Simulation of Electromagnetic Environment of Class D Amplifier

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***Abstract*—Class D amplifier possess high efficiency, but generate electromagnetic interferences. Influence of class D amplifier input signal level on a level of conductive noise is considered on the basis of signal spectral representation. Measuring of generated noise level is done for the cases of input signal presence or absence. It is confirmed that the presence of signal in general reduces a noise level. Offered equivalent schemas of class D amplifier considering parasitic parameters for forecasting of noise level on the design stage.**

Keywords — class D amplifiers, electromagnetic compatibility, radiofrequency interference, EMI 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 characterized by highest efficiency (theoretically 100 percent), but has an essential disadvantage namely considerable level of the electromagnetic interferences (EMI). These EMI are spreading in the conducting wires and in the form of electromagnetic emission.

Therefore it is necessary to attain on the design stage an electromagnetic compatibility (EMC) of class D amplifiers with another parts of audio equipment, main and variety technical devices. Providing of accordance of 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] along with the well-known methods of EMI reducing [6], applicable for all switch mode devices. The brief review of sources of EMC and methods of their suppression is given in [7]. An origin and a distribution of EMC in the modern power supplies and in class D amplifiers have a similar character due the pulse mode of operating, although the additional factors related to modulation of the audio signal affect on the EMC level of class D amplifiers. Such factors can be an audio signal amplitude and total harmonic distortion (THD).

Aim of this article – to analyze influence of the input signal amplitude on EMC level of the class D amplifier, to obtain experimental data of conductive interferences, to create the equivalent scheme of the class D amplifier containing the paths of distribution of conductive interferences and to create an electric chart of model of the class D amplifier including parasitic parameters in the Multisim environment and to compare experimental data to results of the computer simulation.

II. Estimation of EMI level depending on the input signal level

As is known [8], expression for the unmodulated sequence of rectangular pulses looks like:

$$e(t) = E_m\gamma + 2E_m\gamma\sum_{n=1}^{\infty}\frac{\sin n\pi\gamma}{n\pi\gamma}\cos n\omega(t-t_0), \qquad (1)$$

where E_m – pulse amplitude;

t_0 – the middle of the first pulse relative to beginning of coordinates;

$\gamma = \frac{\tau_u}{T}$ – the duty cycle;

$\omega = \frac{2\pi}{T}$ – angular frequency of pulses.

Expression (1) allows to do next conclusions: a permanent component and amplitudes of all accordions are proportional to γ and E_m, and distribution of amplitudes of *n* harmonics submits to the law Sa(*x*), where $x = n\pi\gamma$.

Expression for the modulated sequence of rectangular pulses has more complicated form [8]:

$$e(t) = E_m\gamma_n + \frac{E_m t_\mu}{T_i}\sin(\Omega_c t + \theta) + \frac{E_m}{n\pi}\sum_{n=1}^{\infty}\sum_{m=-\infty}^{\infty}J_m(n\omega t_\mu)\sin[(n\omega + m\Omega_c)t - n\omega t_{HH} + m\theta] - \frac{E_m}{n\pi}\sum_{n=1}^{\infty}\sin n\omega(t - T_i), \qquad (2)$$

where T_i – tact interval;

$t_\mu = \mu T_i$ – modulation depth in system with PWM;

Ω_c – frequency of the useful signal;

$J_m(a)$ – Bessel function (cylinder function) of m-th order;

t_{HH} – beginning of nonmodulated pulse;

$\omega = \frac{2\pi}{T_i}$ - angular frequency of pulses.

Expression (2) allows to draw conclusion that in the spectrum of output signal there are harmonic with frequency of useful signal Ω_c, harmonics of quantization frequency and multiple to her $n\Omega_i$, and also combination harmonics with frequency $\Omega_{кг} = n\Omega_i \pm |m|\Omega_c$. Amplitudes of harmonics since the second at a large difference between carrying and modulating frequencies considerably less then amplitude of the first harmonic.

Thus 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.

