Modification method to determining the output parameters in the audio power stage with complex load

Plamen Angelov[1]

Abstract –**The aim of the proposed article is to modified a known method to project the power stage in audio power amplifier. This method uses specific parameters of the output load, whose aim is to define the type of the output power transistors. Out of the numerical experiments we can adequately identify the electronics elements (type of the output transistors) in linear power stage. The results obtained in this scientific experiment relate to real complex load - DISCOVERY 15M/4624G00**

Keywords –**modification method, audio amplifier, power transistors**

I. Problem Condition

In audio power amplifiers it is necessary harmonization between the high output resistance of the transistors and the low resistance of the load. To deliver the indispensable output current and low output resistance the power stages amplifier work in common collector scheme. The power amplifications is implemented by preamplifier, while the power stage works as current amplifier. At the other hand the load impedance is not completely active and it's value depends on the working frequency. Example of the impedance change of a loudspeaker with change of the frequency is shown on fig.1.1. When designing Hi-Fi audio amplifier this would lead to additional asymmetry in the work of the stage and respectively in the parameters of the output signal. To achieve ultimate effect it has to be considered the variable load impedance while designing an amplifier. When designing low-frequency amplifier class AB in the known so far methods of designing [1-4] account multiple parameters such as: maximal output power, bandwidth, total harmonics distortion, load impedance. In most cases the methodic doesn't account the impedance characteristics of the load, which makes it incomplete. Practically every loudspeaker has different frequency characteristic. Modification of this characteristic leads to change of it's resistance in function of the applied frequency (when this parameter is missing it has to be examined in laboratory). In many cases when designing audio power stage class AB this brings complications with conciliation to the output transistors. This requires additional measurements of the amending of the load impedance with the change of the operating frequency.

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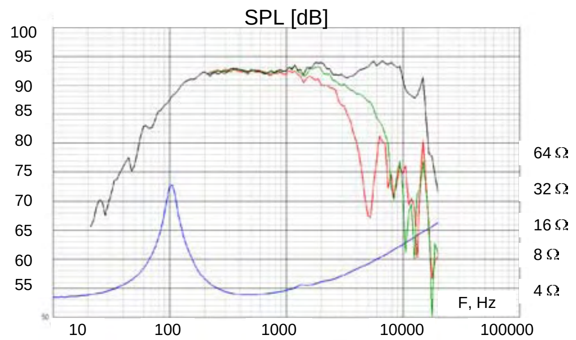

fig.1.1. Impedance characteristics of the loudspeaker Discovery – 15M/4624G00 [7]

The proposed modified method of designing accounts the equivalent electric scheme of the loudspeaker and its impedance characteristic. With this method all this parameters take part in the consistency of design. For this purpose will be examined the equivalent substitute scheme of loudspeaker shown on fig. 1.2. To define all parameters on the shown electric scheme of the loudspeaker are used the know equations [5],[6]

$$R_2 = \frac{(B.L)^2}{R_{ms}}, \; L_2 = C_{ms}.(B.L)^2, \; C_2 = \frac{M_{ms}}{(B.L)^2} \quad (1)$$

where: voice coil resistance R_{dc} (dc resistance); voice coil inductance – L_0; Force factor - $B.L$; Suspension compliance – C_{ms}; moving mass of the loudspeaker– M_{ms}; mechanical losses resistance–R_{ms};

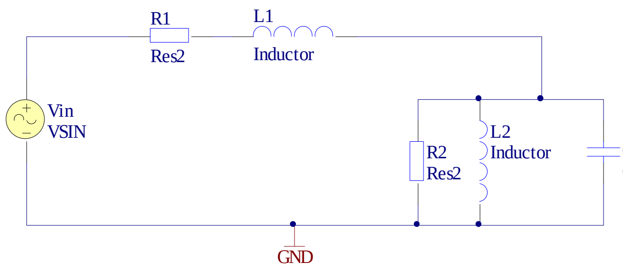

fig.1.2. Equivalent replacing scheme of loudspeaker

First let's convert the parallel double-pole in consecutive with the equations:

$$R_S(f) = \frac{G_2}{G_2^2 + B(f)_2^2},$$
$$X_S = \frac{B_2}{G_2^2 + B(f)_2^2}$$
$$G_2 = \frac{1}{R_2} \qquad (2)$$
$$B_2(f) = \frac{1}{2\cdot\pi\cdot f\cdot L_2} - 2\cdot\pi\cdot f\cdot C_2$$

After that the shown equivalent scheme is converted to the different type shown on fig 1.3.

