, frequency responses of the electrical impedance (magnitude and phase) measured.**

## I. Introduction

The conversion from electronic signals to sound is the task of the loudspeaker. The electrodynamic loudspeaker is an electroacoustic transducer widely used in many application areas as audio reproduction, communication equipment and others systems. For performance of a loudspeaker precisely, must an exploration of the electrical input impedance at higher frequencies area.

## II. Electrical Analogous Circuit of Loudspeaker and Loudspeaker Systems

The math expression, Eq. (1), which describes the input impedance, includes the sum of the voice coil electrical impedance $Z_e = R_e + i.\omega.L_e$, the impedance introduced by the mechanical system $Z_{вн}$ [1] and the acoustic volume $Z_a$ (Figs. 1 and 2).

$$Z(\varpi) = R_e + i.\omega.L_e + \frac{(B.L)^2}{R_{ms} + \frac{1}{i.\omega.C_{ms}} + i.\omega.M_{ms} + Z_a.S_d^2} \quad (1)$$

The elements of Fig.1 are Thiele and Small parameters [5], [9].

Fig. 2 is an analogous circuit of Fig.1 with all mechanical and acoustical elements transformed to the electrical part.

Fig. 3 is an analogous circuit of Fig.1 with all mechanical and electrical elements transformed to the acoustical part [1]. The elements of Figs. 2 and 3 are defined by the Thiele and Small parameters [1].

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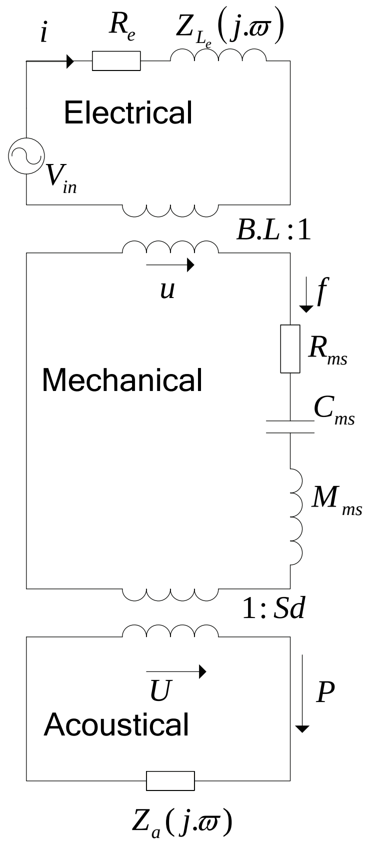


Fig.1. General electro-mechanic-acoustical equivalent circuit

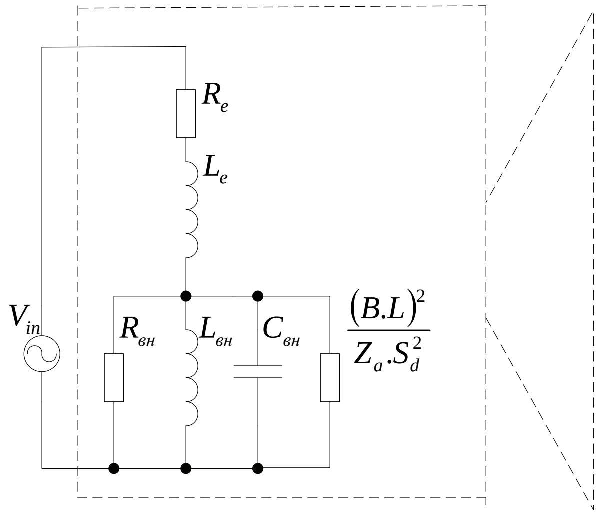


Fig.2. Classic electrical equivalent circuit diagram

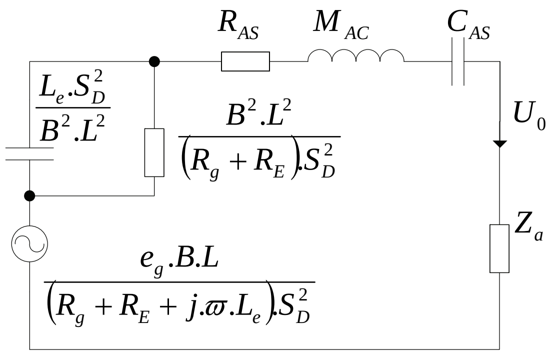


Fig.3. Classic acoustical equivalent circuit diagram

## III. MODELS FOR ELECTRICAL IMPEDANCE

Even the most precisely values of $L_e$ lead to comparatively great differences in comparison to the ones declared by the producer, or with our results from the investigations of the impedance.

