Instantaneous Power Dissipation in Class B Stage, Operating with Complex Load Impedance

Student author: Hristo Zhivomirov[1]
Mentors: Ekaterinoslav Sirakov[2] and Boris Nikolov[3]

Abstract – **The present paper describes analysis of the instantaneous power dissipated by active elements in class B push-pull amplifier stage. Both situations of operating with resistive and complex load impedance are treated. The simulation results that confirm the theoretical formulation are given using OrCAD PSpice.**

Keywords – **Instantaneous power, Dissipation, Class B, Complex load.**

I. Introduction

The study of power parameters and characteristics of the power amplifier stages is a major task in the analysis and design of amplifiers. In this paper, because of the restriction volume the focus is primarily on the instantaneous power dissipated by the active elements in amplifiers operating in class B with complex load impedance.

II. Analysis

The functional circuit of the power amplifier stage working in class B with bipolar transistors is given in Fig. 1.

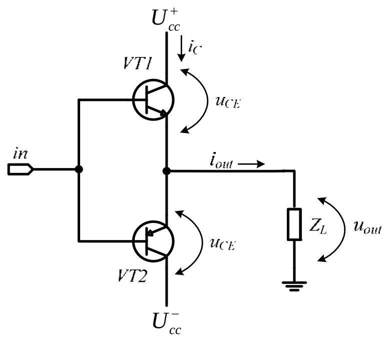

Fig.1. Functional circuit of the power amplifier stage working in class B

Student author:
[1]Hristo Zhivomirov is with the Technical University-Varna, Studentska Street 1, Varna 9010, Bulgaria.
E-mail: hristo_car@abv.bg

Mentors:
[2]Assoc. Prof. Ekaterinoslav Sirakov is with the Technical University-Varna, Studentska Street 1, Varna 9010, Bulgaria, E-mail: katiosirakov@abv.bg
[3]Asst. Boris Nikolov is with the Technical University-Varna, Studentska Street 1, Varna 9010, Bulgaria, E-mail: boris84@abv.bg

The output voltage and current of the amplifier when sinusoidal signal is applied can be described as [1]:

$$u_{out} = U_{out\,m} \sin(2\pi t / T)\text{, V} \tag{1}$$

$$i_{out} = \frac{U_{out\,m} \sin(2\pi t / T)}{Z_L}\text{, A} \tag{2}$$

where: $U_{out\,m}$ – amplitude of the output voltage, V;
Z_L – impedance of the load, Ω;
T – period of the signal, s.

For the time $0 \le t \le T/2$, works the transistor that is connected to a positive voltage supply rail U_{cc}^{+}, and the voltage drop on transistor is $u_{CE} = U_{cc}^{+} - u_{out}$. Similarly for the time $T/2 \le t \le T$, works the lower arm and the voltage drop on the transistor working in it is $u_{CE} = \left| U_{cc}^{-} - u_{out} \right| = u_{out} - U_{cc}^{-}$. Usually $U_{cc} = U_{cc}^{+} = U_{cc}^{-}$ [1].

Instantaneous power dissipation with resistive load

The power dissipated by each transistor can be represented as a product between the voltage drop u_{CE} and the current through it $i_C = i_{out}$. Thus for the instantaneous power dissipated by transistors with resistive load is obtained the expression [1], [2]:

$$P_{D(inst)} = \left[U_{cc} - U_{out\,m} \sin\left(\frac{2\pi t}{T}\right) \right] . \frac{U_{out\,m}}{R_L} \sin\left(\frac{2\pi t}{T}\right)\text{, W} \tag{3}$$

If the coefficient of effective use of supply voltage is assumed to be $\xi = \frac{U_{out\,m}}{U_{cc}}$ [3], the latter expression can be written as:

$$P_{D(inst)} = \frac{U_{cc}^2}{R_L} \left[\xi \sin\left(\frac{2\pi t}{T}\right) - \xi^2 \sin^2\left(\frac{2\pi t}{T}\right) \right]\text{, W} \tag{4}$$

Since $\frac{2\pi t}{T} = 2\pi f t = \omega t = \alpha$, rad [4], then:

$$P_{D(inst)} = \frac{U_{cc}^2}{R_L} \left(\xi \sin\alpha - \xi^2 \sin^2\alpha \right)\text{, W} \tag{5}$$