III. Experimental research of input signal influence on the EMI level of class D amplifier

The level of EMI generated by the class D amplifier is determined by many factors. The basic sources of noises are output stages working in the switch mode. Additional high-frequency noises are created by the surges of voltage at power transistors turning on [6]. The radiation interferences spread in several ways: from "parasitic antennas" formed by PCB wires; by radio frequency emission of wires connecting amplifier's output with loudspeaker (or acoustic system); by radio frequency emission of output filter. Thus a noise level created by class D amplifier depends on design and output power, that in turn is determined by application of the amplifier. According to the classification offered in [7] depending on purpose class D amplifier can be divided into four groups: amplifier for portable devices, class D amplifier for the automotive acoustic systems, amplifier for domestic electronics and powerful/professional amplifier. Class D amplifier based on TPA3100D2 chip from Texas Instruments was used for testing as automotive power amplifier. The amplifier was tested by standard methodology without additional noise suppressing elements in two variants (with and without input signal). Test sample was powered from unipolar nonstabilized linear power supply [8]. Curves of electromagnetic interferences levels of tested amplifier and permissible limits according to CISPR 25 are presence on [3].

It is evidently from charts that almost in all range of measuring frequencies level of conductive noises without input signal is higher than in case of output power 10 W. On frequencies 600 kHz, 6 MHz and 30 MHz noises level exceeds permissible limits. In a band of frequencies higher 10 MHz a noise level also has getting up about 10-15 dB because of influence of the parasitic parameters of PCB mounting. But on frequency about 20 MHz a peak noise level is higher with input signal than without it. It should be noted that a standard regulates measuring of EMI levels at power equal to 1/8 from nominal power of amplifier during the noise-emission tests of professional audio apparatus [2]. Circuit design and element base of class D amplifiers allow them to be successfully used in professional sound reproduction. Therefore it is necessary to take into account during the testing of professional class D amplifiers, that generated noise level without input signal on some frequency bands can exceed a noises measured on standard methodology.

A successful EMI suppression depends on many factors and is an complicated problem. It is clear that the maximum influencing factors on a noise level taking in account on the stage of development will considerably simplify and reduce in cost a process of EMI providing at a stage of production and finishing. Therefore computer modeling of class D amplifier as sources and propagators of electromagnetic noises is an useful instrument on the design stage. Computer modeling will help to determine a necessary facilities of EMC supplying.

IV. Modeling of class D amplifier considering parasitic parameters

Equivalent scheme of class D amplifier for the analysis of generation processes and distribution paths of EMI is shown on a fig. 1.

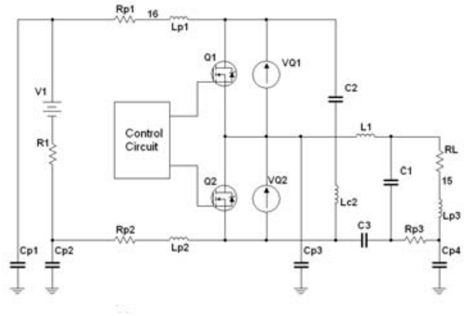

Fig. 1. Equivalent scheme of class D amplifier considering EMI components.

There are regular elements of signal amplification and elements of electromagnetic noises creating and distributing on the scheme. Regular elements are transistors Q1 and Q2, decoupling capacitor C2, filter elements L1, C1 and load resistor RL. The EMI receptor is internal resistance R1 of power source V1. The basic sources of electromagnetic noises are transistors Q1 and Q2. The sources VQ1 and VQ2 modeling pulse voltages on transistors outputs. EMI spread on power wires, thus resistances and inductances of power conductors Rp1, Lp1 and Rp2, Lp2 are taken into account. Resistance and inductance of wires to the loud speaker of Rp3, Lp3 are also taken into account. Parasitic inductance Lc2 is connected in series with the decoupling capacitor C2, that 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 elements. Cp1 and Cp2 is a capacity between each of power wires and "earth" or car chassis. Cp3 is a capacity between the output of amplifiers and "earth", and Cp1 is a capacity between the wires of loudspeaker and "earth". The interturn capacity of filter inductance coil is not considered in this equivalent scheme because of a small number of turns it is too small. This equivalent scheme is taken for basis of the class D amplifiers scheme model considering EMI components.

