High power radiators of ultra-short electromagnetic quasi-unipolar pulses

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Abstract. Results of creation, operation, and diagnostics of the high power radiators for ultra-short length electromagnetic pulses (USEMPs) with a quasi-unipolar profile, which have been developed in our laboratory, are presented. The radiating module contains: the ultra-wideband (UWB) antenna array, the exciting high voltage pulse semiconductor generator (a pulser), the power source and the control unit. The principles of antenna array with a high efficiency aperture about 0.9 were developed using joint four TEM-horns with shielding electrodes in every TEM-horn. Sizes of the antenna apertures were (16-60) cm. The pulsers produced by “FID Technology” company had the following parameters: 50 Ohm connector impedance, unipolar pulses voltages (10-100) kV, the rise-time (0.04-0.15) ns, and the width (0.2-1) ns. The modules radiate the USEMPs of (0.1-10) GHz spectrum, their repetition rate is (1-100) kHz, and the effective potential is E*R = (20-400) kV, producing the peak E-field into the far-zone of R-distance. Parameters of the USEMP waves were measured by a calibrated sensor with the following characteristics: the sensitivity 0.32 V/(kV/m), the rise-time 0.03 ns, the duration up to 7 ns. The measurements were in agreement with the simulation results, which were obtained using the 3-D code “KARAT”. The USEMP waves with amplitudes (1-10) kV/m and the pulse repetition rate (0.5-100) kHz were successfully used to examine various electronic devices for an electromagnetic immunity.

1. Introduction
The high power impulse radiators of the ultra-short duration electromagnetic pulses (USEMPs) are successfully used in a number of applications such as checking of the electromagnetic immunity of electronic systems and in the experiments devoted to stop the transport facilities [1, 2]. Some advantages of the USEMP waves in comparison with the pulsed radiation of sinusoidal filling (the type of radar pulses) – they are lower. The USEMP waves generate the electromagnetic (EM) fields with the ultra-wideband (UWB) frequency spectrum of fh/fl > 10 –(ratio of the upper and the lower frequencies) that allows reduce of the number of tests. These tests often require both high amplitudes of E(t,R) –the strength of electric field (typical levels are (1-20) kV/m – peak values at the distance R placing the objects), and relatively high repetition rate pulses. The USEMP radiation allows also fabrication of the radiators with non-high average power, because it employs a high duty cycle as a division of the long period of pulse repetition Tp,p at a pulse width of radiation impulses Tw,p, typically Tp,p/Tw,p > 10⁴. This gives also lower dangers as an ether soiling or physical damages in the examined electronic systems.
1.1. Radiators. Construction of the pulsed high power radiators met the complex problems like: the EMC of systems with high-voltage pulsed sources, the triggering and the control devices with low-voltage pulses; and the realization of coherent radiation from few radiators at various conditions; providing both the reliable wideband frequencies at radiation and the electrical insulation inside the antenna units with high-voltage pulses. We had built a series of the autonomous module radiators with a highly efficient antenna array using the UWB TEM-horns [3-6]. The modules can radiate the USEMP waves with (1-100) kHz repetition rate, UWB frequency spectrum (0.1-10) GHz, and with the effective potential of $U_{rad} = E_p(R)\cdot R = (20-400)$ kV – (producing of the peak E-field into a far-zone of the distance R).

In our works, we solved a problem of increasing the radiation aperture efficiency $\eta_A = A_{eff}/A_a$ for antennas using the TEM-horns. This $\eta_A$ is a ratio of the antenna effective aperture $A_{eff}$ to the physical aperture $A_a = (h\cdot b)$, where $h$ is the gap and $b$ –the width of antenna aperture. Note, that the ratio $A_{eff}/A_a$ is widely used to analyze the microwave radars, and it is useful also for the impulse radiators if the analysis will use the reciprocity theorem [7]. It predicts that the effective apertures $A_{eff}$ will be equal in the receiver and the transmitter modes (see details in section 2). Basic TEM-horns with square cross-sections and long electrodes (triangular plates with a separation angle < 30° and a length $L_{hh} > c\cdot T_{w,p}$) are known as good UWB antennas but with an average efficiency of $\eta_{A,H} = A_{eff,H}/A_{a,H} \approx 0.6$ [8]. Using the antenna array with joining four TEM-horns and with shielding electrodes in the every TEM-horn, we obtained the increasing efficiency up to $\eta_A = 0.9$ [3-6, 9] for antenna apertures 16...60 cm.