Instantaneous power dissipation with complex load

A complex load means load that has impedance, composed of resistance and reactive (reactance) capacitive (capacitance) or inductive (inductance) component, according [4]:

$$\dot{Z}_L = R_L \pm jX_L = \left|\dot{Z}_L\right|.e^{j\varphi} = Z_L\angle\varphi\,,\Omega \qquad (6)$$

$$\left|\dot{Z}_L\right| = \sqrt{R_L^2 + X_L^{\,2}}\,,\Omega;\;\; \varphi = arctg\left(\frac{X_L}{R_L}\right),\text{ rad} \qquad (7)$$

Further in this paper will be assumed $Z_L = const$.

If the phase shift between current i_C and voltage u_{CE} is denoted as φ, then from Eqs. (3) and (5) for the instantaneous power dissipation with complex load can be recorded:

$$P_{D(inst)} = \frac{U_{cc}^2}{Z_L}\left[\xi\sin\alpha - \xi^2\sin(\alpha+\varphi)\sin\alpha\right],\text{ W} \qquad (8)$$

Fig. 2 presents an analysis of the expression for ξ = 1 and different load phase angles φ. It can be seen that the peak of $P_{D(inst)}$ could be about 6,4 times more than average power dissipation when resistive load is applied to the amplifier.

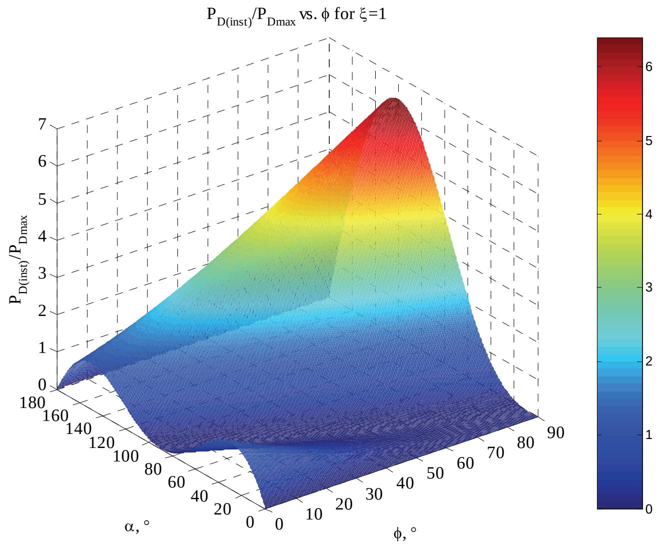

Fig. 2. Instantaneous power dissipation $P_{D(inst)}$ for ξ = 1 as a function of phase shift φ, with complex load

Fig. 3 presents the analysis of Eq. (8) for phase shift angle φ = 90 ° and different values of ξ.

The instantaneous power dissipation when resistive load is applied, i.e. when phase shift φ = 0°, is shown in Fig. 4 as a function of the coefficient ξ. It can be noted, that the peak of $P_{D(inst)}$ in that case is about 1,23 times more than the average power dissipated by active elements.

The instantaneous power is rated to a maximum average power dissipation of both active devices for resistive load P_{Dmax}. The last one can be described when $\xi = 2/\pi$, as [1], [5]

$$P_{Dmax} = \frac{2U_{cc}^2}{\pi^2 R_L},\text{ W} \qquad (9)$$

In Fig. 5 and Fig. 6 the peak instantaneous power dissipation $P_{D(inst)peak}$ as a function of the coefficient ξ, with parameter phase shift angle φ is presented.

