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CALCULATION OF REACTIVE CIRCUITS USED FOR HIGH-POWER CURRENT PULSES FORMATION ON AN INDUCTIVE LOAD

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Abstract. The theory of bipolar circuits is employed to treat the case of generating high-power current pulses by means of an artificial shaping line with an inductive load. The results are applied to the development of a pulsed modulator used as a power supply for flashlamp-pumped solid-state lasers.

Linear circuits with lumped elements generating pulses with nearly rectangular shape are used widely in practice, especially in high-power pulsed modulators with complete discharge of the storage capacitors. A relatively large number of works [1–4] has been dedicated to solving the problems of synthesizing such circuits, especially for the important practical case of artificial shaping lines. Most of the analyses and calculations treat the case of bipolar shaping circuits in series with the load. The amplitude of the output-pulse voltage is then equal to half of the supply voltage.

When bipolar circuits are calculated, the following assumptions must be made:

- the square pulses generated have finite edges with duration determined by the number of loops;
- since the current pulse is to be dissipated on a reactive load, the bipolar circuits synthesized must contain an inductance connected in series with the load. In the case considered here, the analysis is devoted to the shaping of a square pulse dissipated on an active load; the latter is in series with the inductance of the bipolar circuit whose value includes that of the inductive load. This simulates the case of flashlamp pumping of solid-state lasers.

Fig. 1 presents a uniform artificial shaping line constructed by lumping the static inductance and capacitance of a natural line into separate loops. The dashed line shows how the artificial line is divided into T-shaped loops that are K-type low-frequency filters. The duration t_i of the propagating pulse is equal to twice the line delay-time t_d:

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$$t_i = 2t_d = 2\frac{l}{\nu} = 2n\sqrt{\left(\frac{L_j}{C_j}\right)} \tag{1}$$

where l is the line length, ν is the pulse propagating velocity, n is the number of loops, and L_j and C_j are the inductance and capacitance of a single loop, respectively.

When the line has a matched load, i. e., $R_1 = \rho = \sqrt{\left(\frac{L_j}{C_j}\right)}$, one can find the values of the elements forming the artificial line:

$$L_j = \frac{R_l t_i}{2n}, \qquad C_j = \frac{t_i}{2R_l n} \tag{2}$$

where R_l is the value of the active load.

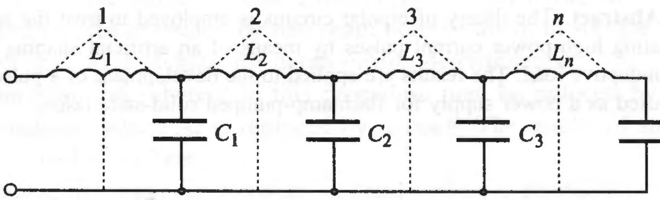

Fig. 1.

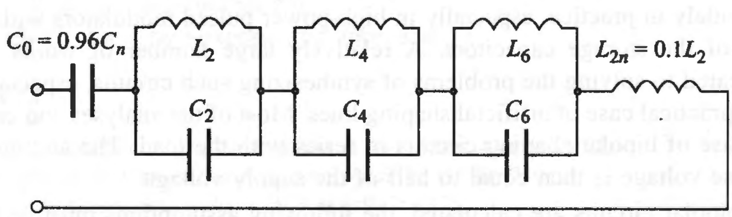

Fig. 2.

The shaping line illustrated in Fig. 1 is easily implemented in practice due to the identity of the elements in the separate loops. Moreover, the fact that it is constructed by K-type low-frequency filters makes it possible to analyze the transition processes taking place by means of the characteristic parameters of a symmetric quadripole circuit where the incident and reflected waves are described by Bessel functions. If the remaining loops are identical, the transition processes can also be described in the case when one or two loops have different parameters. E. g., as one can see in Fig. 1, $1/2L_1$ is not part of the T-filter and can be considered as an additional inductance. By varying the values of L and C one can obtain the necessary parameters of the pulse shaped.