Reasons can be found in [3]:

1. The equivalent circuit diagram is not completely precise;
2. The sound range is comparatively wide, from 20 Hz to 20 kHz; differences get higher especially within the high frequency area;
3. The pole linings are made of steel, where steel causes Faucault currents losses;
4. The voice coil is made of a solid wire, causing the skin effect; and
5. Presence of local resonances, not definitely expressed.

### *A. Leach model*

M. Leach [5], [7] proposed a function of the complex frequency $j.\varpi$ on exponent $n$ as an approximation for $Z_{L_e}(j.\varpi)$.

$$Z_{L_e}(j.\varpi) = L_e.(j.\varpi)^n \; ; \; \varpi = 2.\pi.f \; , \; 0{,}2 \le n \le 1 \qquad (2)$$

### *B. LR-2 (shunted inductance) Model*

This model uses a series inductance $L_e$ connected to a second inductance $L_2$ shunted by resistance $R_2$, see fig. 4 [6].

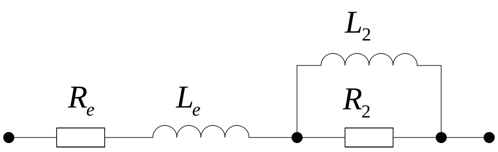


Fig. 4. LR-2 Model

$$Z_{L_e}(j.\varpi) = j.\varpi.L_e + (R_2.j.\varpi.L_2)/(R_2 + j.\varpi.L_2) \qquad (3)$$

### *C. Wright model*

J. Wright [2], [6] proposed a model using separate weighted power functions in $\varpi$ for both the real and imaginary part of impedance.

$$Z_{L_e}(j.\varpi) = K_{rm}.\varpi^{Erm} + j.(K_{xm}.\varpi^{Exm}) \qquad (4)$$

### *D. Effective Inductance Model*


Fig. 5. Effective Inductance Model

$$Z_{L_e}(j.\varpi) = R_{eff}(f) + j.\varpi.L_{eff}(f) \qquad (5)$$

M. Leach also proposed normalising the imaginary part of the electrical impedance $Z_{L_e}(j.\varpi)$ to the frequency $j.\varpi$ and introducing of an effective inductance $L_{eff}(f)$ which varies with frequency [6]. The real part of $Z_{L_e}(j.\varpi)$ also has to be considered as a frequency dependent; resistance $R_{eff}(f)$ describing the losses as shown in Fig. 5. There are a number of parameters since this model. This model requires two parameters for each frequency point (real and imaginary). The parameters are easy to interpret and convenient for graphical representation.

## IV. LR-N MODEL OF VOICE COIL

Loudspeaker producers provide a typical, measured impedance response to frequency.

To measure the impedance response [11], it is convenient to use some special software: Audio Tester [12], Loudspeaker Lab [13], Speaker Workshop Loudspeaker Design [14] MLSSA [15], or any other applicable.

PC assistance in electrical and acoustical measurements provides many advantages for the purposes of analyzing and processing the results.

The voice coil inductance is presented as *n LR* elements, Fig. 8.

Based on the measured electrical impedance (magnitude and phase curves, nyquist plot), it is possible to define the values of the LR-n elements from the equivalent electrical circuit for a loudspeaker.

Some requirements [3], [4] be defined for the values of elements $L_{0n}$ and $R_{0n}$. Increasing the number of the LR elements leads to expanding the band of coincidence of the measurements and the model. In practice, comparatively good results, depending on the loudspeaker type, can be obtained with 3÷7 LR elements

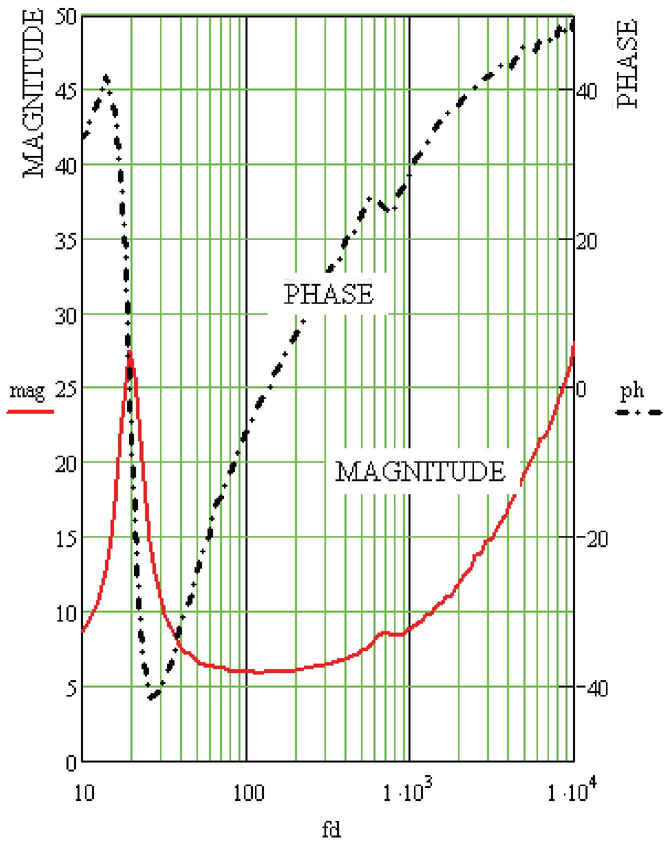


Fig. 6. Typical measured responses impedance (magnitude and phase) of electro-dynamical loudspeaker 30W-75-Dynaudio, measurement date file, see Table I