The autonomous module assembled: the UWB antenna array with four TEM-horns, the exciting high voltage pulse semiconductor generator (Gp,V), the power source and the control unit. The Gp,V generators were manufactured by “FID Technology” company [10] with the following parameters: 50 Ohm impedance of the output coaxial feeder, mono-polar pulses (10-100) kV, the rise-time (0.04-0.15) ns, the FWHM of (0.2-1) ns, and (1-100) kHz repetition rate, fed by DC power ~0.3 kW. The time deviation of Gp,V pulse sync was ~ 30 ps, which allows the use of multi-module radiators with an efficient potential of a multi-megavolt level.

1.2. Measurements and analysis. A creation of the effective pulsed high power radiators requires both the reliable measurements of radiator parameters, and the computer electromagnetic modeling. We used the numerical full electromagnetic 3-D code “KARAT” [11] for simulation of the non-stationary processes occurring in real electro-dynamic principal sites. The pulse electric fields $E(t)$ in the transverse electromagnetic (TEM) traveling waves were measured using various antenna sensors like those described in [3-6, 9, 12]. These antennas had the receiving tracts with an ultra-wideband range with the upper boundary of $F_h > 10$ GHz and a rise time $T_{0.1-0.9} \leq 0.03$ ns for pulsed EM waves.

2. UWB strip-line sensor with small cross-section. Principle of Reciprocity for Pulsed Antennas

The design of the last version of strip-line sensor having the long dielectric stalk with high permittivity $\varepsilon = 16$ and small sizes of cross-section (1.5x1.5 mm$^2$) [6, 12] allowed us to solve two main problems of the pulsed UWB electromagnetic probes: 1) to realize the direct calibrations of sensors; 2) to enlarge the permissible time interval up to 7ns in measurements of the electric fields $E(t)$ in the traveling waves.

1.3 Results of simulation by code “KARAT”. The sensor model in the simulations had the length of 8 cm (5 times lower than the real sensor of StF4) and a small cross-section about $h_{CS} \times b_{CS} = 1.5 \times 1.5 \text{ mm}^2$ (like a real sample). The dielectric stalk (the dark tape in figure 1) had a high permittivity $\varepsilon = 16$. At its face edge ($z = 1$ cm), a thin low conductive region was placed as a load $Z_{CS} = 52 \text{ Ohm}$. This resister is connected with a signal foil tape placed over a dielectric stalk. Note, in the real sensor, a connecting coaxial signal cable with the impedance 50 Ohm played the role of this input load. At the end of strip-line (the point $z = 9$ cm in figure 1), a short circuit for the signal foil was done. The sensor was placed into the TEM-line-cell with 1cm gap (figures 1, 2) between two plane electrodes.

The plane TEM-wave with field components $E_y(t), H_x(t)$ (step-like pulses with a rise-time $T_{0.1-0.9} \approx 0.02$ ns) is transmitting through an entry window ($z = 0$ cm in figure 1). This wave was coming into
the gap along the axis z between two plane electrodes (\(y_G = 0; y_V = 1\) cm), and it went away through an end window (\(z = 10\) cm) without visible reflections. These results show that the strip-line sensor with a small aperture \(A_{ACS} = (1.5 \times 1.5 \text{ mm}^2)\) will produce low disturbances in the TEM-wave in the gauge line-cell with a gap of more than 1 cm. The calculated by KARAT electric field \(E_{ACS}(t)\) at a load \(Z_{CS}\) equals \(E_0(t)/5\), where \(E_0\) – the electric field in the line-cell wave. Using this ratio and the \(h_{CS} = 0.15\) cm, we calculate \(V_{CS}(t)\) – a “measured voltage” at the load \(Z_{CS} = 52\) Ohm and the sensor sensitivity \(K_{CS}\) in (1):

\[
V_{CS}(t) = E_0(t)h_{CS} = E_0(t)K_{CS}; \quad E_{CS}(t) = E_0(t)/5, \quad K_{CS} = V_{CS}(t)/E_0(t) \approx 0.3 \text{ V/(kV/m)} = 0.3 \text{ mm}; \quad (1)
\]