Besides contributing to the study of the physical processes in the line, the theoretical considerations will permit calculation of the effective values of the currents and average power dissipated in the shaping line elements thus allowing determination of their relative loading.

The expressions derived below will yield the dimensionless current i_c/I (i_c being the current through a separate loop); the time is also considered dimensionless ($t = \omega t_i$); the effective value I^c_{eff} of the current through the inductances of the artificial line is then

$$(I^c_{\text{eff}})^2 = I^2 \frac{1}{T} \int_0^T i_c^2(t)dt \tag{3}$$

where T is the dimensionless pulse repetition period; it is related to the true period T_i by the expression

$$T = \omega_0 T_i = 4\pi \frac{T_i}{t_i} \,. \tag{4}$$

The square of the effective value of the current through the load is

$$I^2_{\text{eff}} = \frac{I^2 t_i}{T_i} \,. \tag{5}$$

Bearing in mind (3) and (4), we obtain an expression for the square of the effective value of the current in a dimensionless form:

$$\frac{{I^c_{\text{eff}}}^2}{I_{\text{eff}}} = \left(\frac{1}{4\pi}\right) \int_0^T i_c^2(t)dt \,. \tag{6}$$

Assuming that the current pulses through the artificial line elements have square shape

$$\frac{{I^c_{\text{eff}}}^2}{I_{\text{eff}}} = 1 - \frac{j}{n} \,. \tag{7}$$

The above expression shows that the value of the current through the inductances depends on the order number j of the loop — a maximal value is obtained at the beginning of the artificial line.

The effective value of the current through the capacitors is

$$\frac{{I^2_{\text{eff}}}^2}{I_{\text{eff}}} = \frac{1}{n} , \tag{8}$$

or the effective value of the current through the capacitors does not depend on the loop's order number — i. e., the capacitors are loaded identically.

Fig. 2 presents an artificial line consisting of anti-resonant loops. An advantage of the circuits is the parallel coupling of the capacitors and inductances in the separate loops; this allows one to compensate the parasitic capacitances of the inductances. Another positive feature of the circuit is the fact that only one capacitor (C_0) is under voltage during the charging cycle. A fundamental drawback, however, of the circuit is that the capacitors have different values; identity of the capacitances is a very important requirement when high-power pulses are generated. We shall not, therefore, analyze this circuit.

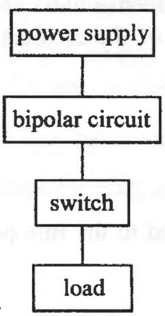

Fig. 3.

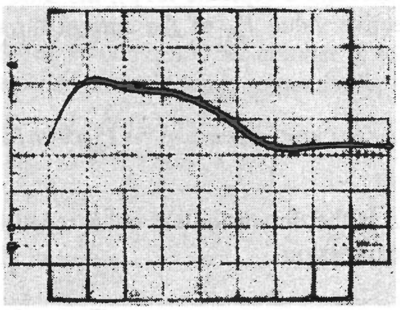

Fig. 4.

The block-diagram of a pulsed generator with a uniform artificial line is shown in Fig. 3. Usually, in order to improve the overall energy efficiency of the system, a recharging circuit, consisting of a diode and an inductance, is included in the bipolar circuit (for simplicity, this circuit is not shown in the figure). The capacitances of the artificial line are then self-charged which significantly shortens the charging cycle, i. e., increases the possible pulse repetition rate.

Bearing the above theoretical consideration in mind, we implemented a pulsed modulator with artificial shaping line and used it to pump a Xe flashlamp. The pulse parameters used in the calculations were as follows: pulse duration 1×10^{-3} s, leading edge duration 50×10^{-6} s, amplitude of the first current overshoot 12.3 %. A typical oscilloscope trace taken using a Tektronix 446 storage oscilloscope is shown in Fig. 4 (horizontal division 200 μs, vertical division 50 kA).

To conclude, we used the theory of bipolar circuits to treat the case of formation of high-power square current pulses on inductive loads. The results were applied to the important practical case of developing pulsed power supplies for flashlamp-pumped solid-state lasers.

References

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