VIDEO PULSE POWER AMPLIFIER FOR ACCELERATOR TECHNOLOGY APPLICATIONS

V.P. Cherepanov, Budker INP, Novosibirsk, Russia

Abstract

Video pulse power amplifier for VEPP-4M storage ring vertical betatron oscillations damping system (BINP) is designed. Low level signal band of the amplifier is of 0.5-50*MHz*, impulse power is of 400*W*. The amplifier is made in standard "Cherry", module dimensions are of 80x240x400*mm*.

In sight the amplifier will find applications in beams betatron oscillation frequencies measurement systems of accelerators and storage rings and as preamplifier for RF systems of heavy particles beams accelerators. In the report the amplifier structure, MOSFETs bias currents settings and stabilization principles, and also parameters of various modes of operation are described.

Design documentation for production of small set of the amplifiers is prepared.

AMPLIFIER STRUCTURE

At Fig. 1 simplified scheme of output stage (in rectangular outline limits) and external loads for two paraphrase outputs of the amplifier is presented. Transistors are of the type IXZ2210N50L RF Power MOSFET (***IXYS Company***) – two MOSFETs in one case. Mode of operation the MOSFETs is close to *AB* that with the gates characteristics being quadratic provides good linearity of the amplifier as applied to the tasks mentioned above.

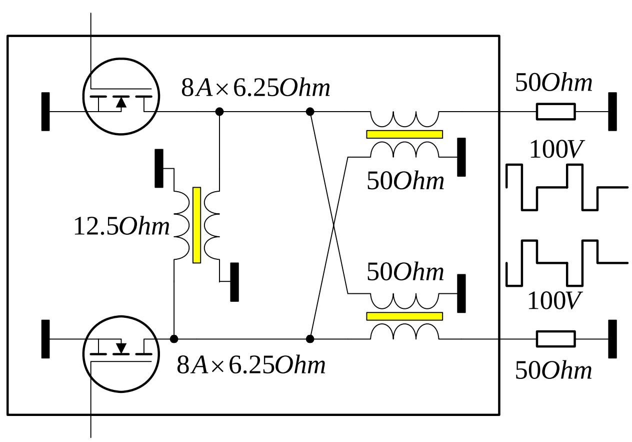

Figure 1: Output stage scheme of amplifier.

Full output impulse power of 400*W* provides with peak MOSFETs currents of 8*A*. Bias MOSFETs currents at supply voltage of 80*V* are equal 1.6*A*. A method for bias currents calculation depending on supply voltage will be considered in section "MOSFETs bias currents".

All transformers are of "long line" type. With the lines impedances indicated on Fig. 1 there is no voltage overload at impulse signals fronts and, thus, there is no retardation of the fronts. Each of two output transformers has 17 turns of RG-174 type cable over ferrite rings of type K45x28x8 M1500NM3. These transformers have impulse characteristics not worth then 100*Vmcs* that provides low cut frequency for square wave of 0.5*MHz*. A transformer with impedance of line about 12.5*Ohm* has 10 turns of two 7-wire lines in parallel over ferrite ring of type K28x16x9 M1500NM3. This transformer has impulse characteristic not worth then 50*Vmcs* that are well matched with the impulse characteristics of output transformers.

At Fig. 2 simplified scheme of driver for one of MOSFETs is presented. The driver provides amplitude of signal up to 4*V* at the MOSFET gate. Driver amplification is equal to 8. Paraphase signals at inputs of drivers are formed by chip of type AD8131 which has amplification equal to 1. Thus maximum permissible amplitude on the amplifier input is equal to 0.5*V*.

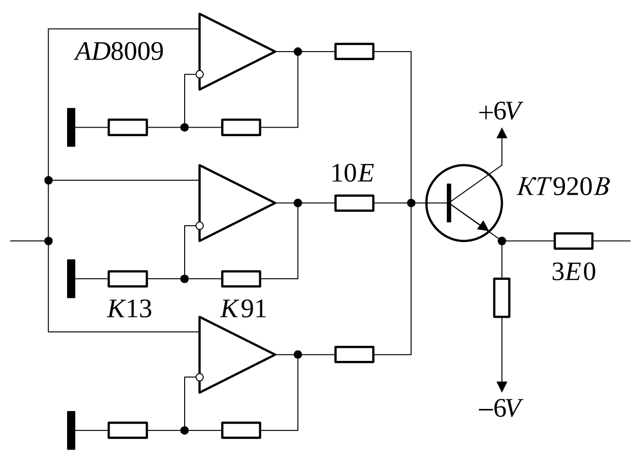

Figure 2: MOSFET driver.

The total amplifier voltage amplification (input – one of the amplifier outputs) for low level signal is equal to 240. At big signal mode of operation, transfer coefficient decrease to 200 (at supply voltage of 80*V*).

MOSFETS BIAS CURRENTS

At Fig. 3 the ways of current which is generated by the left MOSFET and dependence of the drain current from the gate voltage (apart from necessary bias voltage) are presented.

