

Simulation of Electromagnetic Environment of Class D Amplifier

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Abstract — In this article the equivalent circuit of class D amplifier with elements that create and distribute conducted electromagnetic interferences is suggested. SPICE simulation of class D amplifier inclusive parasitic parameters with connection to LISN have been realized. The results of computer simulation with experimental data of the interferences measuring are compared. The theoretical and experimental analysis of the influence of input signal amplitude on the noise level of class D amplifiers are confirmed. Simulation results are generally coincide with the measurement ones.

Keywords — class D amplifiers, electromagnetic compatibility, EMI modeling, radiofrequency interference, simulation

I. INTRODUCTION

Modern class D power amplifiers have a high efficiency and audio performance and are highly competitive with a class A, B, AB linear amplifiers [1]. Switch mode operation of class D amplifiers supplies highest efficiency (up to 100 percent theoretically), but has an essential disadvantage namely considerable level of the electromagnetic interferences (EMI). EMI are spreading in the conducting lines as electromagnetic emission.

Therefore it is necessary to reach at the design stage an electromagnetic compatibility (EMC) of class D amplifiers with other parts of audio equipment, mains and various devices. Assurance of the compliance of the class D amplifiers to the requirements of EMC standards [2,3] can be attained by complex application of class D amplifier special methods of the electromagnetic noises suppression [4,5,6] along with the well-known methods of EMI reducing [7], applicable for all switch mode devices. The review of sources of EMC and methods of their suppression is given in [8]. An origin and a distribution of EMC in the modern power supplies and class D amplifiers have a similar nature due to the switch mode of operation, although they have the additional factors related to modulation of the audio signal influence on the EMI level of class D amplifiers. Such factors can be an amplitude of audio signal and a total harmonic distortion (THD).

This paper aims to consider the equivalent circuit of the class D amplifier with the parasitic parameters of assembly, wires, capacitors, transistors etc. In this paper the simulation circuit of the class D amplifier with parasitic parameters

influence on the EMI level is suggested. The results of simulation of the class D amplifier connected to Line Impedance Stabilization Network (LISN) have been analysed and compared with the experimental data of EMI measurement, obtained previously.

II. ESTIMATION OF EMI LEVEL DEPENDING ON THE INPUT SIGNAL LEVEL

It is known that spectrum of the sequence of rectangular pulses contains harmonics that are multiples of the fundamental frequency. The spectrum of pulse-width modulated signal contains harmonic with frequency of useful signal, harmonics of switching frequency and multiple to it, and also a combination of harmonics mentioned above. Amplitudes of harmonics since the second has a large difference between switching and signal frequencies and considerably less than amplitude of the first harmonic. One can assume that EMI level of the class D amplifier with an input signal will be less, than without it, because of more "spread" spectrum of electromagnetic noises.

The estimation of the input signal level, THD and other factors influencing on the EMI level of the class D amplifier was performed during experimental researches. The results of researches are presented in [9]. Class D automotive power amplifier based on TPA3100D2 chip from Texas Instruments was tested in accordance to the standard methodology of conducted EMI measuring in the frequency range from 0,15 MHz to 30MHz without additional noise suppression in two versions (with an input signal and without it). Test sample was powered from unipolar nonstabilized linear power supply. The curves of EMI levels and permissible limits are taken from [9] and presented in Fig. 1.

It is evident from Fig. 1 that almost in the whole range of measuring frequencies the level of conducted noises without input signal is higher than in case of output power 10 W. At frequencies of 600 kHz, 6 MHz and 30 MHz noises level exceeds permissible limits. In a band of frequencies higher than 10 MHz a noise level also increases at 10-15 dB because of influence of the PCB mounting parasitic parameters. But on frequency of about 20 MHz a peak noise level is higher with input signal than without it.

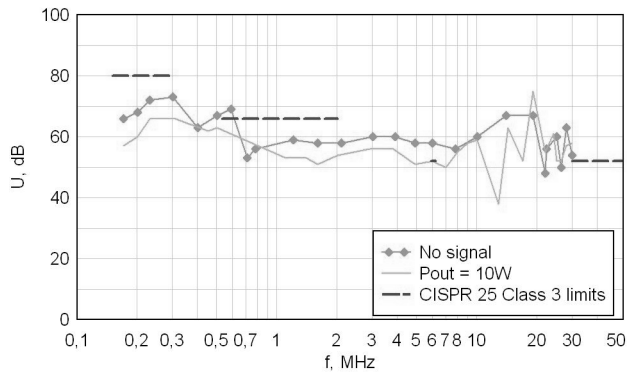


Fig. 1. EMI levels of TPA3100D2 and CISPR 25 limits.