We estimate the effective aperture \(A_{eff,CS}\) in the sensor by the equality of \(P_{AL}\) – the electrical power in a load \(Z_{CS}\) and \(P_{E,CS} = A_{eff,CS}(E_0(t))^2/Z_0\) – the coming wave power in this effective aperture, \(Z_0 = 377\) Ohm, as:

\[
A_{eff,CS}(E_0(t))^2/Z_0 = (V_{CS}(t))^2/Z_{CS} = P_{AL}, \quad A_{eff,CS} = (K_{CS})^2Z_0/Z_{CS} \approx 0.3(h_{CS})^2, \quad \eta_{ACS} = A_{eff,CS}/A_{a,CS} \approx 0.3
\]

Note, the symbols \(\eta_A\) or \(A_{eff}\) in (2) and others we introduced in the section 1.1 as the characteristics of TEM-horns, but they will be used further for any antennas. The specifics of antenna types like those presented in figure 1 is a matched load in a face aperture (in a real sensor, instead, it is a connected coaxial signal cable, a so-called antenna feeder). In this case, the full absorbed power from the flow of wave power in the face aperture will equal to the double power in the antenna load \(2P_{AL}\). May be, it will be correct to use \(A_{eff} = 2A_{eff,CS}\). But this is a wrong idea, because the only value of the sensor effective aperture \(A_{eff,CS}\) from (2) is an identical value of radiating aperture for the sensor used in the transmitting antenna mode. That is a demand in agreement with the reciprocity theorem (see section 2.3).

2.2 Experiments. The E-field sensor antenna of StF4 is a non-symmetrical two-wire line with a high dielectric permittivity \(\varepsilon = 16, 40\) cm length, and the cross-section \(A_{a,StF4} \approx 1.5 \times 1.5\) mm\(^2\) (a face real aperture). This line was placed on a brass plate of 0.5 mm thickness, 8 cm width, 50 cm length. The coaxial cable with the impedance \(Z_S = 50\) Ohm and the length 1.5 m is the input load. The sensor was contained into a foam plastic box of 1.9 cm thickness, 8 cm width, and 70 cm length. The StF4 data were directly measured by means of placing its inside compact the TEM-line-cell. The line-cell data were: 2 cm gap, 8.3 cm width of signal foil, 70 cm work length, and wave impedance of 58 Ohm. Each end of the cell was connected with the TEM-half-horn of 17 cm length, one half-horn was loaded by 58 Ohm. Another one was connected to 50 Ohm coaxial feeder for test generator voltage \(V_G(t)\). An absence of the reflections in the line-cell was tested by the Tektronix DSA8200 with 80E08 TDR. A
rise-time in the line-cell input was \( \approx 0.03 \) ns. The electric field \( E_{gl-c}(t) \) in the gauge line-cell was calculated as:

\[
E_{gl-c}(t) = V_C(t) \times (116/108)/2 = 0.54 \times V_C(t) \text{ (V/cm)}, \quad \text{or} \quad E_{gl-c}(t) = 54 \times V_C(t) \text{ (V/m)} \quad (3)
\]

Experimental data for the signals of the StF4 strip-line sensor in the TEM wave traveling along the gauge TEM line-cell with 2 cm gap and the \( E_C(t) \) electric field in the cell are shown in figures 3 and 4.

\[\text{Figure 3. } E_{st}(t) = V_{StF4}(t)/K_{StF4} - \text{ signal from StF4-sensor. } E_C(t) = V_{gl-c}(t)/0.02m - \text{ in the gauge line-cell which was excited by step-like pulsed voltage}\]

\[\text{Figure 4. } E_{st}(t) = V_{StF4}(t)/K_{StF4} - \text{ signal from StF4-sensor. } E_C(t) = V_{gl-c}(t)/0.02m - \text{ in the line-cell it was excited by bell-type voltage}\]