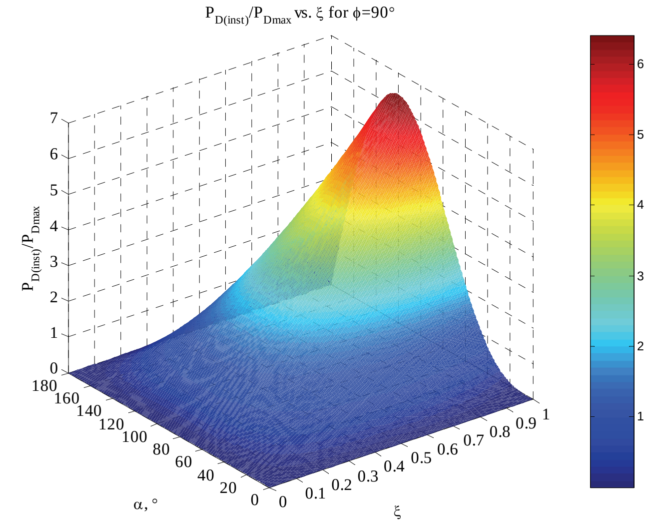

Fig. 3. Instantaneous power dissipation $P_{D(inst)}$ for φ = 90° as a function of the coefficient ξ when reactive (inductive) load is applied

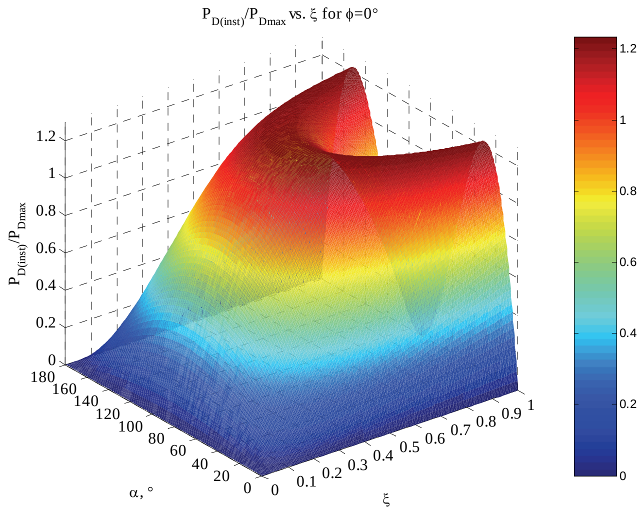

Fig. 4. Instantaneous power dissipation $P_{D(inst)}$ for φ = 0° as a function of the coefficient ξ when resistive load is applied

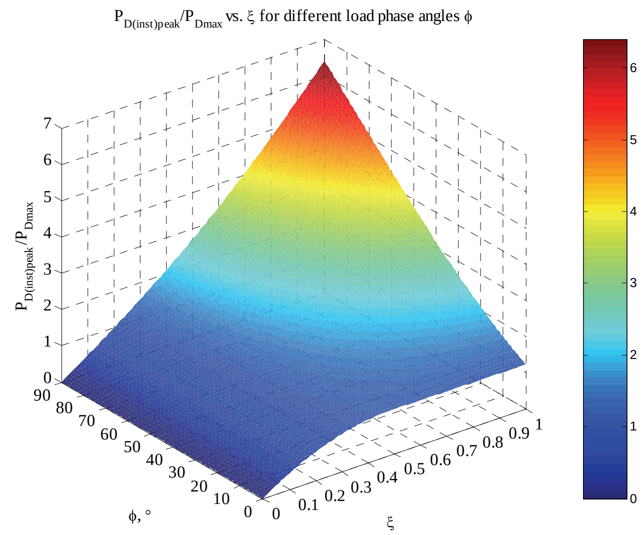

Fig. 5. Peak instantaneous power dissipation $P_{D(inst)peak}$ as a function of the coefficient ξ, and parameter phase shift φ (3D expression)

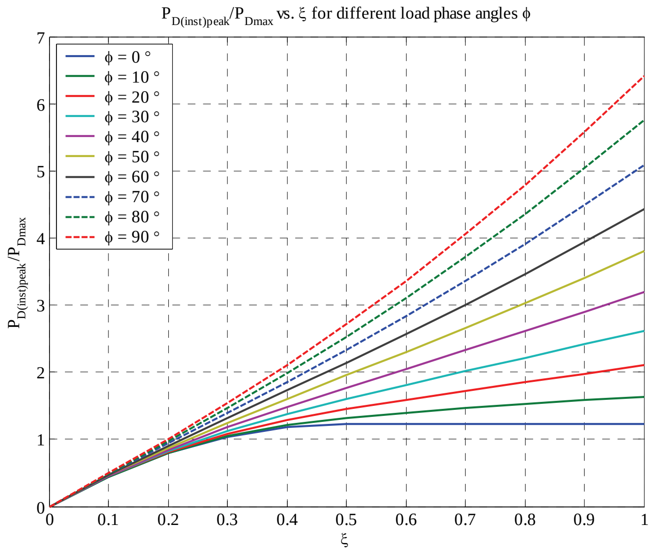

Fig. 6. Peak instantaneous power dissipation $P_{D(inst)peak}$ as a function of the coefficient ξ, and parameter phase shift φ