When defining the values of the R_s and X_s is more comfortable in their mathematical equations to write down the known limitations for resonance resistance ρ and resonance frequency ω_0. Using these parameters we can standardize the relative resistance of the circuit “k” and the relative frequency „η” with the equations:

$$\rho_2 = \sqrt{\frac{L_2}{C_2}}$$
$$\eta = \frac{R_2}{\rho_2}$$
$$f_0 = \frac{1}{2\cdot\pi\cdot\sqrt{L_2.C_2}} \qquad (3)$$
$$\kappa = \frac{f}{f_0}$$

Then for the serial equivalent transformations we are obtaining the equations:

$$R_S(f) = \frac{G_2}{G_2^2 + B_2^2} = R_2\frac{1}{1+\eta^2.(\kappa^{-1}-\kappa)^2} \qquad (4)$$

$$X_S(f) = \frac{B_2}{G_2^2 + B_2^2} = R_2\frac{\eta^{-1}.(\kappa^{-1}-\kappa)}{1+\eta^2.(\kappa^{-1}-\kappa)^2} \qquad (5)$$

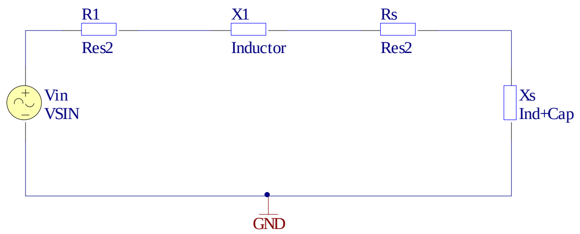

fig.1.3 conversion of parallel to consistent double-pole

$$R(f) = R_1 + R_2\frac{1}{1+\eta^2.(\kappa^{-1}-\kappa)^2}$$
$$X(f) = 2\cdot\pi\cdot f\cdot L_1 + R_2\frac{\eta^{-1}.(\kappa^{-1}-\kappa)}{1+\eta^2.(\kappa^{-1}-\kappa)^2} \qquad (6)$$
$$Z_{load}(f) = \sqrt{R(f)^2 + X(f)^2}$$

The obtained model of electric substitute scheme of loudspeaker provides simple way to design. The expected result will be refinement of the output parameters of the loudspeaker according to the specific equivalent model. From the obtained parameters we can make numeral experiment which will show us correct result if we are in the right direction. To verify the equivalent electrical model of the selected loudspeaker we derive graphics of the load’s impedance characteristic. The simulative examination is performed on MathCAD with the following parameters : Voice coil resistance – R_{dc}=3,2Ω - Voice coil inductance – L_0=230μH; - Force factor - *BL=5,3Tm*; suspension compliance – C_{ms}=0,41mm/N; moving mass of the loudspeaker – M_{ms}=6,2g; mechanical losses of the loudspeaker –R_{ms}=0,69kg/s. After substituting the obtained data in eqation.1 for the values for the elements L2, R2, C2 occurs: L2=12mH, C2=220,7μF; R2=40,71Ω. When we use the obtained results in the electric substitute scheme for the amendment of the impedance of the loudspeaker we will get as result the result from fig.1.4. Comparing the result from the numerical simulation with the manufacturer's recommendations (fig.1.1) shows that the amendment of the impedance is identical. This means that the obtained mathematical dependencies describe quite accurate the amendment of the load and can be used for determining the active output power with equation 7.

$$P_l(f) = I^2.R(f) = \frac{U_{lm}^{\ 2}}{2}\frac{R(f)}{R(f)^2 + X(f)^2} \qquad (7)$$