In figure 3, the gauge line-cell was excited by 80E08 module (\( E_C \) – a dotted line) and in figure 4, it was excited by TMG60 test generator [13] (\( E_C \) – a dotted line). We used the test results to calibrate the StF4 sensor parameters for any measurements realized in the TEM traveling-waves. The parameters are the following: the sensitivity \( K_{StF4} = 0.32 \text{ V/(kV/m)}, T_{0.1-0.9} < 0.03 \text{ ns} \) - the rise-time, and the work time gap of \( T_{max} = 7 \text{ ns} \). We calculate the effective aperture \( A_{eff,StF4} \) and the efficiency \( \eta_{A,StF4} \) for the StF4 sensor antenna (4) in the same way as (2):

\[
A_{eff,StF4}(E_0(t))^2/Z_0 = (V_{St}(t))^2/Z_S, \quad A_{eff,StF4} = (K_{StF4})^2 Z_0/Z_S = 7.7 \times 10^{-3} \text{ cm}^2, \quad \eta_{A,StF4} = A_{eff,StF4}/A_{a,St} \approx 0.34 \quad (4)
\]

Note, the computer simulation of the sensor model gives the values (1, 2), which are close to the experimental ones. Note, the design of StF4 sensor is a type of directional wave coupler with a finite length. The interval finite time work gap \( T_{max} \approx 7 \text{ ns} \) is clearly displayed in figures 3, 4 (the signal duration is lower than \( T_{max} \)).

We measured the \( K_{StF4} \) -sensitivity for various directions of the coming waves [12]. In the first, the StF4 sensor is an antenna with a linear polarization (along the normal to the base plate). In the second, the \( K_{StF4} \) -sensor sensitivity does not change within the broad angles in the H-plane, and vice versa in the E-plane (the normal to the base plate), it is increasing by a factor of 1.3 (it is maximum) for 30° angle deflection. Measurements with an accuracy 5% using the StF4 sensor demonstrated a deflection of the aim angle towards the radiator within the interval of (0-6) degrees in the plane normal to the base plate and ±20 degrees in the plane of the base plate (see results in figure 5). Note, for other types of sensor as the TEM-half-horn antenna we measured [12] relative more effects both for increasing sensitivity and for distortions of pulse shapes. Applications of the TEM-half-horn antenna sensors to measure the EMP waves from high power radiators are in [14, 15].

2.3 Principle of Reciprocity for Pulsed Antennas. It is known, the so-called the reciprocity theorem is used often to analyze the linear electrical systems, radio antennas, and sometimes, for the antennas with pulsed non-sinusoidal signals [7, 16]. This theorem predicts that the received pulsed signals will be identical when we change places of the receiving and radiating antennas. In this cases, it is necessary to provide some conditions as reported in [7]: 1) the cables connecting the antennas with a generator and with a measuring device should be of a sufficient length and have to be equal to the
impedances 50 Ohm; 2) there should be a sufficiently large “free space” around antennas for
decreasing parasitic reflections.