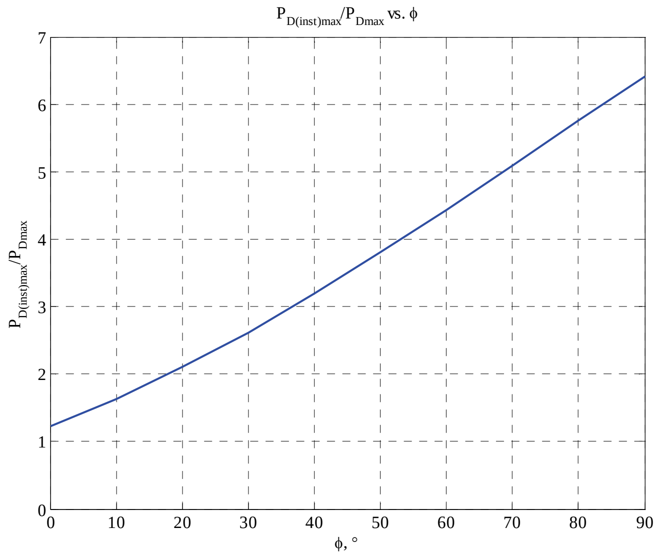

Fig. 7. Absolute maximum value of $P_{D(inst)peak\ max}$, as function of phase shift φ

It can be seen (Fig. 2) that the absolute maximum value $P_{D(inst)peak\ max}$, which can reach the instantaneous peak power dissipation with phase shift angle φ is obtained when the full phase of the signal is:

$$\begin{aligned} \omega t = \alpha &= 30^\circ + \frac{\varphi}{3}, ^\circ \\ &= 0,5236 + \frac{\varphi}{3}, rad \end{aligned} \quad , \qquad (10)$$

if the current anticipates the voltage, i.e. the voltage lags the current (capacitive load) † and:

$$\begin{aligned} \omega t = \alpha &= 180^\circ - \left(30^\circ + \frac{\varphi}{3}\right), ^\circ \\ &= \pi - \left(0,5236 + \frac{\varphi}{3}\right), rad \end{aligned} \quad , \qquad (11)$$

if the current lags the voltage (inductive load)† and can be found if substituting the value for α obtained by Eqs. (10) and (11) in Eq. (8). Derived expressions do not match those in [2]. Such an analysis is made in [3], where the resulting expression is essentially different from Eqs. (10) and (11), but gives an equivalent result.

The dependence given with Eqs. (10) and (11) is presented graphically in Fig. 7 again rated to P_{Dmax}. The problem has been solved with the use of numerical methods and the graphical form is identical to that obtained from the analytic solution so that demonstrates the consistency of the displayed dependence. The same result is shown in [2].

† The starting point (α = 0) is the point at which current passes through it's zero value.

III. Computer Simulations

At the following figures are shown the computer simulations made with OrCAD PSpice 9.1 (Cadence Design Systems). The Transient analysis in the time domain of the load voltage, the current through one of transistors and it's instantaneous power dissipation as product between collector current and collector-emitter voltage drop are presented. All simulations were carried out with coefficient ξ = 1. Similar results are shown in [6].

Fig. 8 shows the test circuit for simulation of instantaneous power dissipation with a resistive load R_L = 8 Ω. Fig. 9 shows the results from the simulation (transient analysis), in the time domain.

From Fig. 9, $P_{D(inst)peak}$ = 7 W when P_{Dmax} = 5,7 W, i.e. $\frac{P_{D(inst)\,peak}}{P_{Dmax}} = 1,23$, in agreement with Eq. (5) and Fig. 6.