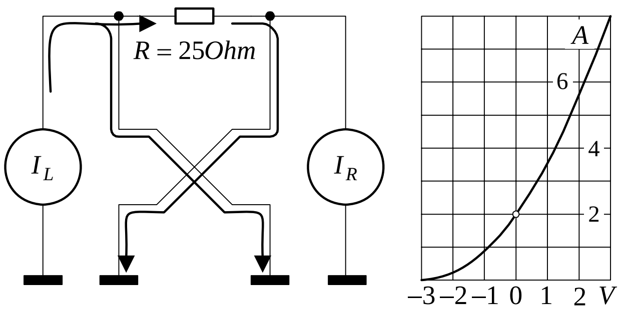

Figure 3: Ways of the left MOSFET current and its gate characteristic.

The MOSFET gate characteristic is quadratic (apart from saturation effect):

$$I_L = I_m (1+u)^2/4,\; I_R = I_m (1-u)^2/4 .$$

Here $u(\varphi)$ – *normalized* periodical voltage without constant component at the MOSFET gate (for MOSFETs of type IXZ2210N50L normalized voltage is about 3.0*V*), $I_m = 8A$ – peak MOSFET current at calculated impulse output power of the amplifier $P_m = 400W$.

In principle, in order in view of quadratic gate characteristic to have linear transfer characteristic of the amplifier, *nominal* MOSFET bias current should be equal to quarter of peak current. Let us mark that in this case the power which dissipates in MOSFETs has peak at idling with supply voltage E_s being in limits $E < E_s < 2E$. Here $E = 50V$ – *nominal* (i.e. apart from saturation voltage) supply voltage for maximum output impulse power of $P_m = 400W$. Really one needs to have some *excess* of supply voltage over the nominal voltage: $\psi = E_s/E$. In that case the powers – output (P_{out}), consumable from supply ($P_s = E_s I_s$) and dissipated in MOSFETs (P_{TT}) are described by the next expressions:

$$P_{out} = R\left\langle \left(\frac{I_L}{2} - \frac{I_R}{2}\right)^2 \right\rangle = R\left(\frac{I_m}{2}\right)^2 \left\langle u^2 \right\rangle = P_m \left\langle u^2 \right\rangle ,$$

$$P_s = \psi E \left\langle I_L + I_R \right\rangle = \psi E \frac{I_m}{4} 2\left(1 + \left\langle u^2 \right\rangle\right) = \psi P_m \frac{1 + \left\langle u^2 \right\rangle}{2} ,$$

$$P_{TT} = P_s - P_{out} = P_m \left(\frac{\psi}{2}\left(1 + \left\langle u^2 \right\rangle\right) - \left\langle u^2 \right\rangle \right)\Bigg|_{\psi = 2} = P_m .$$

The lust expression indicates principle possibility to have such a mode of operation at which P_{TT} does not depend from signal level at the MOSFETs gates (that is very desirable).

Let bias current be less then the nominal bias current: $I_0 \le I_m/4$. Then maximum amplitude at the MOSFETs gates *in limits of quadratic area* of its characteristics will be equal

$$u_m = \sqrt{4 I_0 / I_m} .$$

That case is analogously to the case described above, when supply voltage isn't used completely. Corresponding supply voltage *excess coefficient* will be equal:

$$I_m / I'_m = I_m / 4I_0 > 1 .$$

At actual supply voltage excess $E_s/E = \psi$, which is necessary because of saturation effect, *effective* excess coefficient is given by the next expression:

$$\psi_{eff} = \psi \cdot I_m / 4I_0 .$$

In order the effective excess coefficient would not be less then 2, bias current should be not less then

$$I_0 = \psi \frac{I_m}{4\psi_{eff}}\Bigg|_{\psi_{eff} = 2} = \psi \frac{I_m}{8}\Bigg|_{I_m = 8A} = \psi A .$$

At bias current $I_0 = \psi A$ P_{TT} in principle does not depend from signals level on the MOSFETs gates up to $u_m = \sqrt{4 I_0 / I_m}$. With further increase its amplitude (up to $2 - u_m$ to provide peak drain current I_m) P_{TT} becomes somewhat less (see Tab. 1 below). While in this area resulting gate characteristic rises as rest of parabola of *the one* of MOSFETs, that has small influence on form of transparent transfer characteristic because of more essential effect of limitation as a result of MOSFETs saturation effect.

BIAS CURRENT STABILIZATION

For MOSFETs bias currents stabilization some feed back loops are provided.

T-loops stabilize MOSFETs bias currents $I_L = I_R = I_s/2$ almost completely compensating the effect of additional changing of *effective* voltages at gates because of MOSFETs junctions *temperature* changing while one tunes bias currents ($\Delta T = \Delta I_s E_s R_T$):

$$\Delta u_g^{eff} = \Delta I_s E_s R_T \cdot du_g / dT - \Delta I_s / 2 \cdot R^- = 0$$

at $R^- = 2E_s R_T \cdot du_g / dT$. Here $R_T = dT/dP$ – thermal resistance of MOSFETs junctions – environment, R^- – the T-loop feed back resistance.