Figures 5, 6 show the experimental results for the “Rad+3.5m distance +Rec” set-up, which have been
obtained using the devices: 1) antennas of the StF4-(a small aperture) and the A16-(16×16cm² =A_a,A16
, in [3, 6]); 2) TMG40R ([13], T_{r,p} ≈ 25 ps, T_{w,p} > 1 ns, V_0 ≈ 43 V, 100 kHz) as an exciting source of
step-like pulses; 3) the digital sampling oscilloscope DSA8200 (0-30 GHz bandwidth, 12 bit
resolution) with 80E07-09 remote modules. Figure 5 shows the curves (top and bottom) of the StF4
sensitivity without changes for various set-ups. This figure shows lower two similar superposition
curves for the set-ups of StF4 as (Receiver/Radiator) and the A16 as (Radiator/ Receiver), that
demonstrates the efficacy of the reciprocity principle. A better test of the reciprocity principle is
demonstrated in figure 6 for the following conditions: 1) the step pulsed voltage generator with a rise-
time T_f ≈ 25 ps ; 2) the A16 antenna has the L_o =16 cm >> c·T_{r,p} -a “big” aperture and the StF4 antenna
has a small aperture, a distance between them is 3.5 m ; 3) the A16 opening surface is turned by 30°
angle towards the beam between two antennas. The curves in figure 6 were moved apart in 0.3 ns at
the time axis for the best comparison. These signals are equally excepting a jump occurring at the time
moment t ≈ 5.4 ns (a parasitic reflection by surrounding objects). Note, the inner structure of A16 is
detected by the data in figure 6: two peaks in the radiated pulse are separated by a delay ≈ 0.14 ns, i.e.
the spatial gap ΔL ≈ 0.14×30 = 4.2 cm. This is the distance between the centers of two “small horns”,
which are turned at 30° angle: Δz_{th} = 8 sin(30°) = 4 cm. The A16 was made by four “small horns” of
8×8 cm² size.

2.4 Summaries. The test results confirm that we can change the places for any receiving and
transmitting antennas, and that the received pulsed signals will have an identical shape and magnitude.
It can be realized: if the A_{eff} - antennas effective apertures would be equal in the receiver and the
transmitter modes. In (2), it is given that the effective antenna aperture A_{eff} = P_{Al}/\Pi_{EA} equals to
the power in the matched receiver antenna feeder load P_{Al} = (V_{AF} )^2/Z_{AF} divided by the flow density power
in the TEM-wave coming in the normal to the antenna face \Pi_{EA} = (E_{TE} )^2/Z_0. They are: Z_{AF} = 50 Ohm
– the feeder impedance; Z_0 = 377 Ohm – the free space impedance; V_{AF}(t) – the receiving voltage in the
feeder; E_{Te}(t) –the electric field of the incoming wave in the antenna face. According to these
equations, A_{eff} is a function of ( t ) – the time, though, for the antenna, there may be some pulse signals
received with small distortions. For example, the StF4 sensor antenna has the constant A_{eff} for
the USEMPs with the rise-time T_{r,p} > 30ps and the pulse duration T_{w,p} < 7ns, (see (4), and the data of
figures 3, 4). The antenna parameters can be measured by the experiments similar to figure 5. The
transmitter with the StF4 –as an antenna, which was excited by a step-like pulses would radiate the
USEMPs waves with a shape like $\delta(t)$ – a delta function. Any antenna, receiving such wave impulse, will produce in its feeder $V_{\delta}(t)$ – the voltage response, according its pulsed characteristic.

In the analysis of antennas of high power impulses we ordinarily use simple approximations [7, 12, 15] (see equation (5) below): $A_{a,A}$ – the antenna face aperture; $\eta_A$ – the antenna efficiency for pulses with the “average time” parameters: $T_{f,p} > T_{f,A}$ and $T_{w,p} < T_{0.9,A}$. Here: $T_{f,A}$ – the antenna transient rise-time and $T_{0.9,A}$ – the antenna “work time gap”, for signal impulse data of $T_{f,p}$ – the rise-time, and $T_{w,p}$ – the pulse width. The antenna impulse characteristics are received as written above. Often $T_{0.5,A}$ – the full width at half-maximum (FWHM) for the $V_{\delta}(t)$ is used instead of $T_{f,A}$ – the rise-time $(T_{f,A} \approx 1.05 \cdot T_{0.5,A})$.

We can note that the reciprocity principle is very useful in numerical simulation (an example reported in [12]) of the radiation pattern for pulsed antennas. It is well known, to solve this task, we needed calculations for EM-fields at a free space in the far-field zone of the radiating antenna. A size of this far-field zone should be much greater than that of the antenna. Simulations of the pulsed antenna as a receiver of the EMPs waves allowed us to decrease spatial sizes around the antenna. Although, one variant of calculations giving the antenna characteristics for the radiation/receiver is only for one spatial direction.

