

# Linear modulators on the monitor screen

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**Abstract.** The simulation software to research the work of the linear modulator with the discharge line on the thyatron (generator with a soft switch) is presented. In this software it is possible to configure the generator and to research the influence of the parasitic inductances and capacitances on the nanosecond pulses.

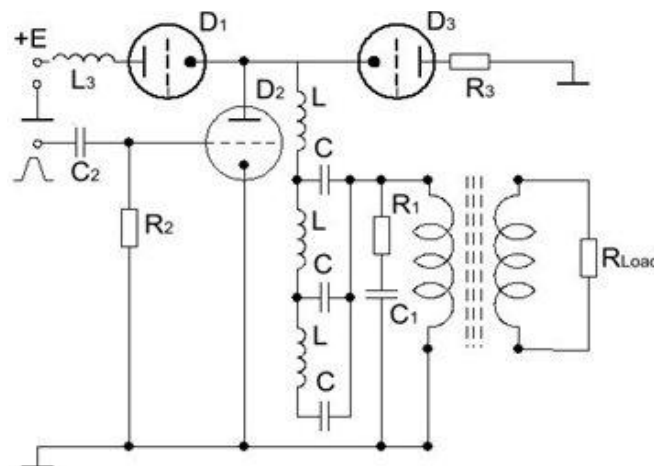
## 1. Introduction

The development and exploitation of high-power pulsed devices, the most important elements of which are the microsecond and nanosecond range generators, become much easier when you use computer programs that simulate the operation of these devices using the appropriate mathematical models.

GENS software simulates the operation of the linear modulator with considering the charge of the forming line and the discharge it to the load connected via transformer. The mathematical model of the generators is described, the description of the graphical user interface is given.

The calculation takes into account the features of the forming line and almost all the main parameters of the circuit elements, including the pulse correction block, which considers the features of mathematical modelling of high-power pulsed devices.

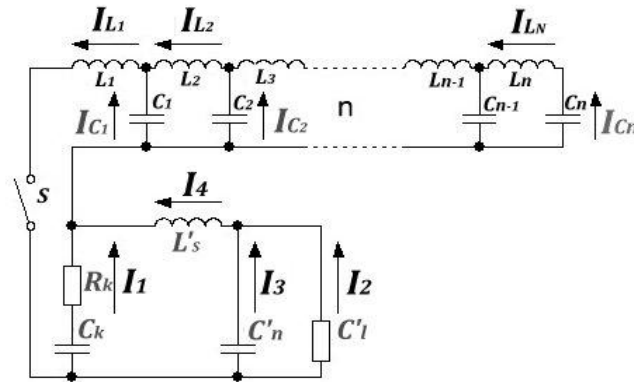
## 2. Linear modulator mathematical model



**Figure 1.** Thyatron modulator with DC power supply.

The circuit of the linear modulator is shown in figure 1. The requirements for a pulse fall time reduction tend to increase the storage capacitor capacitance, and hence its size. An alternative is to use a no-load long line or its equivalent as a storage element. This is particularly useful in the absence of the pulse duration fast regulation. The electrical length of the line determines the duration of the pulse.

The forming line capacitance is charged through the charging choke  $L_3$ , diode  $D_1$  and the load resistance. The diode  $D_2$  excludes a voltage change on the line. The pulse transformer can be plugged at the modulator output. To shunt the fluctuations in the rise a correcting  $R_1C_1$  chain is often connected in parallel to the transformer primary winding. The switch turns on after the voltage on the line is set. The switch is a soft commutator, which has a very low resistance in the conduction mode. After the end of the line discharge to the load the line charge occurs again, and the process repeats. The forming line circuit consists of  $N$  cells with the same values of inductance  $L$  and capacitance  $C$ . On the circuit  $N = 3$ .



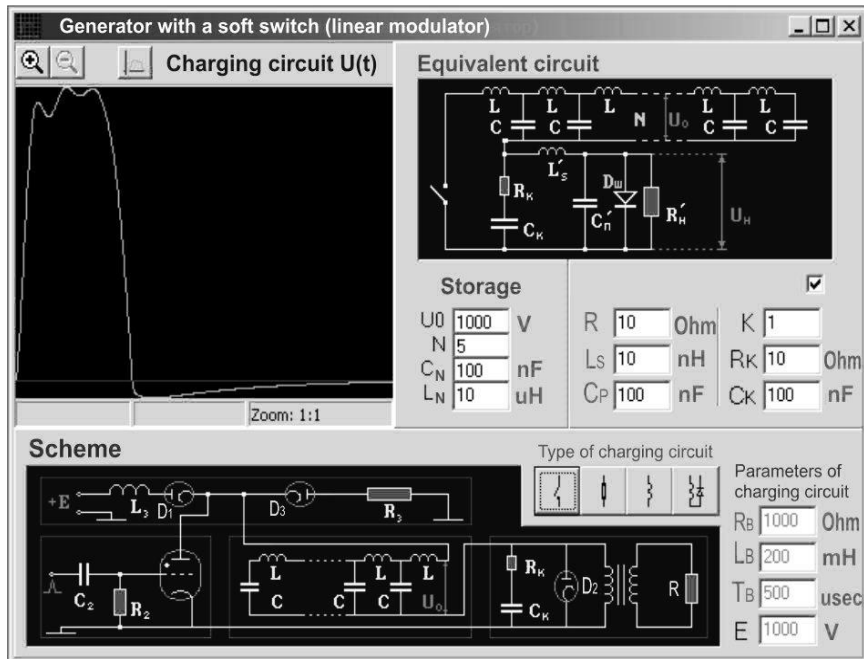
**Figure 2.** The equivalent circuit of discharging the forming line.