It should be noted that a standard regulates measuring of EMI levels of professional audio apparatus during the noise-emission tests at power equal to 1/8 from nominal power [2]. Therefore it is necessary to take into account that during the professional class D amplifiers testing, that the generated noise level without input signal on some frequency bands can exceed a noises measured with standard methodology with input signal.

The computer model of the class D amplifier connected to LISN was developed in order to compare the obtained experimental results to the simulation data.

III. MODELING OF CLASS D AMPLIFIER CONSIDERING PARASITIC PARAMETERS

The computer simulation of class D amplifier with parasitic parameters can be used for predicting of the generated EMI levels at the development stage. EMI simulation of class D amplifiers appears a useful instrument at the development stage and will considerably simplify and reduce in the cost a process of EMI providing at a stage of production and finishing.

In papers [10, 11] the methods of simulation of conducted EMI in class D amplifiers are considered. The research of integrated amplifier in TQFP case were performed in the paper [10]. The EMI of two amplifiers was compared: one amplifier with a carrier-based PWM, other with a self-oscillating modulation based on sliding-mode control. The results of simulation are close to the measured, but the simulation of EMI levels was performed only for the amplifier output signal. In the article [11] the method of passive components presentation (output filters and loudspeaker) is used as impedance matrix with their subsequent association in single one and simulation of output currents of class D amplifier. This method has high accuracy too, but requires measuring of passive elements impedance by means of high-priced equipment. As in paper [10] the simulation of EMI levels was performed only for the amplifier output signal.

In presented paper the procedure of simulation in the Multisim environment of EMI levels measured by a selective microvoltmeter on the output of LISN is undertaken. LISN is plugged in the power supply circuit of class D amplifier in accordance with the standard (CISPR 25 for automotive

electronics). Predicted level of conducted EMI is depending on supply voltage, output power, parasitic parameters values etc.

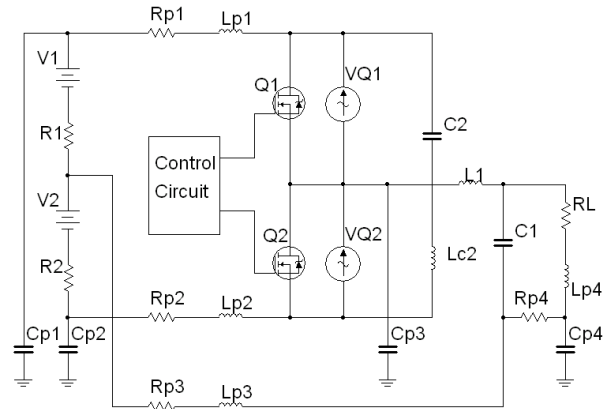


Fig. 2. Equivalent circuit of class D amplifier containing EMI elements.

Equivalent circuit of class D amplifier for the EMI analysis is presented in fig. 2. There are components of signal amplification and EMI creating and distributing elements (components and parasitic parameters) on the circuit. Real components are transistors Q1 and Q2, decoupling capacitor C2, filter elements L1, C1 and load resistor RL. The EMI receptor is internal resistor R1 of power source V1. The basic sources of electromagnetic interference are transistors Q1 and Q2 which are replaced by voltage pulse generators VQ1 and VQ2. These sources are modeling pulse voltages on transistors outputs. EMI propagate in all wires, thus resistances and inductances of power lines Rp1, Lp1 and Rp2, Lp2 are taken into account. Resistance Rp3 and inductance Lp3 of wires to the loudspeaker, are also taken into account. Parasitic inductance Lc2 is connected in series with the decoupling capacitor C2, which in case of long pins of C2 or long PCB board connectors and at the wrong place of setting can increase a generated noise level. Capacitors Cp1 - Cp4 are parasitic components of wires. Cp1 and Cp2 is a capacity between each of power wires and "ground" or car chassis.

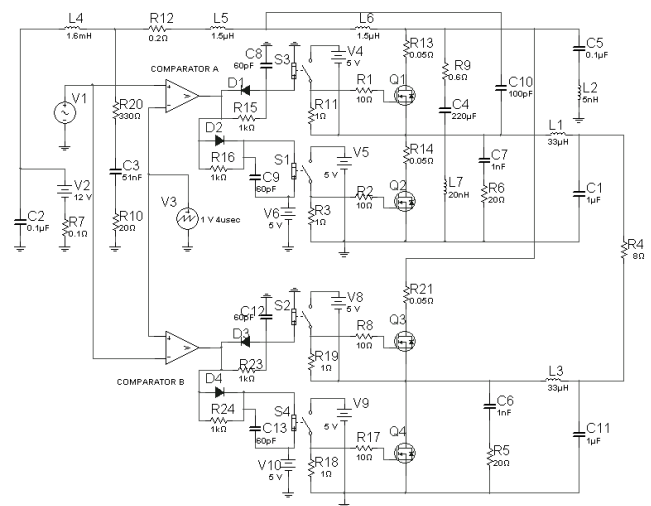


Fig. 3. Class D amplifier simulating circuit containing parasitic elements.