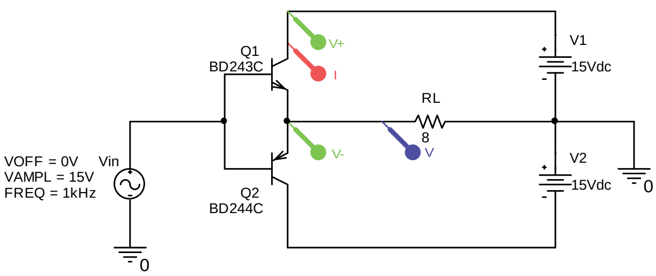

Fig. 8. Test circuit for simulation of the instantaneous power dissipation when a resistive load is applied

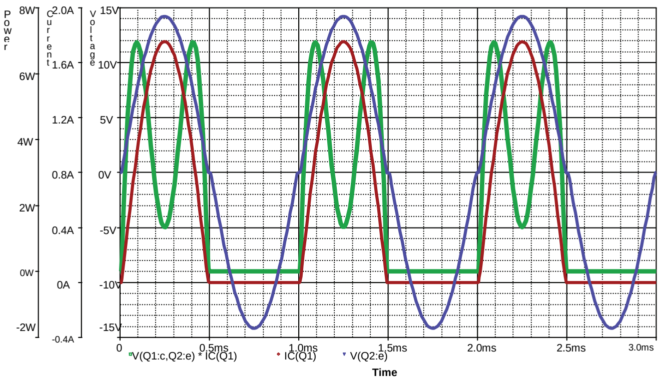

Fig. 9. Signals in the time domain for the simulated circuit in Fig. 8

Fig. 10 shows the simulation circuit for instantaneous power dissipation in case of a complex load $Z_L \angle \varphi = 8\angle 90^\circ\ \Omega$. Fig. 11 shows the results from simulation. From Fig. 11, $P_{D(inst)peak} \approx$ 37 W when P_{Dmax} = 5,7 W, i.e. $\frac{P_{D(inst)peak}}{P_{Dmax}} = 6{,}5$, in agreement with Eqs. (11), (8) and Fig. 6.

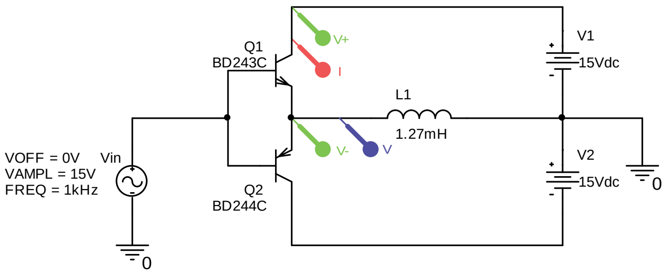

Fig. 10. Test circuit for simulation of the instantaneous power dissipation when a complex load (reactance) is applied

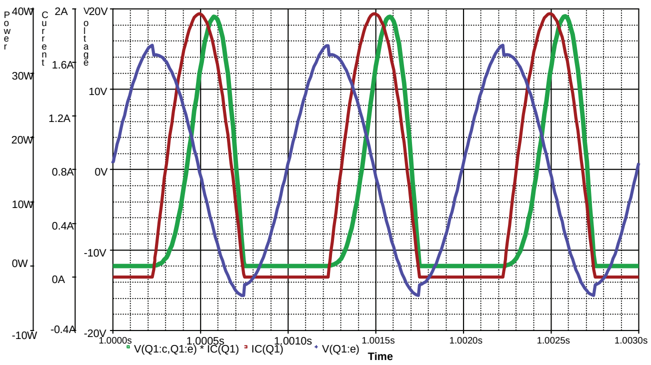

Fig. 11. Signals in the time domain for the simulated circuit in Fig. 10

IV. Conclusion

An examination of the instantaneous power dissipation by the active elements in Class B amplifiers with a complex load is presented. The affected subject is of particular importance for the design and analysis of power amplifiers, especially in the low-frequency applications. The statement concerns the work of all active components, no matter the type – integrated or discrete, solid state or vacuum. Conducted computer simulations demonstrate unequivocally the reliability of the theoretical formulation. In the statement Eqs. (5) and (8) and Figs. 3, 5 and 6 are originally presented, and Eqs. (10) and (11) are original contribution.

This work can serve the design and improvement of amplifier equipment, and theoretical analysis of amplifiers.

Consideration of the theme will continue with finding the necessary power parameters that are required to have active components operating in the class B amplifiers, with a complex load.

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