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Nanosecond and picosecond Pulse Formers with semiconductor electronic components

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ABSTRACT

In a review of methods of generating pulses, the proposed new circuit design techniques that consider practical scheme using serial diodes

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Purpose and principle of impulse formation

With the nano - and picosecond front

The application of high-voltage pulses with nano - and picosecond front and (or) of the same duration in engineering and experimental physics are very diverse as zapuskovyh for powerful thyratrons and spark gaps, as the pump pulses of semiconductor lasers, for TOF analyzers, mass and energy of the particles, and so on.

Lately, they have been successfully used in radio and ultrasonic location [32], where their advantages over monochastotnymi radio ¬ pulses appears to reduce the average power output and increasing the pulse power, which gives the gain in resolution and range of application.

In our opinion, interesting would be to use short nanosecond pulses at a repetition rate units - tens of kilohertz as pulling in the injectors diagnostic ions and neutral atoms. Substantial increase in electrical strength of vacuum and surface gaps in the nanosecond range (as well as low energy breakdown) should raise the brightness injector decreases the average energy supply and maintaining a sufficient temporal resolution.

Consider the well-known principles of nanosecond pulses. All Drivers (generators) for them ¬ pulse circuits with lumped parameters can be reduced to two types or to a combination of the first type has a closer energy storage (tanks or lines) to the load, and the contactor is connected in series with the load and drive.

The second type has a switch, a current, in parallel to the drive-load (inductance or line). Drivers within the same type are used as switches.

The third type of soliton pulses select conditioners. They are based on the pulse sharpening lines with nonlinear elements (races ¬ tributed or kvaziraspredelennymi).

Table 1 summarizes the data collected from literature sources.

№	Type	Key	Vout / RL, Vout / CH	tf (t nw)	f	L.
l		Bipolar transistors	100/50	> 1ns	> 1MHz	1
2		is flooded	300/75	1ns	10 KHz	2
3			6000/(50)	3ns	10 Hz	3
4		FETs	400/50	(1.3ns)		4
5		Photothyristors	5000/1	5ns	10KHz	5
6		Thyristors Si	1000/50	5ns	30 Hz	6
7			5000/50	50 ns	30 Hz	6
8	1		3000/50	20 ns	1 KHz	A
9		Thyristors GaAs	1000/50	1ns		7
10		Avalanche GaAs diodes	100/50	1ns	100KHz	8
11		Delayed Avalanche	1000/50	70 ps	10KHz	12
12		Diode (DZLP)	1300/50	0,2 ns	100 Hz	14
13		2 diodes with accumulation	200/50	(1,5ns)	5 MHz	15
14		charge (DNG)	400/50	1 ns	100 KHz	A
15	**2**	Drift Sharp Recovery Diode	1700/50	2ns	10 KHz	17
16		(DSRD)	6000/(100)	20ns	1 KHz	18
17			1000/50	1ns	1 KHz	19
18			1000/50	1ns	1 KHz	20
19			1000/50	1ns	100 KHz	21
20			5000/50	(5ns)	1 KHz	A
21			1000/50	1ns	50 KHz	A
22	1	And DSRDs DZLTS	1500/50	80ps		22
23	and		2500/50	(0.8ns)	1 KHz	A
24	2	Avalanche tr-ture and DZLP	1000/50	0,3ns	5 KHz	23
25	3	Line with ferrite				24
26		Line with varicaps	50/80	(80ps)	10 KHz	25

The second column indicates the type of generator, the third - the type of code, and the fourth - the resulting output voltage Vout, V resistance or capacitance load (RL Ohm CH pF) in the fifth - the rise time and half-width of the pulse t p, tpf in the sixth - repetition frequency (f), in the seventh - a reference to the literature, the index of A is marked with the authors' data for comparison.

Drivers on avalanche transistors have low efficiency due to the large residual stress key (~ VOUT), this implies restrictions on the formation of f high-voltage pulses. Top results from Vout avalanche transistors [3] obtained in their series connection.

Significant progress in the development of high-current fast ¬ FETs, in [4] states that there are no obstacles to the emergence of transistors on a 1kV, 20A time inclusion ~ 1ns. Unfortunately, domestic indus ¬ laziness is far from these results.

In [5] open-frame for a high-voltage thyristor ¬ indulged neodymium laser pulse with a rise time ~ 5ns this, Bu ¬ Dimo, mainly determine the front output pulse.
Results of quite impressive, but the driver in a given ¬ dimensional case is a serious setup, and low efficiency.

Designing practical schemes for low-power pulse thyristors was busy S.I.Zienko. [6] They are still relevant (especially the traveling wave generators for increasing amplitude) and the use of both modern Si thyristors (KU220 and KU221), allowing up to f ~ 10 kHz tf ~ 20 ns, and the newly emergent GaAs thyristors [7].

In 1979 IV Sin colleagues showed the possibility of forming kilovoltovyh pulse with less than 1 ns [9,10]. For this diode in series with the load applied to the input DC reverse voltage is close to the avalanche, and the momentum is also reverse polarity to the steepness of the growth of hundreds of volts per ns. Avalanche diode is delayed a fraction of a unit ÷ ns, so that the total voltage across the diode grow about twice the avalanche, then the diode is unlocked with the front of <1 ns, and the residual voltage of the diode may in certain circumstances be significantly less avalanche.
With an increase in the slope of the input pulse formation of a shock wave in the diode and thus the formation of a shorter front on output and without filing a reverse bias to the diode. In the selection of diodes allowed their series connection [9 ÷ 13]. In [14], [23] the possibility of use as industrial DZLP diodes. Currently DZLP form the most powerful picosecond pulses with f up to tens of kilohertz.

As a second type of switches for a long time known diodes with charge accumulation, allowing for our data to obtain V_{out} ~ 50B at t_f ~ 2ns for the diode KA609 and Vout ~ 500V at t_f ~ 1 ns for KD204.