3. High Power Radiators for USEMP waves. Calculations, Experiments

Many our radiating antennas have been built as the antenna array joining four “small TEM-horns” like the A16. Each “small TEM-horn” was connected to its two-wire line and then to the HV-HF coaxial antenna feeder. This feeder had the coaxial connector with the wave impedance 50 Ohm. The connectors were of enlarging sizes for higher voltages at the range 10–100 kV for various pulsed generators as reported in [3–6]. For instance, A16 was supplied by connectors of “HN” male type for the amplitudes about 10 kV. The A16 in 10 kV-version had a transit rise time of about 0.04 ns, according to our results (see figure 5). Each “small TEM-horn” in the antenna array contained the dielectric inset between its two electrodes to condense the wave power and to make the even transit times for waves on the way to a face of antenna. The over electrodes of these “small horns” were mounted for return currents shielding rectangular plates. One edge of this plate was connected with the electrode on the face of antenna, and another far edge was connected with absorption resistors. An assembly of the absorption (for damping) resistors was equal to 50 Ohm.

For pulsed radiators, the equations estimating the effective potential $U_{rad} = E_p(R) \cdot R$ (the product of the peak E-field in the far-zone by R- distance, see above in 1.1) exist in various approximations. In [9], it was manufactured on the basis of the well-known Maxwell’s extended equations and the Kirchhoff-Huygens principle: secondary radiating sources residing at the antenna face surface, the so-called antenna aperture $A_a$, or the antenna opening surface (more detailed in [17]), that is:

$$U_{rad} (A+G) = E_{p,AG}(R) \cdot R \approx (\eta_A \cdot A_{aA})^{0.5} \cdot (30/(Z_G \cdot \pi))^{0.5} \cdot V_G/(c \cdot T_{ef,A}) \approx 0.44 \cdot V_G \cdot (\eta_A \cdot A_{aA})^{0.5} \cdot (30 \cdot T_{ef,A})$$

(5)

In (5), we used symbols like those employed in equation (2) and the additional: 1) $U_{rad}$ – the effective potential for the radiator with the antenna A, which excited by the generator G (V or kV); 2) $A_{aA}$ – the face antenna aperture and $A_{ef,A} = \eta_A \cdot A_{aA}$ – the effective antenna aperture (cm$^2$); 3) $\eta_A$ – the antenna efficiency (for our antennas $\eta_A \approx 0.9$); 4) $Z_G = 50$ Ohm – the generator/feeder wave impedance, $(30/(Z_G \cdot \pi))^{0.5} = 0.437$; 5) $V_G$ – the amplitude of a rapid mono-polar pulse for exciting the generator of the $G_p$(V or kV); 6) $c = 30$ cm/ns – the light velocity in a free space; 7) $T_{ef,A} \approx ((T_{G,A})^2 + (T_{f,A})^2)^{0.5}$ – the rise-time (ns) for a pulsed wave in the antenna plane aperture, $T_{G,A}$ – the rise-time of the generator pulse and $T_{f,A}$ – the rise time for the antenna feeder-aperture transient time (or antenna impulse characteristic: 1.05$\cdot T_{0.5,A} \approx T_{f,A}$, see above in section 2.4).

In figure 5, the experimental result demonstrated for the radiator (A16+TMG40R) is $U_{rad} (A16+TMG40R)_{exp} \approx 200$ V and calculated by (5) is $U_{rad} (A16+TMG40R)_{cal} \approx 210$ V $\approx 200$ V, for $V_G = 43$ V, $T_{ef,A} \approx 0.045$ ns. This $T_{ef,A}$ equals to 1.05$\cdot T_{0.5,AG}$ for $U_{rad} (t; A16+TMG40R)$ – the
transmitter impulse in the experiments of figure 5. Using these data, we estimate the transient time of the antenna A16 by the value \( T_{f\text{A16}} \approx 40 \text{ ps} \).