The object of software simulation of class D amplifier considering parasitic parameters is a forecasting of EMI levels on the stage of development. Simplified electric chart of class D amplifier model on the base of TPA3100D chip containing parasitic elements and connected to V-shaped Line Impedance Stabilization Network (LISN) is created by means of the Multisim 11 program and is shown on Fig.2. In this chart there are elements of adjusting of "dead time" at switching of output transistors and such parasitic parameters of electrolytic capacitor as pin inductance, internal resistance and inductance and resistance of wires are taken into account. Parasitic inductances and capacities have the distributed character, but taking into account, that electromagnetic noises are propagating in band up to 30МГц, they can be treated as the concentrated elements L and C [9,10].

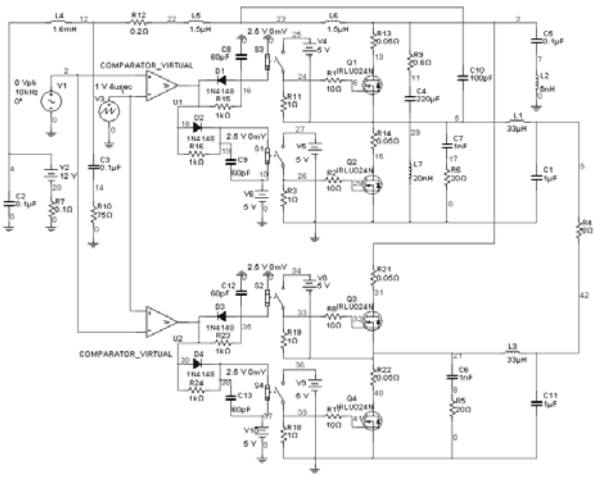

Fig. 2. Class D amplifier simulating schema containing parasitic elements.

On this basis the parasitic capacitances between the power supply wires and high current elements of amplifier are presented as a capacitor between the output of amplifier and one of the power wires. 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.

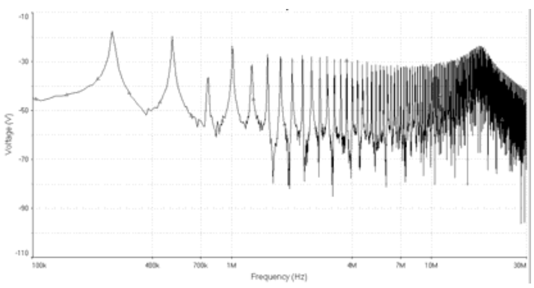

Fig.3. EMI level of class D amplifier without input signal.

On Fig.3 and Fig.4 the simulation curves of EMI levels on the exit of LISN are presented. It is easy to see from curves that on frequencies above 4MHz noise level for some frequencies is smaller up to 6-8 dB when amplifier has input signal.

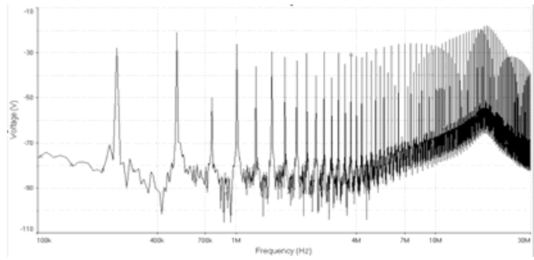

Fig.4 EMI level of class D amplifier with output power 10W.

Growing of EMI levels on frequencies above 10MHz is caused by influence of the parasitic elements introduced in the model of amplifier for the simulation of the real surges of noise voltages on this frequency band. Simulation curves have rises on frequencies below 1MHz and on frequencies of 15-20MHz. Experimental curves have the similar getting up. Thus validity of choice of parasitic parameters for this model is confirmed.

V. CONCLUSION

The theoretical analysis of influence of input signal on the EMI level of class D amplifier is made, the curves of noise voltages depending on the level of input signal are obtained. It is shown that a decline of noise level takes place due to modulation of input signal, as compared to the mode of its absence. Although on separate frequencies a noise level increases due to influence of parasite parameters. An equivalent scheme and model of class D amplifier with the generalized parasitic parameters are offered that allow to get the estimation of possible EMI level depending on frequency.

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