In 1983 and. Grekhov colleagues demonstrated another way to produce high-power nanosecond pulses in the shapers of the second type with the drift diodes with a sharp reduction of the locking properties [16]. If you miss a DSRDs pulse forward current I_+, duration t_+, and then pulse reverse current I_-, duration t_-, then the condition of preservation of the charges:

$$t_+ + t_- < t_{zh} \qquad (1)$$

where t_{zh} is the lifetime of minority carriers, diode locked at equality:

$$\int_0^{t_+} I_+ \, dt = \int_0^{t_-} I_- \, dt \qquad (2)$$

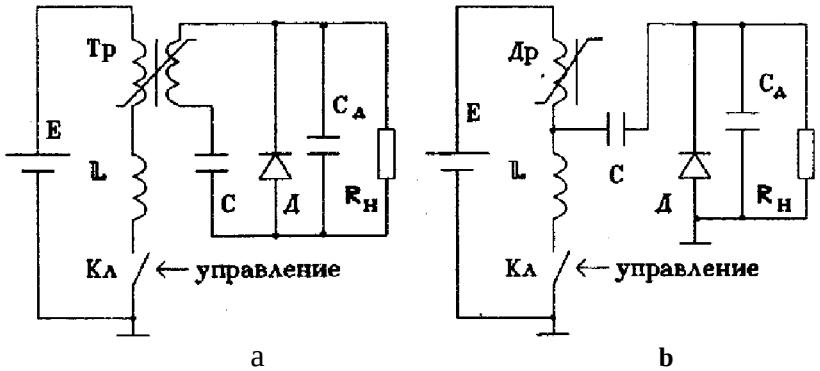
and locking time is less than a few nanoseconds.
If the amplitude of I_- is larger than the amplitude I_+, then there is a break of nonzero current I_-, and parallel-connected diodes and the load results in the formation of an output pulse.

The first scheme formers are given in [16 ÷ 19], and in [18 ÷ 19] demonstrated the use of industrial diodes as DSRDs.
In [21] a two-stage driver DSRDs short pulses, which are used to drive inductive circuits forward and reverse currents of the diode, and as the switch of the current - transistors. This yielded an efficiency of> 25% and f = 100 kHz. In [22] integrated circuits with DSRDs and DZLP, and in [23] - avalanche transistors and DZLP

The third type of shapers - lines with ferrites - are well known. [24]
Typical parameters of the output pulses: amplitude - tens of kilovolts at the front in a few nanoseconds, their flaws - big size.

Now we know with varikapnymi lines [25] and others. The output pulses of such lines in record numbers tf, but still significantly less than other shapers of the voltage.

Pulse shaper circuitry with DSRDs, DZLPs and saturable INDUCTORS.
Consider the circuit shown in Figure 1. [26]. The timing diagrams of these circuits are shown in Figure 2, they are the same up to a constant shift of polarity and Uc



a b

Fig. 1

Circuits are driven by the switch Ka, the power source E, a constant inductance L, saturable transformer (Tr in Fig. 1a) or saturable inductor (reactor Dp in Fig. 1b), Capacitor C, DSR Diode – D, C_D - the capacitance of the DSR diode.

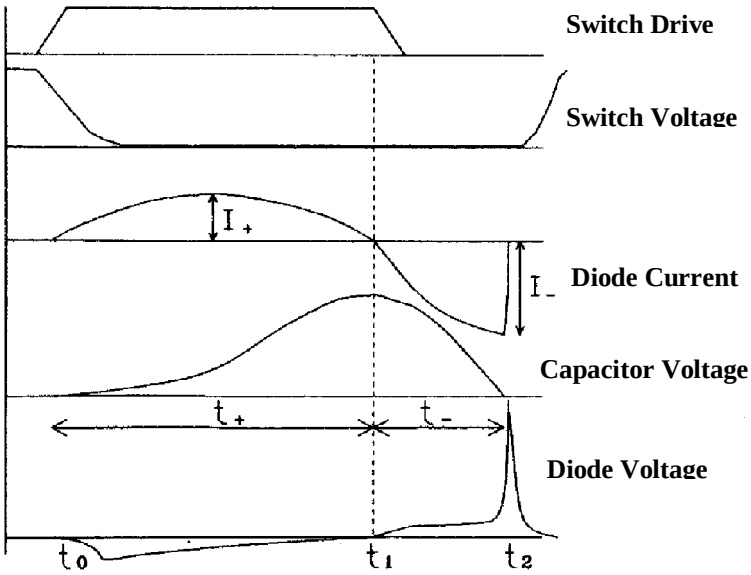


Figure 2

The switch Ka closes at the time t_0 and begins to charge the capacitor C (or discharge for Fig.1b).
The charging current flows through D in the forward direction, thus the current I is positive. The inductance in the charge circuit is the sum of L and the leakage inductance Tr – Ls of the secondary winding, for Fig. 1a (for simplicity, consider Tr with the 1:1 turn ratio) or only the L in Fig. 1b.

During the interval t_0 - t_1 the Tr (Ap) is not saturated, the magnetizing inductance Tr (inductance of Ap) is much larger than the inductance in the charging circuit and its influence can be neglected.

Windings of Tr (Ap) are chosen in such manner that the core of Tr (Ap) becomes saturated at the time t_1, that is, at the moment of maximum charge in capacitor C. During the interval t_1 - t_2 the capacitor C discharges through the inductance of the secondary winding of saturated Tr (Ap) and through the same circuit as during the charging interval (if the switch Ka conducts the reverse current), but usually the currents in this charging circuit can be neglected at that stage. The discharge current becomes the reverse current of the diode (current I is negative). Excluding losses we have:

$$I_+ = E/\sqrt{(L + L_s)/C} \; ; \quad I_- = 2E/\sqrt{L_m/C} \; , \tag{3}$$

respectively

$$t_+ = \pi\sqrt{(L + L_s)C} \; ; \quad t_- = 0,5\pi\sqrt{L_m C} \tag{4}$$

If $Lm \le L = Ls$ have $I- \ge 2I_+$ and break the current (at time t_2) is at the maximum I-. Note that at the exact condition (2), ie, equal amount of charge passed through D in the forward and reverse directions, and caused the same initial and final voltage across C:

$$Uc\ (t_2) = Uc\ (t_0).$$

Realistically, this is satisfied if $t_+ + t_- << t_{zh}$, or, in other words, the diode operates without losing any charge.
The switch Ka can be opened immediately after t_1, while the current in the diode falls down at zero or reverses, which contributes to its rapid shutdown. After this pulse, the Tr (Ap) becomes demagnetized due to the termination of the current in its windings. The time needed to complete the demagnetization is determined by the properties of the magnetic material used in the core and is usually measured in less than a few microseconds. To increase ΔV, which is useful, as we will see with more of the calculations, we can add a magnetic bias winding to Tr (Ap).