The forming line is shown in figure 2, where  $R'_l$  – reduced load,  $C'_n$  – reduced parasitic capacitance,  $L'_s$  – inductance of the transformer,  $R_k$ , and  $C_k$  – correction circuit. The forming line charged to voltage value  $U_0$  and consisting of  $N$  same cells with the inductance  $L$ , capacitance  $C$ , described by the following equations:

$$\left\{ \begin{array}{l} I_1 + I_4 - I_{L1} = 0 \\ I_{L1} + I_{C1} - I_{L1} = 0 \\ \dots \\ I_{LN} + I_{C_{N-1}} - I_{L_{N-1}} = 0 \\ \frac{I_{C1}}{pC} - \frac{U_0}{p} + pLI_{L1} + LI_0 + R'_HI_2 + pL'_SI_4 + L'_SI_{LS0} = 0 \\ pL'_SI_4 + L'_SI_{LS0} - \left( R_KI_1 + \frac{I_1}{pC_K} - \frac{I_{Ck0}}{p} \right) + R'_HI_2 = 0 \\ \frac{I_3}{pC_{\Pi}} - \frac{U_{Cn0}}{p} - R'_HI_2 = 0 \\ \frac{I_{C2}}{pC} - \frac{U_0}{p} + pLI_{L2} - \left( \frac{I_{C1}}{pC} - \frac{U_0}{p} \right) = 0 \\ \dots \\ \frac{I_{CN}}{pC} - \frac{U_0}{p} + pLI_{LN} + LI_0 - \left( \frac{I_{C(N-1)}}{pC} - \frac{U_0}{p} \right) = 0 \end{array} \right. \quad (1)$$

The analytical solution for system of equations (1) is very difficult, Here it is advisable to use numerical methods such as the finite difference method.

### 3. Linear modulator simulator interface



block "Oscilloscope" can also be run in its own interface window (figure 4). Circuit parameters include:

Storage options:

1.  $U_0$  – voltage on the capacitors in a simulated line.
2.  $N$  – number of LC-circuits in a simulated line (not more than 50).
3.  $C_N$  – the LC-circuit capacitance of a simulated line.
4.  $L_N$  – the LC-circuit inductance of a simulated line.

Load Settings:

1.  $R_l$  – load resistance
2.  $L_S$  – parasitic inductance
3.  $C_P$  – parasitic capacitance
4.  $K$  – transformation ratio
5.  $R_K$  – correcting chain resistance value
6.  $C_K$  – correcting chain capacitance value
7.  $D_W$  – if enabled (checkbox is checked), in the circuit a shunt diode  $D_W$  is presented, if no – no diode.

In addition, it is possible to study the processes in the charging circuit of several types, either of which may be chosen using the buttons "type of charging circuit" in the upper right corner of the oscillator circuit. Types of charging circuits include:

"Switch". It is used to view the signal in the discharge circuit, which indicates an appropriate note on top of the screen. In all other types of charging circuit the signal is displayed in the charging circuit.

1. "Resistance".  $RC$  – charging circuit.
2. "Inductance".  $LC$  – charging circuit.
3. "Inductance and diode".  $LC$ -charging circuit with a diode.

Charging circuit parameters:

1.  $R_B$  – charging resistance (for  $RC$  -circuit)
2.  $L_B$  – charging inductance (for  $LC$  and  $LC$  with diode circuits)
3.  $T_B$  – pulse period (storage charge time)
4.  $E$  – supply voltage.

It should also be noted that the correcting parameters  $R_K$ ,  $C_K$ , and parasitic parameters  $L_S$ ,  $C_P$  are not included in the calculation processes in the charging circuit that appropriately displayed on the equivalent circuit. In addition, the calculation is carried out only in the case of line, consistent with the load. If the line is not consistent with the load, the line inductance is changed automatically so to provide matching. When considering the discharge circuit it is assumed that the line is already charged up to voltage  $U_0$  at the initial time.  $U_0$  is set by the user and is not calculated from the parameters of the charging circuit

#### 4. Conclusion

The high-power linear modulator can be represented as the electrical circuits containing conventional elements with lumped parameters and elements with distributed parameters, such as transmission line with variable distributed electrical parameters. The pulse forming line which is a circuit element modeled as a sequence of identical cells with lumped parameters, which greatly simplifies the

calculations. The relative simplicity of the mathematical model allows its use in the development of Web-based applications for educational virtual laboratories of powerful pulse technology.

This software interfaces is purpose for initial study of high-power pulsed generators. Task is to understand the working principles and the influence of the elements of the device on its work so it is much easier than interfaces of professional CAD. The separation of the operation principles study and getting skills of circuit makes the learning curve less sloping and increases the efficiency of the educational process.

## 5. References

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