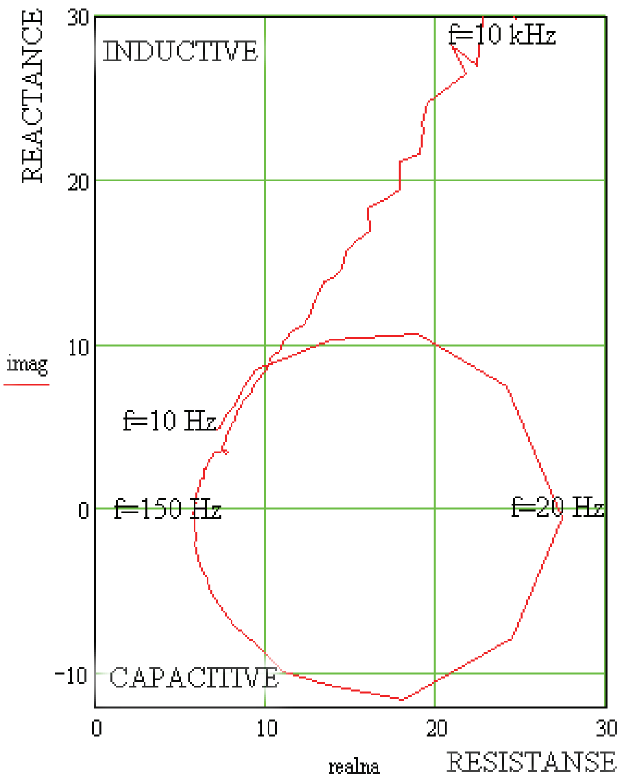


Fig. 7. Complex impedance curve (nyquist plot) based on measured magnitude and phase

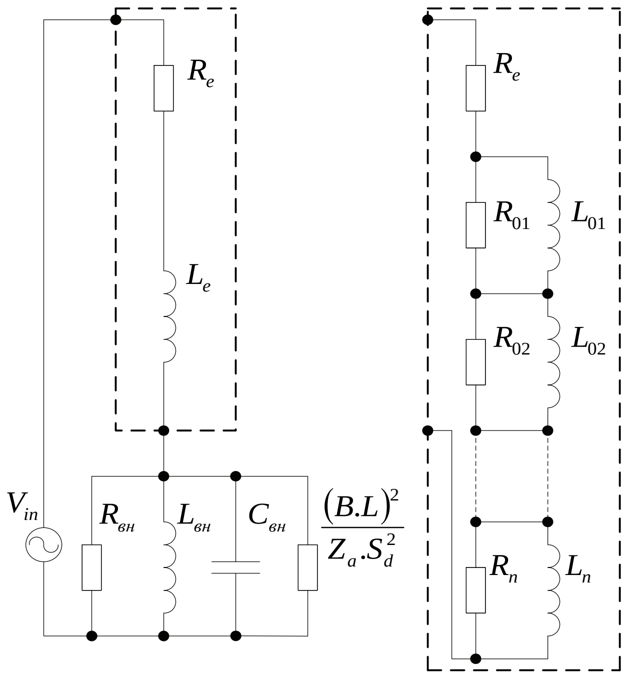


Fig. 8. Classic electrical equivalent circuit diagram and LR-n model of voice coil

TABLE I
MEASUREMENT DATA (typical points)

| № | Frequency, Hz | Magnitude, Ω | Phase, Deg |
|---|---|---|---|
| 1 | **10.00** | **8.65** | **33.74** |
| .. | .. …. | .. … | .. …. |
| 6 | 14.14 | 12.67 | **41.93** |
| .. | .. …. | .. …. | .. …. |
| 11 | **20.00** | **27.51** | **-1.18** |
| .. | .. …. | .. …. | .. …. |
| 15 | 26.39 | 14.82 | **-41.56** |
| .. | .. …. | .. …. | .. …. |
| 36 | 105.56 | **5.88** | -5.19 |
| .. | .. …. | .. …. | .. …. |
| 38 | 139.29 | 5.91 | **-0.35** |
| .. | .. …. | .. …. | .. …. |
| 59 | 597.14 | 7.87 | **25.80** |
| .. | .. …. | .. …. | .. …. |
| 62 | 735.17 | **8.61** | 23.78 |
| 63 | 787.93 | 8.41 | 23.42 |
| 64 | 844.48 | 8.39 | 25.24 |
| .. | .. …. | .. …. | .. …. |
| 82 | 2940.67 | 14.72 | 41.44 |
| .. | .. …. | .. …. | .. …. |
| 99 | **10000.00** | **27.71** | **49.74** |