The scheme of Figure 1 as well as the scheme [21] does not have any additional resistance in the circuits forming the forward and reverse current of the diode. This defines a high efficiency schemes and, therefore, more acceptable repetition rate. The losses in the circuit in Figure 1 are mainly determined by the losses in the magnetic circuit. It sets the maximum permissible superheat f. The advantage of the proposed scheme, the sufficiency of only one switch, and the possibility of cascading circuits without additional switches.
Two stage circuit with saturable transformer is shown in Figure 3. The second stage operates similarly to the first, but if the first stage is the input pulse voltage after the switch, for the second - the output pulse of the first stage. In the second stage can be used diodes with lower than in the first, t_{zh}, and since time is usually proportional to lock DSRDs t_{zh} a two stage circuit can generate pulses with less tf and tpsh

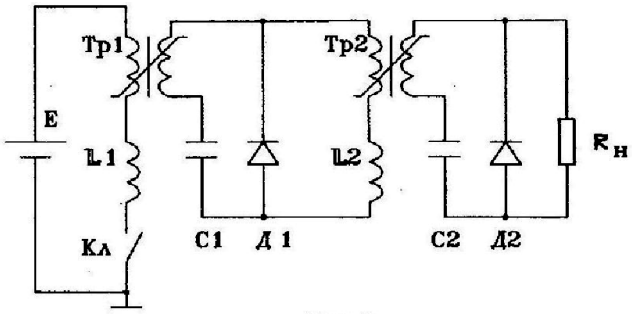


Figure 3

The scheme of Figure 1 requires a fully controllable switch (transistor, vacuum tube). The use of uncontrollable switches (thyristors, thyratrons, etc.) it is almost impossible, since such a switch can be opened only during the interval t_1 - t_2 for duration of t.. However from (1) and (4) we know, that for most types of diodes which are suitable as DSRDs, the t. << $0.3t_{zh}$ and t_{zh} ≈ 50ns-500ns. This is not enough time for even the fastest closing uncontrollable switches. For them, the circuit can be modified by the introduction of load resistor with a current charge lower holding current switch. One of the options discussed below under specific schemes. However, it is immediately clear that the introduction of load resistor is reduces the efficiency at least twice and further limits f. Therefore, we turn now to the schemes, application of uncontrollable switches (as well controllable, but lacking in speed for the circuit Figure 1) without load resistor.

Since the late 50's known schemes magnetic pulse shapers [27 - 29], based on the use of saturable inductors in LC - lines. According to the classification [28], there are two types of links such lines, A and B, as shown in Figure 4.

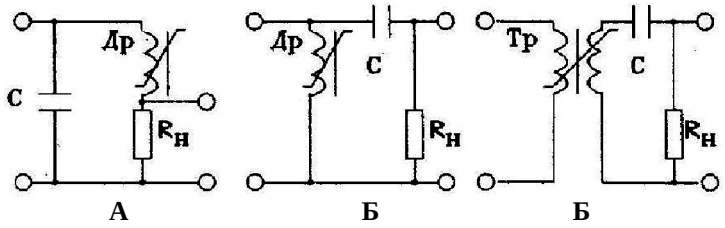


Figure 4

Comparing Fig. 4 and Fig. 1, easy to understand, that the scheme of Fig. 1 minus the switch is a hybrid type B level magnetic generator and DSRDs.

Now take the next step - using the entire arsenal accumulated schemes for the synthesis of magnetic formers previous links. In this case, the primary switches are the switches of any type. In [28] and the review [29] described the theoretical basis and calculations, as well as many practical circuits magnetic formers, so we restrict ourselves to a functional diagram Figure 5, showing a hybrid of multi-magnetic generator and DSRDs. The first stage of the scheme L, C1 is a link of type A.

In [29] mentioned the need for such a hybrid, but practical steps have not been made.

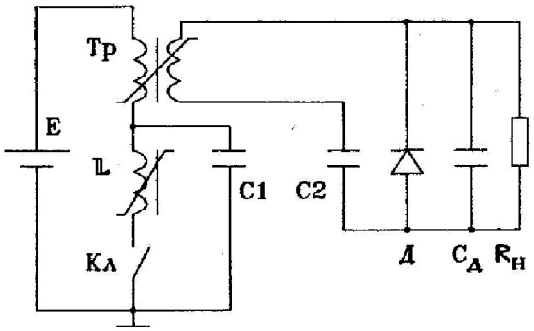
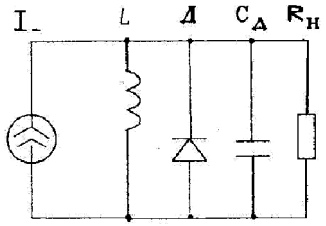


Рис.5

Let us turn to the calculated ratios for circuits Figure 1 and Figure 5, and start them with the last link of the shaper.

At the stage of the pulse, when the last inductor (choke or trans ¬ Mataram) is rich and has a minimum value Ln, output stage together the load can be represented by an equivalent circuit

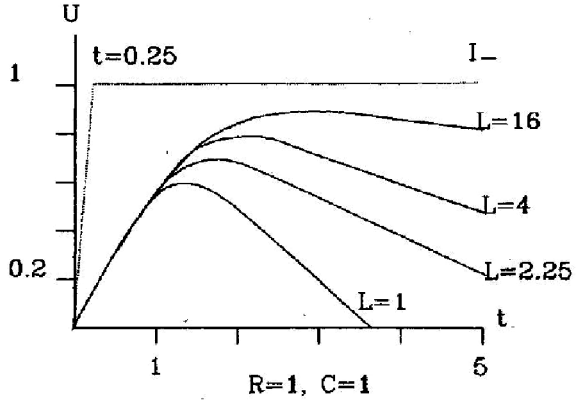


(Fig. 6) in a parallel circuit with parallel
he mo ¬ snym current generator and the load. Last
for ease of pre ¬ representation is active
resistance. Inductance - Ln, capacity -
capacitance diode LED without its nonlinear ¬ sion that

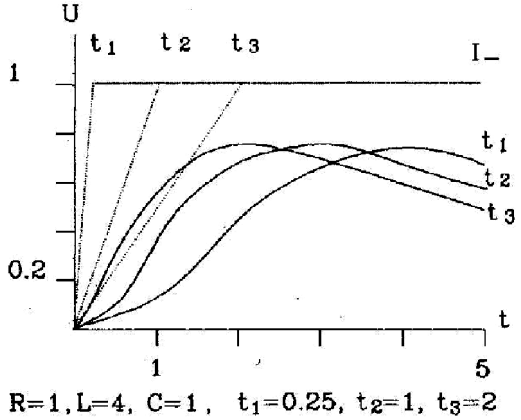
justified in the formation of high-voltage pulses

Figure 6 close to the maximum allowable for the diode.

Current generator of ¬ commutes torn current, its front (τ) is determined by the properties of the diode. We are interested in the front (tf.) and voltage (Un) on the output.