Figure 7 shows \( E(t;R;A30) \cdot R \) at \( R = 8 \text{ m} \) in the experiments with A30 antenna \((30\times30 \text{ cm}^2\text{-aperture})\) and the generator \( G_{p100} \) \((70-100 \text{ kV}, \ 0.1-0.15 \text{ ns}, \ 1 \text{ kHz} [10])\). Figure 8 shows the set-up of a similar autonomous radiator (A36+Gp100): A36 antenna is placed in the left-side; \( G_{p100} \) and DC source (the accumulator assembly) with control devices are placed in right-side.

![Figure 7. Radiating potential for \( E(t; R; A30) \cdot R \) from the (Ant30+ Gp100) radiator](image)

![Figure 8. The radiator (A36+Gp100), into right-side box are placed Gp100, DC source (accumulator assembly) and control devices](image)

The amplitude of \( E(t) \cdot R \) curve shown in figure 7 is about 210 kV. Using this value and the equation (5), we can apply it for an approximate definition of the parameters of GIN100 by (6):

\[
U_{\text{rad}} \ (A30+Gp100) \approx 0.44 \cdot V_{G100} \cdot (\eta_A \cdot A_{a,A36})^{0.5} / (30 \cdot T_{f\text{ef}}) \approx 4.15 \cdot V_{G100} \cdot (0.1 \text{ ns} / T_{f\text{ef}}) = 210 \text{ kV} \quad (6)
\]

Using (6) and the FWHM \( 1.05 \cdot T_{0.5,AG} = T_{f\text{ef}} \approx 0.14 \text{ ns} \) in figure 7, we do the estimation: \( V_{G100} \approx 70 \text{ kV} \). These values are realistic data for the (A30+Gp100)-radiator. In experiments with the (A30 + TMG40R)-radiator, similar to figure 5, we measured the rise-time for the antenna A30: \( T_{R\text{A30}} \approx 0.09 \text{ ns} \). Using this data and \( T_{f\text{ef}} \approx 0.14 \text{ ns} \) for the (A30+Gp100)-radiator, we estimated the rise-time \( T_{R\text{G100}} \approx 0.11 \text{ ns} \) for the generator Gp100. The magnitude of \( V_{G100} \approx 70 \text{ kV} \) is a rapid part of the impulse of the generator Gp100. We estimate a full amplitude of the voltage \( V_{\text{max}}(Gp100) \approx 80 \text{ kV} \) by adding the voltage of pre-pulse base (for Gp100 it is about 15%). It is close to the measured voltage. Figure 8 shows a typical design of the high power USEMP source of the autonomous high power radiator (A36+Gp100).

### 4. Conclusion

There was considered a new electromagnetic field sensor of type StF4, which is a non-symmetrical two-wire line small cross-section of about 1.5×1.5 mm² and 40 cm length. The pulsed characteristics of the StF4 sensor antenna were calibrated using the gauge TEM line-cell. The StF4 parameters were: the sensitivity \( K_{S\text{StF4}} = 0.32 \text{ V/(kV/m)} \), the rise-time \( T_{0.1-0.9} < 0.03 \text{ ns} \), and the work time gap of the \( T_{\text{max}} = 7 \text{ ns} \). The transmitter with StF4 as an antenna, which was excited by the step-like pulses, would radiate the “calibrated” USEMPs waves with shape like the delta-function. Such source is a good device for the measurements of pulsed antennas. Non-stationary processes in the receiver/radiator were studied analytically and by numerical 3-D code “KARAT”. At our laboratory, we had constructed the models of the autonomous compact high power radiators, using highly efficient, up to \( \eta_A = 0.9 \) antenna apertures (the size of one side of 16…60 cm) of the antenna array joining four TEM-horns and shielding the electrodes in every TEM-horn [3-6, 9]. The UWB radiators were built with a highly efficient antenna array, with the generators of pulsed voltage \((10-100) \text{ kV} \), and the repetition rate \((1-100) \text{ kHz} \) with a control synchronization. These radiators generated the radiating effective potentials \( U_{\text{rad}} = E_{\text{max}} \cdot R \approx (20-400) \text{ kV} \). The radiators have been successfully tested for the electromagnetic immunity of various electronic systems.
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