Cp3 is a capacitance between the output of amplifiers and "ground", and Cp1 is a capacitance between the wires of loudspeaker and "ground". The interturn capacity of filter inductance coil is not considered in this equivalent circuit because the number of turns is too small. This equivalent circuit is taken as basis of the class D amplifiers model containing EMI components.

Simplified simulation circuit of class D amplifier connected to LISN is shown on Fig.3. In this circuit there are elements of output transistors "dead time" adjustment. Pin inductance of capacitors, inductance and resistance of wires are taken into account. Parasitic inductances and capacities have the distributed nature, though considering, that analysed band is up to 30 MHz, they can be treated as the undistributed elements L and C [12].

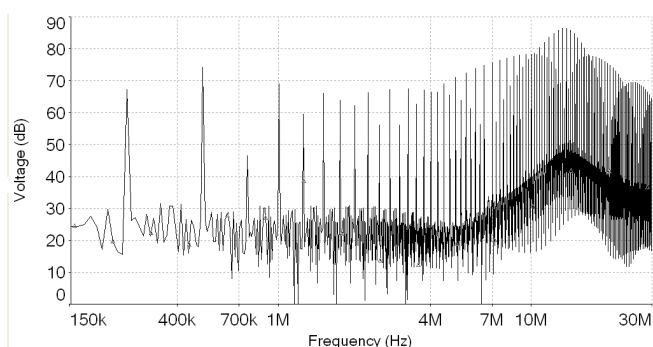


Fig. 4. EMI level of class D amplifier without input signal.

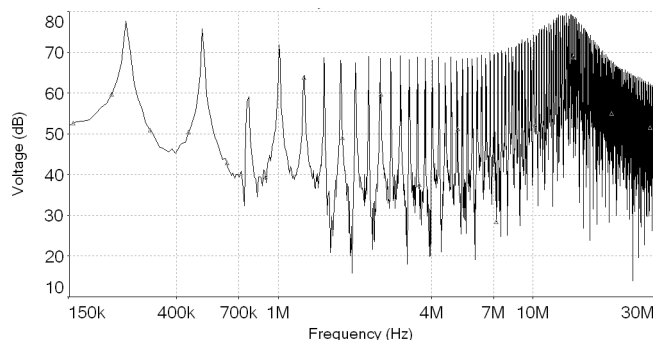


Fig. 5. EMI level of class D amplifier with output power 10W.

The parasitic capacitances between the power supply lines and high current components of amplifier are presented as a capacitor between the output of amplifier and one of the power lines. The parasitic parameters of output transistors (drain-to-source resistance, output capacity of transistors, parameters of output diode etc.) are set by a SPICE model.

In Fig.4 and Fig.5 the simulation curves of EMI levels on the exit of LISN are presented. In Fig. 4 curve corresponds to the case when there is no signal on the amplifier's input. Fig. 5 shows the curve that corresponds to the case when output power on the amplifier is equal to 10W. It is easy to see that at frequencies above 4MHz noise level for some frequencies is smaller up to 6-8 dB in the case when amplifier has input

signal. The increase of EMI levels at frequencies above 10 MHz is caused by the influence of the parasitic parameters shown in the model of amplifier for the simulation of the real surges of noise voltages on this frequency band. Simulation curves have rises at frequencies below 1MHz and at frequencies of 15-20MHz. Experimental curves in Fig.1 have the similar behavior. Simulation curves differ from experimental ones no more than 8-10 dB. It confirms the validity of the parasitic parameters choice for this model.

IV. CONCLUSION

The equivalent circuit of class D amplifier contains components of generation and distribution of conducted EMI is offered. Simulations of class D amplifier considering parasitic parameters are realized. Frequency dependences of simulated and experimental curves generally are the same. The computer simulation and experimental data showed that the EMI level with input signal is less than without a signal. Though the noise level increases at separate frequencies due to the influence of the parasitic parameters. In further research the increased number of parameters influencing on the EMI level will be taken into account for prediction of electromagnetic environment of different types of class D amplifier.

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