Puc.7a



Puc.7b

Calculations presented in Figure 7, are made using the LES [33] in the following points:
ρ = 1, 1.5, 2, 4RH; where

$$\rho = \sqrt{L_П / C_д}, \quad R_H = 1, \; C_д = 1$$

at τ = 0.25 for Fig. 7a, and τ = 0.25, 1 and 2 for ρ = 2, R = 1 for Fig. 7b.

Calculations show that for ρ = (1 - 3) RL with sufficient accuracy can be assumed that:

$$t_ф = \tau + \sqrt{L_n C_д} \quad и \quad U_H = I_- \rho R_H / (\rho + R_H) \sim I_- R_H (0.5 \div 0.75) \qquad (5)$$

Optimal in terms of total criteria min tf. and mahUn and is the choice of ρ ≈ 2RH Thus, wondering Un, tf, RL and SD (and then it will be clear that the choice of the diode connected to RH and Un) and assuming τ << tf that often true, we are quite rigidly defined ¬ Fissile Ln and I-:

2Rn Ln = tf; I_ = (1,5 - 2) Un / RL (6)

$$C_n = \frac{4t_-^2}{\pi^2 L_n}$$

termined from (4): (7)

Energy from the last link: $U_n = I_- \sqrt{L_n / C_n}$ (8)

Generally speaking, this is sufficient to using [27] to calculate all the other links and the demand on the switch. We still give their formulas, considering them more clear and easy to use, as well as considerations for choosing cores, especially in the last stage, and the choice of capacitor types.
Specify the number of links n, consider all toroidal magnetic cores. For each ring set: Sef effective sectional area of the magnetic circuit;

Sob sectional area of the winding;
1m - the length of the power line;
μn - permeability of the saturated ring;
ΔV - saturation induction.

Determined: wn - the number of windings level n;
tn-1 - the delay level n, ie charging time Cn-1 to the saturation moment Ln;
Ln-1 - inductance of the saturated n-1 link.

$$w_n^2 = \frac{L_n l_{\text{ж}n}}{\mu_0 \mu_n S_{\text{об}n}}$$

$$t_{n-1} = \frac{2\Delta B w_n S_{\text{эф}n}}{U_{cn}}$$

$$L_{n-1} = \frac{t_{n-1}^2}{2 C_{n-1}}$$

Velocity factor level or, equivalently, the ratio of current links:

$$I_n/I_{n-1} = t_{n-1}/t_n \qquad (12)$$

Link capacitors may be the same at face value, but we must take into account the voltage drop on the link to the link in the 10% - 20%, primarily due to losses in the magnetic circuit. Alternatively, you can select the capacity respectively on the preceding link is greater. The best types of capacitors for f ≥ 1 kHz are polypropylene (K78), mica, and for high-power - high-frequency ceramic.

The materials used permalloys of magnetic amorphous alloys and ferrites. Ferrites have a wide range of rings, are easily accessible, but they are significant drawbacks - low and high residual ΔV μn ~ 2 - 3, even in very strong fields (~ 100 Ns).
For permalloys and amorphous alloys is permissible to consider μn = 1. Sob coincides with the physical cross section of the winding at w ≥ 25, otherwise it is necessary to take the correction factor, increasing μn. In reality, this only applies to the last link.
In the last link is most often required to obtain minimum inductance saturation, as (6) - (8) that in this case the minimum and maximum tf Un at the same energy-tick level. From the above (and confirmed in practice) that the best materials are the last link of the magnetic amorphous alloys with large ΔV (eg 2NSR).

Let us return to Fig. 1 and consider some of the reasons to choose between a transformer circuit (Figure 1) and a model with a choke (Fig. 1b). Figure 5 for a scheme that applies to the on ¬ recent cascade. The scheme of the transformer is more convenient in that it allows an easy change of polarity of the output pulse, obtaining simultaneous bipolar output pulses, which include an even number of identical diodes in series, as well as the common point is taken as the midpoint of the diodes (possibility of series-connected diodes is discussed below.)
Transformer circuit has a greater degree of freedom is also due to the possibility to change the turns ratio of the primary and secondary windings. This allows, for example, use low-and high-volt ¬ switches.
The lack of a transformer circuit - the emergence of high-frequency oscillations in the output pulse in some implementations because mezhobmotochnoy capacity. In the scheme with the throttle can be another advantage, since in principle the throttle with the same parameters on Ut can be done on a smaller magnetic core, which gives a lower inductance saturation.

INDUSTRIAL RESEARCH diodes as DSRDs and DZLP

In [18, 19] have shown the possibility of using these diodes as DSRDs : KD206, KD210, VL25 and the like. The authors investigated KD204, KD220, KD226, KD2E0, DL112-16 DL112-25, the other series diodes DL, D and DF with rated current 50 - 800 A, as well as some other types. The measurements were performed in the range of t_-= 10ns-150 ns, I_-= 5A-50A for low-power diode in a circuit similar to Figure 1, and in the range of t_-= 30ns-300 ns, I_-= 40A-800A for power diodes in a scheme similar to Figure 5.

Table 2 summarizes the main parameters of these diodes.

Type	**$U_{обр}$**[V]	**I** [A]	**I_{imp}** [A]	**t_{zh},** [μs]	**Sd/10V**[pF]	**Sd/200V** [pF]
KD204A	400	0.4	5	1	15	7
KD220G	1000	6	60	1	50	20
KD226D	800	1,7	10	0,5	20	10
KD230G	1000	3	20	1	60	20
DL112-16	1500	16		10	100	30
DL132-50	1500	50		15	400	120
DL123-320	1200	320		30	2000	500
DCH143-800	1400	800		10	4500	1000
B2-320	1200	320		30	1200	300
D133-400	2400	400		40	2000	500
D143-800	2400	800		60	3500	800

In Fig. 8 shows the waveforms of the voltage drop on the diodes on the stages of passage forward and reverse currents up to impulse.