In presence of signal not all power that consumes from supply dissipates in MOSFETs – a part of it goes to load. While initial T-loop signal is proportional to *supply power* the bias currents decrease. P-loop – the loop by output power, corrects that secondary effect of T-loop:

$$\Delta u_g^{eff} = \Delta P_{TT} R_T \cdot du_g / dT - I_s / 2 \cdot R^- + \Delta P_{out} S_d =$$

$$= \left(\Delta P_s - \Delta P_{out}\right) R_T \cdot du_g / dT - \Delta P_s \frac{R^-}{2E_s} + \Delta P_{out} S_d =$$

$$= \Delta P_s \left(R_T \frac{du_g}{dT} - \frac{R^-}{2E_s} \right) + \Delta P_{out} \left(-R_T \frac{du_g}{dT} + S_d \right) = 0$$

at $S_d = R_T \dfrac{du_g}{dT} = \dfrac{R^-}{2E_s}$. Here $S_d = du_d / dP_{out}$ – the output power detector sensitivity.

In addition to these principal feed back loops, for the MOSFETs bias currents stabilization there are also loops referring to heat sink temperature and to supply voltage.

VARIOUS MODES OF OPERATION

In Tab. 1 bias currents values and other *calculated* parameters for modes of operation with different supply voltage and periodical signal with form of « +1,–1,0,0 » (off-duty factor of active phase is equal to 2, see Fig. 1) are presented. Maximum average output power $P_{out}^{\max} = 200W$, impulse power $P_{out}^{pulse} = 400W$.

Table 1: Modes of operation parameters

E_s, V	75	80	85
For saturation, V	25	30	35
I_0, A	1.5	1.6	1.7
$P_s^0 = P_{TT}^0$, W	**225**	**256**	**289**
$u_m \times 3V$,	2.6	2.7	2.8
$(2 - u_m) \times 3V$, V	3.4	3.3	3.2
$P_s^{\max}$, W	412.5	448	484.5
$P_s^{\max} - P_{out}^{\max}$, W	**212.5**	**248**	**284.5**
Maximum environment temperature at $R_T = 0.3°/W$		98	88
Maximum environment temperature at $R_T = 0.6°/W$	40	21	
Cooling	Air		Water

A prototype of the serial amplifier had air cooling, so the amplifier characteristics were tested at mode of operation with supply voltage of 75*V*. At Fig 4 the amplifier amplitude characteristic is presented, and in Tab. 2 – the corresponding mode of operation parameters.

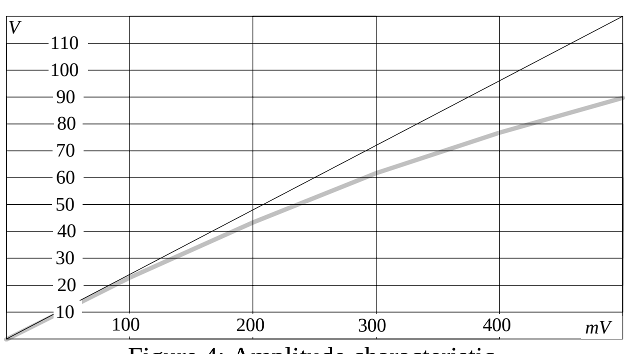

Figure 4: Amplitude characteristic.

As far as VEPP-4M storage ring vertical betatron oscillations damping system is concerned (mode of 2x2 bunches) it is necessary to have at the amplifier output 4 signals with form « +1,–1 » with total duration not grater then 400*ns*, which corresponds to active phase minimal off-duty factor of 3 (period of beam circulation in VEPP-4M is about 1200*ns*). In that case with grater supply voltage one can get grater impulse power of the amplifier.

Table 2: Modes of operation parameters

u_{in}, mV	0	100	200	300	400	500
E_s, V	75.7	75.6	75.5	75.2	74.8	74.2
I_s, A	3.00	3.11	3.43	3.96	4.60	5.19
P_s, W	227	235	259	298	334	385
u_{out}, V	0	23	43.5	62	77	90
P_{out}, W	0	11	39	81	128	182
P_{TT}, W	227	224	220	217	206	203

In Tab 3 bias currents values and other *calculated* parameters for modes of operation with different supply voltage and periodical signal with form of « +1,–1,0,0,0,0 » (off-duty factor of active phase is equal to 3) are presented. Here 30*V* saturation voltage is excepted.

Table 3: Modes of operation parameters

E_s, V	90	100
I_m, A	9.6	11.2
I_0, A	1.8	2.0
$P_s^0 = P_{TT}^0$, W	324	400
$u_m \times 3V$, V	2.6	2.5
$(2 - u_m) \times 3V$, V	3.4	3.5
$I_s^{\max}$, A	4.4	5.1
$P_s^{\max}$, W	396	507
$P_{out}^{\max}$, W	192	261
P_{out}^{pulse}, W	576	784
$P_s^{\max} - P_{out}^{\max}$, W	204	246
Maximum environment temperature at $R_T = 0.3°/W$	78	55
Cooling	Water	Water

SUMMARY

At present time one of the amplifier prototype is used for beam spin resonant depolarization system on storage ring VEPP-4M. Also a set of 4 analogous amplifiers with transformers for its power summation and other devices, which provides feeding of one of the vertical betatron oscillations damping system kickers, is installed and tested here.