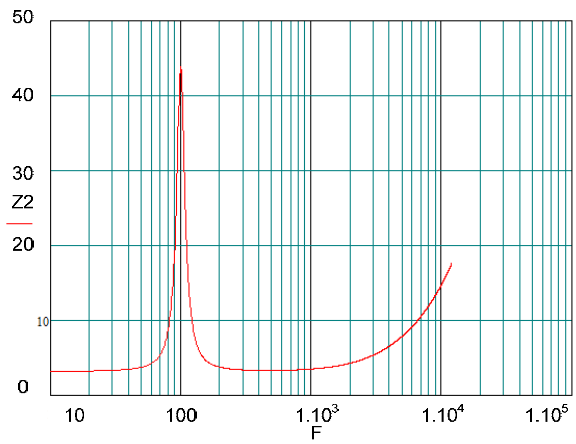

fig.1.4. Numerical experiment for determining the impedance characteristic of the loudspeaker Discovery – 15M/4624G00 [6]

II. MODIFICATION METHODOLOGY FOR DETERMINING THE OUTPUT TRANSISTORS IN LINEAR POWER AUDIO AMPLIFIER CLASS AB

A. Choice of principle scheme

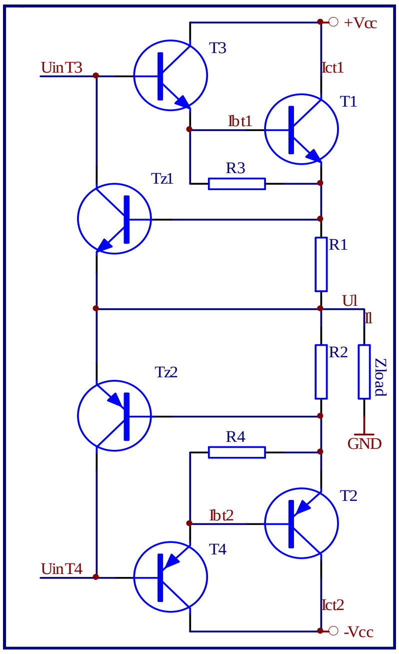

fig.2.1. Audio power stage

There is a big variety of schematic solutions for low frequency audio amplifiers. In the present article is observed circuit of linear power amplifier fog.2.1 class AB. The amplifier is realized with complimentary couple transistors T1 and T2. It's know that the terminal transistors used for relatively high power are with low coefficient h_{21E}. For this reason are added transistors T2 and T4. With their help it's formed darlington transistor T3-T1 which amplification is determinable with the equation:

$$h_{\sum 21e} = \beta_{T3}.\beta_{T1} \qquad (8)$$

where :

β_T - static coefficient of amplification of current (for common emitter circuit). The market offers constituent transistors, which unite as one unit T1 and T3.

In that case to account their power s used the familiar equation:

$$P_{\sum T1T3} = P_{T1} + P_{T3} \qquad (9)$$

where:

P_{T1}, P_{T3} - power dissipation for each transistor.

За проектирането са необходими следните изходни данни:

- The effective output power of the stage - P_l;
- bandwidth $f_l \div f_h$;
- Input Voltage U_i
- all of the above electrical parameters of the selected speaker.

B. Determining the output voltage

The first step is to determine the amplitude of the output voltage by the equation:

$$U_{lm}(f) = \sqrt{\frac{2.P_l.(R(f)^2 + X(f)^2)}{R(f)}} \qquad (10)$$

Substituting the result of equations (4) and (5) in (10) for the amplitude of the output voltage will obtain:

$$U_{lm}(f) = \sqrt{2.P_l.\frac{(R_1 + R_2\frac{1}{1+\eta^2.(\kappa^{-1}-\kappa)^2})^2}{R_1 + R_2\frac{1}{1+\eta^2.(\kappa^{-1}-\kappa)^2}}} \ldots$$

$$\sqrt{\frac{+(2\cdot\pi\cdot f\cdot L_1 + R_2\frac{\eta^{-1}.(\kappa^{-1}-\kappa)}{1+\eta^2.(\kappa^{-1}-\kappa)^2})^2}{R_1 + R_2\frac{1}{1+\eta^2.(\kappa^{-1}-\kappa)^2}}} \qquad (11)$$

where:

U_{lm} - maximum load voltage;

P_l - effective output power of the stage.