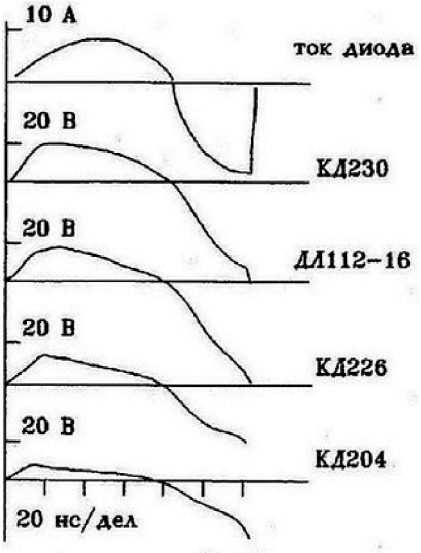


Рис.8

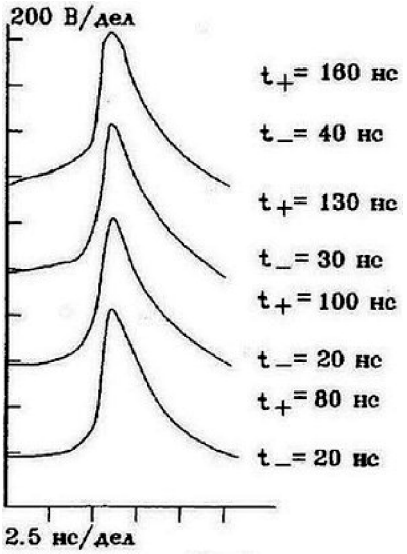


Рис.9

In Fig. 9 shows the output pulses are generated in the diode KD226I depending on the duration of t_+ and t_-.

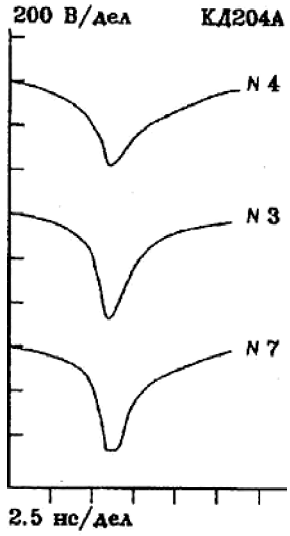


Рис. 10

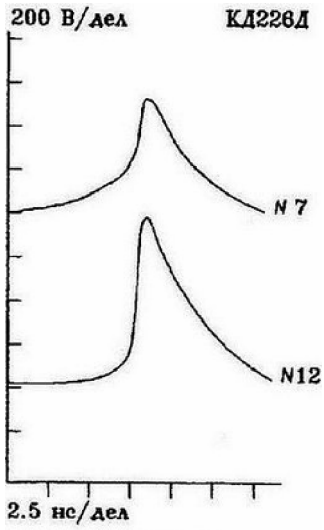


Рис. 11

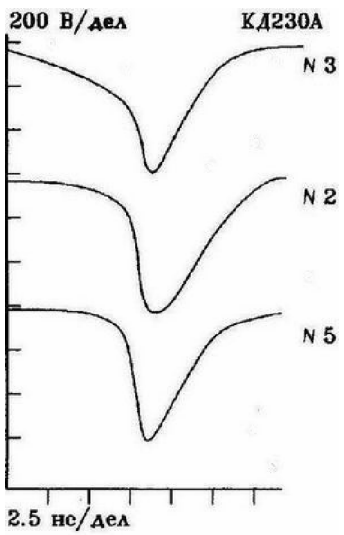


Рис. 12

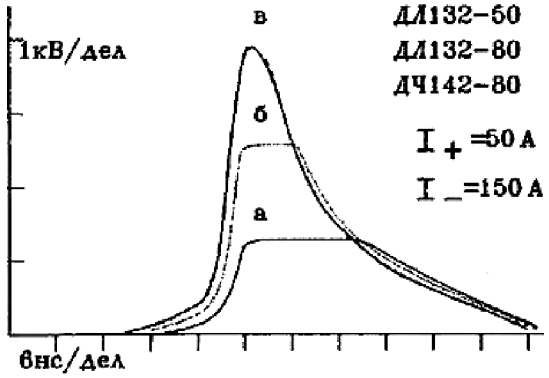


Рис. 13

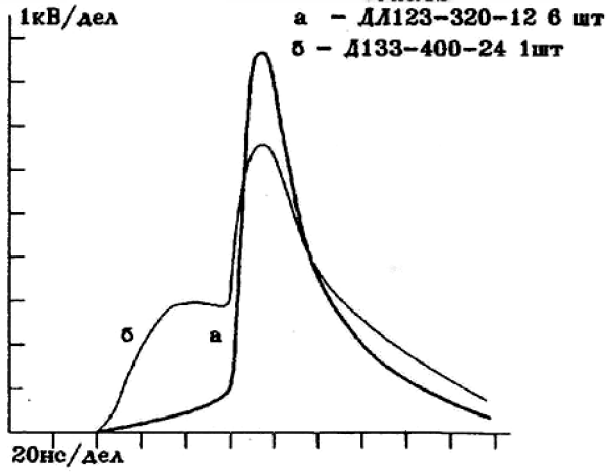


Рис. 14

In Fig. 10 - 14 shows the output pulse waveform into 50 ohms for different types and instances of diodes. Shows the mean, the worst and the best results for a sample of ≥ 10 copies, the numbers denote number of copies.

From the measurements, the following conclusions:
1. It is impossible to judge the results of the diodes as DSRDs based on the information in their datasheets. Even the forward voltage of the diode (which is desirable to know for calculation) is different in the nanosecond region for the different types, and sometimes even within a single instance of the type (see Fig. 8).

2. Excess of $t_+ + t_-$ above a certain value, individual for each instance and type, at constant I_+ leads to a "precursor" - the slow movement edge of the pulse (see Fig. 9, which is highlighted by bold lines). Harbinger appears before execution (2) (and thus with incomplete discharge capacitor in the circuit Figure 1), which indicates a loss of charge.

3. Exceeding I_+ above some individual for each instance and type size at constant $t_+ + t_-$ also leads to a precursor.
While working with a precursor diodes have a large variation in the amplitude and shape output pulse from instance to instance (Figure 10 -12). It is not possible, for example, series-connected diodes for increasing the amplitude of the pulses.

4. If all instances of this type of pulses are formed without warning, the spread pulse parameters is small and possibly series-connected diodes.
In Fig. Waveform and 13 - for one diode, b - for the two series-connected diodes, - for four. When Ir RL> Ud, where Ir - load current, and Ud - avalanche voltage diode pulse is generated from a shelf, as waveforms and b in Figure 13, and Un = Ud c

up to Id rd, where rd-differential resistance of the diode in avalanche mode.
Note that for Id> 600 A work in avalanche mode leads to breakdown even powerful diodes have a shelf with a duration of more than 10 ns.