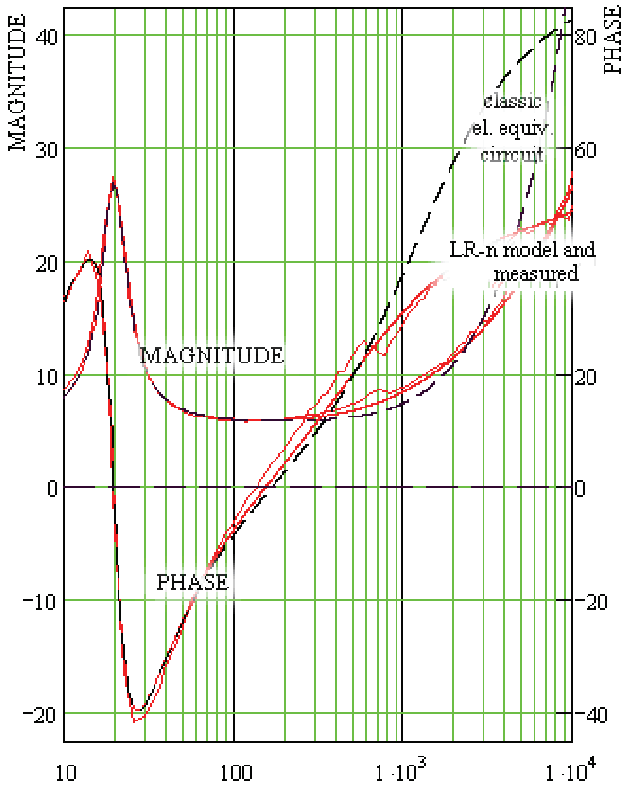


Fig. 9. The impedance magnitude and phase curve for the classic electrical equivalent circuit diagram and, for the LR-n model of voice coil and measured response for the electrodynamics loudspeaker 30W-75 produced by Dynaudio

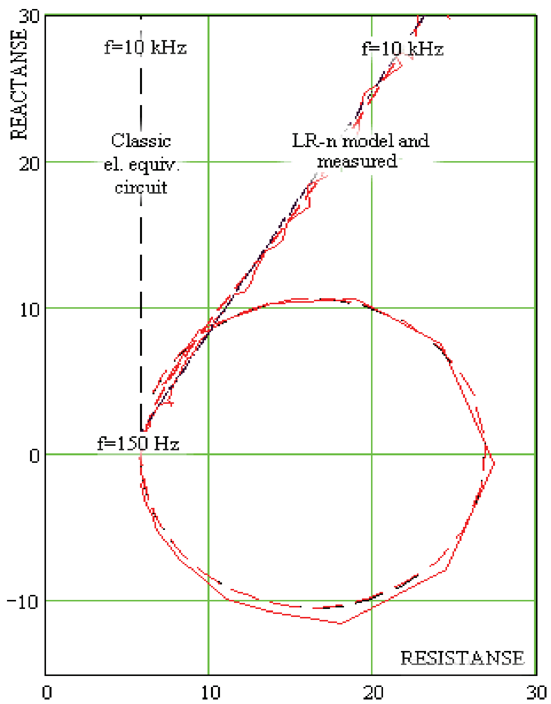


Fig. 10. Complex impedance (nyquist plot) curve for: the classic electrical equivalent circuit diagram and, the LR-n model of voice coil and response based on measured magnitude and phase for the electrodynamics loudspeaker 30W-75 produced by Dynaudio

## V. Conclusion

The results from the measured impedance response to frequency of an electro-dynamical loudspeaker are shown graphically (Figs. 6 and 7) and in a Table I.

Values of the response measured can easily be used for analysis (Fig. 6). and comparison with math expressions describing the impedance (Fig. 9).

The criterion selected to prove validity of the model by Mark Dodd [6], Wolfgang Klippel [8], Marshall Leach [5], [7] and the author in his first publications [3], [4] on this subject is not sufficient (Fig. 9).

The complex impedance curve (Nyquist plot) is modeled based on the calculated real and imaginary parts of the impedance from the measured responses for the magnitude and phase of an electrodynamics loudspeaker (Fig. 7).

The complex impedance curve is a necessary and sufficient criterion to compare theoretical and experimental results (Fig. 10); the ideas offered for a voice coil LR-n model (Fig. 8) being confirmed.

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