The displayed equation shows the frequency dependence of the output voltage according to the frequency change of the load Z_{load}. Using this parameter we according the output resistance of the stage in the specified frequency range.

After calculating the output voltage occurs graphic of the type:

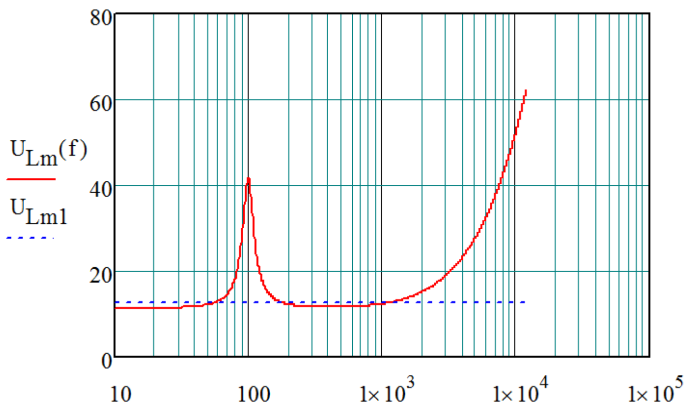

fig.2.2. Numerical experiment to determine the the output voltage

Let's conduct a numerical experiment with the chosen audio speaker with the following output parameters:

$P_l=20W;\ f_l=40Hz;\ f_h=12kHz;\ R_1=3{,}2\Omega;\ L_1=230\mu H;$
$L_2=12mH;\ C_2=220{,}7\mu F;\ R_2=40{,}71\Omega$

In fig.2.2. with a dashed line is mapped second voltage value (U_{lm1}), obtained by numerical simulation with active load. Comparing the two results shows précising of the methodology to 400%, especially for two operating frequencies $f_1 = 100Hz$ $f_2 = 10{,}5kHz$

C. Determining the load current

Using the known equation for the output power we specifies the load current:

$$P_l = \frac{U_{lm}.I_{lm}}{2} \Rightarrow I_{lm} = \frac{2.P_l}{U_{lm}} \qquad (12)$$

where:

I_{lm} - maximum value of the load current;

U_{lm} - maximum value of of the voltage on the load;

P_l - effective output power of the stage.

Substituting equation (10) in (12) for the size of the load current is obtained:

$$I_{lm} = \frac{2.P_l}{U_{lm}} = \frac{2.P_l}{\sqrt{\dfrac{2.P_l.(R(f)^2 + X(f)^2)}{R(f)}}} \qquad (13)$$

This equation displays the amendment of the current through the load impedance at the specified limits. This way in the design is determined the maximum output current and design the audio amplifier without overloading the transistors.

Let's conduct a numerical experiment and determine the amendment of load current. After conducting the program examination are obtained graphics of the type:

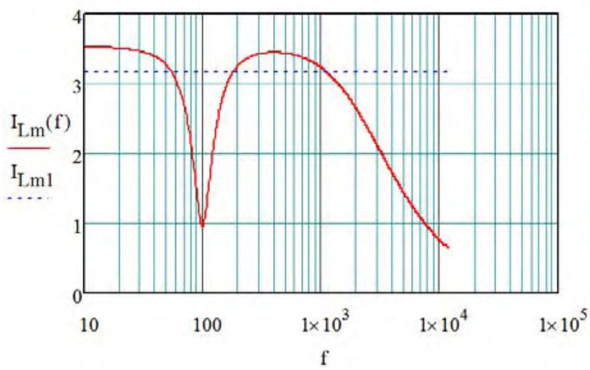

fig.2.3. Numerical experiment to determine the load current

In fig.2.3. with a dashed line is mapped second current value (I_{lm1}), obtained by numerical simulation with active load. Comparing the two results shows a significantly lower consumption at two frequencies $f_1 = 100Hz$ and $f_2 = 10{,}5kHz$ reason for which they are the resonant characteristics of the load.

III. Conclusion

When designing the transistor stage class in AB must be considered the frequency amendment of the loudspeaker. In the process of design the frequency amendment of output impedance determines parameters such as: amplitude of the output voltage, the load current amplitude.This contributes to the linear work of the transistor in the selected area of the class AB audio amplifiers.

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