5. Diodes Series "D" (not avalanche) form pulses differing in form from pulses generated by avalanche diodes. Figure 14 compares the output pulses in one and the same pattern of the diode D133-400-24 (b) and six consecutive diodes DL123-320-12 (a). Impulse begins earlier execution (2), the amplitude increases to orders of the diode, followed by a shelf or decline and, finally, in the moment of performance (2) formed part of a high-voltage pulse with the most sharp edge. The total amplitude pulse reached 8 KB for a single diode 24 classes. Different instances of type diodes D the impulse with the significant variation of parameters for sequential connected diodes formed first. part of the pulse, the high peak of nearly disappears. The theoretical basis for this process is unknown to us.

6. As we studied DZLP KD204, DL112-16 DL112-25 and some other types. Delay the breakdown, as expected, increases with the size and power of the diode is 1 ÷ 3 ns when the input slope ~ 1 kV / ns. The front of the output pulse of 1 ns (one stage on the DL112-16) to ~ 0.2 ns (KD204, 2 stages for DL112), but the latter value likely not determined by the properties of diodes, and design stage and measurement capabilities chains. Residual voltage diodes in the hundreds of volts, that is a significant fraction of the avalanche voltage, and varies from instance to instance. Maximum received Un 500 V for KD204 and 2kV for DL112. In [22] stated that the steepness of the input above a certain signal, the diodes start to operate in DZLP without feeding back offset. For DL112-16 is the case with the steepness of ~ 2 kV / ns. It follows that in multistage sharpener is the second stage does not require submission of bias.

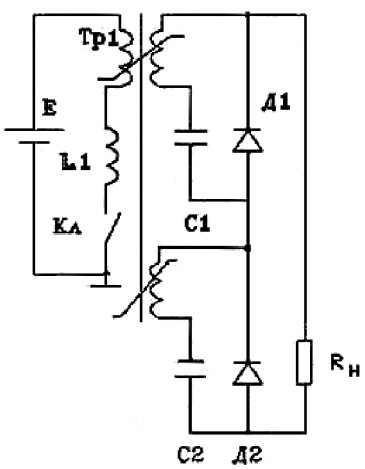
METHODS TO IMPROVE QUALITY pulse parameters

It will discuss the additional circuit design methods in the output stage of the circuit Figure 1 and Figure 5, allowing:

- Use series-connected diodes to increase the amplitude of the pulses in mode with a precursor;
- To compensate harbinger without loss of amplitude;
- To reduce the pulse duration;

- Dampen repetitive pulses.

It has been mentioned that the series-connected diodes in a mode with a precursor not generally lead to an increase in the pulse amplitude of the spread since locking diodes. However, this mode is common in the formation of pulses with tf ~ 1 ns and using serial diodes (see Fig. 9 - 11). The scheme of the output stage, as shown in Figure 15, allows you to bypass this restriction. The secondary windings of the transformer are the same, and the capacitors are chosen such that the diodes were locked together (see (4) for t-).



Necessary variations capacity really no more than 10%, which is easy to do. Get rid of the precursor or significantly suppress it without losing the pulse amplitude can be staging saturable inductance between DSRDs and load. Inductance is performed winding several turns on ferrite rings diameter 7.10 mm and is adjusted individually for a particular implementation of the scheme.

Reduce the duration of the pulse, reducing the time decay in two ways. First - saturable inductor connected across the output. Inductance should be full at the time of attaining the maximum amplitude, then the recession is defined parallel-saturated inductance of the last link Ln (see Figure 6) and additional inductance. For the same magnetic material and the initial magnetization (equal to ΔV) additional inductance can be made smaller than Ln, since Un t_f < Un t_+, and the recession will be determined mainly by

additional inductance. The constraint is the time of the magnetic reversal in the saturated state. For the iron does not exceed units ns. In practice, this way can get the recession ~ (1 ÷ 3) tf.

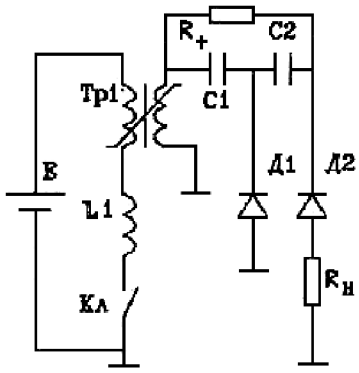
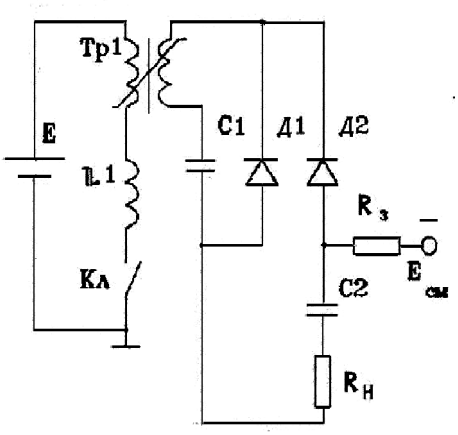


Fig.16

The second method is shown in Figure 16. Between forming a diode D1 and the load another DSRD - D2 is connected in series with the capacitor C2. C2 is chosen to skip the output pulse and cut off the direct current D2 - I +2, which is defined by R_+.

D2 is reverse current load current. I +2 chosen to lock himself in the maximum D2 Un, while I +2 « I_+ and has no effect on D1. If D1 and D2 are the same, the impulse with equal rise and fall with a shape close to a Gaussian (in silent mode precursor).

If R> r / 2, not all the energy output circuit gets a load in the formation of the momentum developed in the circuit nonlinear damped oscillations, and as a result ¬ Tate output appear repetitive pulses of decreasing amplitude. There are at least two easy ways to eliminate them. The first - the same setting saturable inductance pa ¬ parallel output, saturation that must occur before the end of the pulse. As mentioned, the output of the saturation occurs hundreds ns ÷ units microseconds. Appear at this time of repeated pulses dramatically reduced in amplitude due to shunt ¬ Rovani load saturated inductance and losses in it, which ¬ rye further reduce the output Q of the circuit.



The second way is to use a series with the load DZLP (though there may be no need for the intensification of the front), as shown in Figure 17. Amplitude pulses repeated DSRDs can no longer be enough to unlock DZLP.

Fig.17

For this to happen safely, choose τ C2 charge much more than the period of oscillations posleimpulsnyh

C2 is charged through Rz to the voltage required to work DZLP, and then almost completely discharged through the closed DZLP. If by the time the re-pulse C2 is discharged, to choose not DZLP will even equal amplitudes of the first and repeated pulses.

Inductance Lf is used, if necessary to increase in the load.

BROADBAND DIVIDERS current and voltage to the measurement ELEMENTS shaper

Voltage divider, which was used in the pulse shapers with amplitudes up to 10 kV, is based on resistors TVO-0, 25, TVO-0, 5 are rated at 4.3 - 4.7k. [30] In Fig. 18 shows a sketch of a divider.

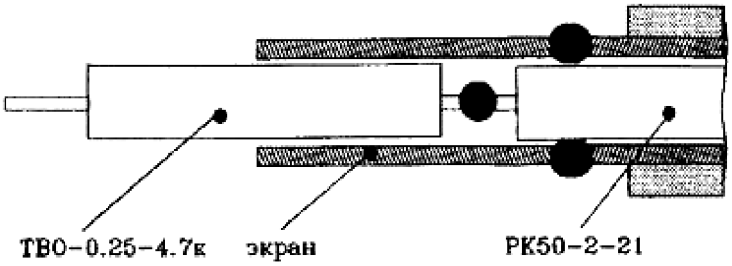


Fig.18

Divisor is loaded on a consistent 50-ohm load, the division ratio is 85 - 100. Figure 19 shows the average response for a screen divider optimal length - 1 to 2 mm longer than the optimum - 2 and 2 cm shorter than - 3.

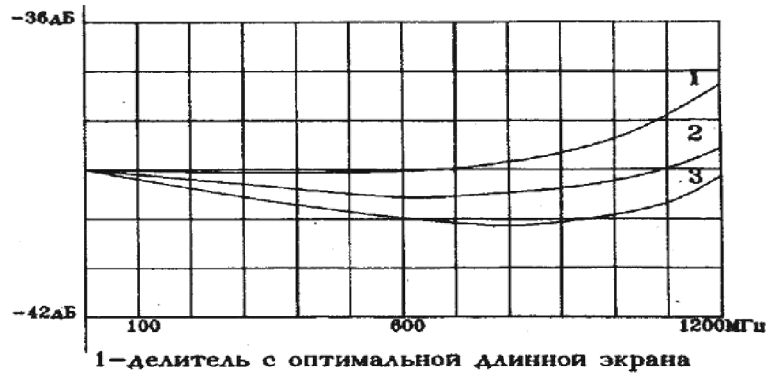


Fig.19

The optimal length of the screen for 1 - 2 mm longer than the middle of the resistor and collected directly from the meter response. In this subgroup uniform response in the band of 1.2 GHz with an accuracy of 1.5 dB, playing the front ~ 0.2 ns with the release of at least 25%.

Divider measured pulses of ~ 1 kV, tpsh ~ 5 ns, f ≤ 50 kHz and 10 kV, 20 ns, 1 kHz, sparks and runaway with time was observed.

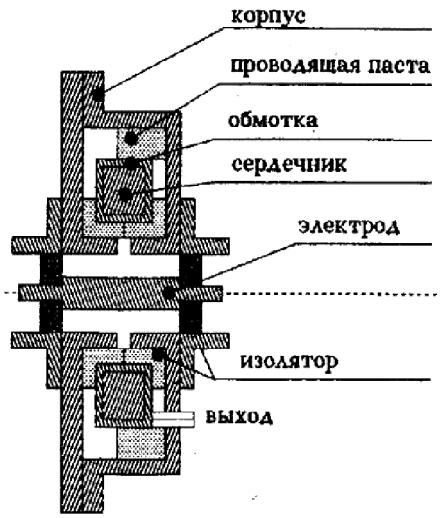


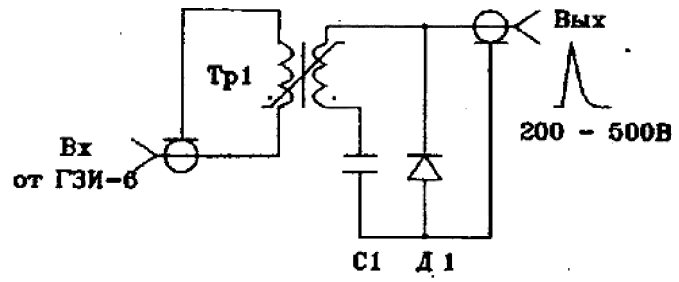
Figure 20

To measure the load current to use the coaxial current transformers (Rogowski coil), similar in design, the transformer, Anderson [31]. But instead concentrated chennyh antizvonnyh resistance they use a conductive paste is placed between the coil and the housing of the transformer, as shown in Figure 20. The paste is composed of approximately equal amounts of graphite and clay with conductivity ~ 1 Ohm • m

Coil wound on a core of Teflon when w ≥ 50 or ferrite at w = 10 ÷ 20. In both cases, all the resonances in the 1.2 GHz band with so much suppressed paste, which gave a decline in the transmission of ~ 2. Unable to suppress the body volume resonance at a frequency of 3.5 GHz with a Q of 2 ÷ 5. As a result of playing in front different structures was 0, 2 ÷ 0,3 ns.

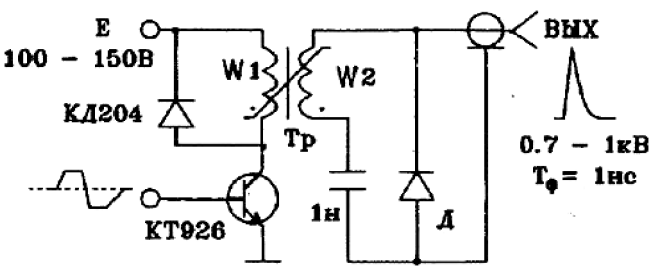
Examples of particular shaper schemes.

The simplest scheme amplitude pulse shaper 200 ÷ 400, 50 ohm load with t_f ~ 1 ns is shown in Fig. 21. The amplitude is defined for a type and a specific instance of the diode, and the quality of its installation. For maximum voltage we should get a minimum inductance of the output circuit, which includes the inductance of the secondary winding of the transformer at saturation, the leads and the diode itself.



Тр1 – К7•4•2 М3000НМ , W1 = W2 = 7
С1 = 1000пФ
Д1 – КД226, КД204, КД230

Fig. 21



Тр – К7•4•2 М3000НМ , W1 = 6, W2 = 12
Д – КД204, КД226, КД230, ДЛ112-16

Fig. 22

With the amplitude of the pulse shaper up to 1 kV into 50 ohm load, with t_f ~ 1 ns and a repetition rate of up to 5.0 kHz is shown in Figure 22. Maximum f (without reducing Un) is determined by the losses in the ferrite and heating which significantly reduces ΔV, and requires the placement of the transformer on a radiator. Thermal contact with the heat sink is provided by a vacuum sealer or VIKSINT.
The transformers circuits in Figure 21 and Figure 22 are wound directly on the ferrite core with smooth edges or wire SEW HF-0,03. Among the ferrite types 1000nm, 1500NMZ, 2000NM, 3000HM the minimal losses were with the last one (3000HM). The efficiency of the circuits with optimal base current pulses rech 40 ÷ 50%. The phase jitter of the rising edge of the output pulse relative to the rising edge of the base current is ;ess than 0.1ns, in the temperature range 20 ÷ 700C.

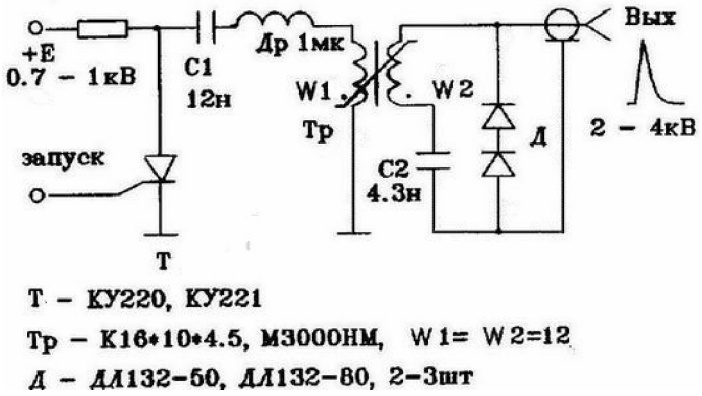
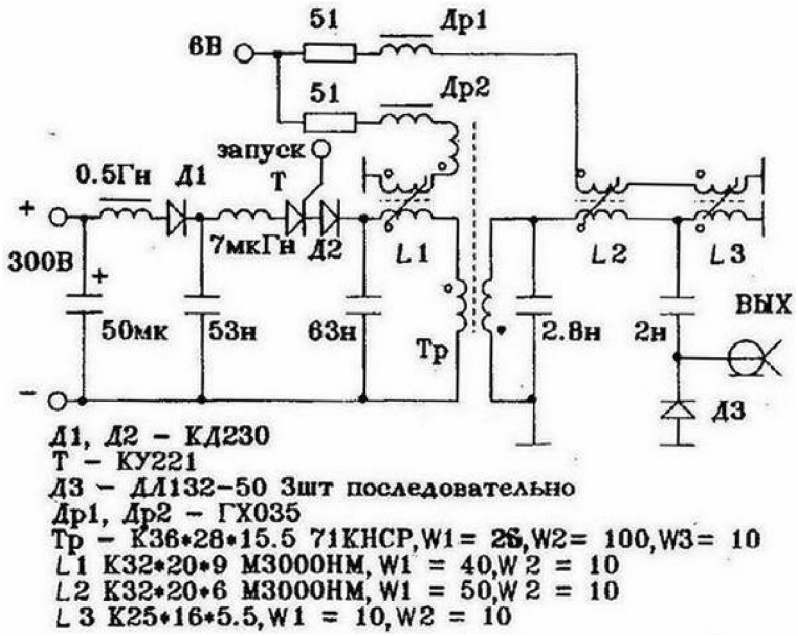


Figure 23 shows a diagram on the shaper with thyristor switch. Capacitance C1 is an intermediate energy storage, its value should be several times larger than C2. Repetition rate determined by the charge C1 through R1 and can reach 1 ÷ 2 kHz. U = 2 ÷ 4 kV at RL = 50 ohms at tf ~ 2 ÷ 5ns, the best results are obtained when used as magnetic permalloys or amorphous alloys.

Fig. 23

Scheme generator with advanced magnetic seal is shown in Figure 24. Un = 5kV at RL = 50 ohms at tf ~ ~ tpsh 2ns and 5ns, f ≤ 2 kHz. The last stage is applied throttle, not a transformer, attempted use of which leads to the appearance of the pulse modulation oscillations with a period of ~ 1 ns, which is associated with mezhobmotochnymi tanks.



in this scheme have field winding W3 and W2 for Tp for LI ÷ L3.

Another variant of this scheme, where the assembly was used DSRDs six DL123-320, had a pulse amplitude of ~ 10 kV (Fig. 14).
To reduce the inductance of the diodes in the circuit of Fig. 23 and 24 of these are used without a housing
The addition of the last two schemes cascade DZLP (Figure 25) provides pulses with Un = 2.5 kV, tf <1 ns and tsp <0.2 ns. On DZLP, parallel to exit and fall time, the bias voltage

Figure 24 is not served.

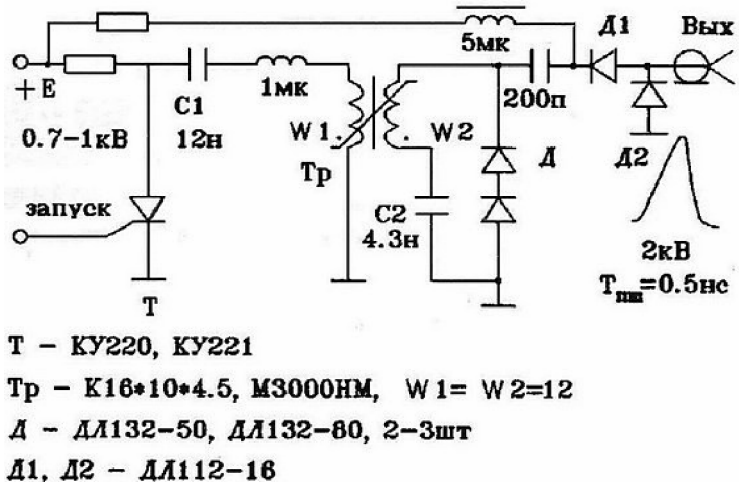


Fig.25

All of these schemes are applicable techniques previously shown to increase the quality parameters.

CONCLUSION

Based on the proposed circuit design techniques using commercially available diode circuits designed shapers with the following parameters:

1. U = 1kB, tf = 1 ns, tpsh = 4NS, f = 50 kHz, 50 Ohm RL;

2. U = 4kB, tf = 2ns, tpsh = 6ns, f = 2 kHz, 50 ohm RL;

3. U = 5 kV, tf = 2ns, tpsh = 5ns, f = 2 kHz, RL = 50 ohms;

4. U = 10kV, tf = 7ns, tpsh = 15ns, f = 1kHz, RL = 50 ohms;

5. U = 2K b, tf = 1 ns, tpsh = 1 ns, f = 2 kHz, RL = 50 ohms.

Correction techniques considered pulse shapes, such as to obtain pulses with durations equal rise and fall times, methods of suppression of repetitive pulses mismatched loads. Simplicity patterns enables their widespread use.

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