Non-Sine Impulse Waveform Generator

V.A. Somov, Ya.N. Chepurnyy, Yu.V. Tkach, V.A. Kucherenko
IEMR, av. Pravdji 5, Kharkov-22, 61022, PO Box 10857, Ukraine
e-mail: tkach@iemr.vl.net.ua

Contents

Abstract

Generator and radiating system of non-sine waveform pulses on the basis of H-waveguide, driven by the gas-filled spark gap with corrector capacitor, are proposed and studied experimentally. Required beam pattern of the radiating system is provided by horn feed and nonsymmetric paraboloidal reflector.

1. Introduction

Feasibility of generation and practical applications of non-sine waveform signals is believed to be considered for the first time in the papers [1, 2], published back in 1960. Afterwards, for a rather long time the interest to this kind of studies have flagged, which was associated, to a certain extent, with a intensive progress in the area of harmonic oscillations generation and its wide application for numerous fundamental and applied problems. Essential role in the reduction of interest to application of the non-sine waveform oscillations was played by difficulties related with generation and transmission.

However, the recent years saw the revival of interest in various applications of impulse non-sine waveforms [3-6]. Growth of this interest is strongly related with progress in modern technologies of energy storage, switching and radiation, which enabled development of compact and technologically feasible sources of these oscillations with gigawatt level of radiated power [7-9].

Nowadays, these sources of emission use pulse-forming lines (PFL) [10] or low-inductance capacitors [11] as the energy storage units. Energy switching in these devices is performed using either ultrafast high-pressure gas-filled spark gaps [12-14] or laser-triggered semi-conductor switches [15]. Radiating elements in the majority of these devices are built around the reflector antennas [9, 11, 12, 16-18] or, far less frequently, antenna arrays [9, 19, 20]. Utilization of modern technologies promoted development of compact impulse non-sine waveform generators applied in broad range of applications.

Majority of these generators employ reflector antennas with the symmetrical reflector and TEM structures, excited by ultrafast high-pressure spark gaps, in the capacity of feeds. Driving spark gaps are usually placed in focus of the paraboloidal reflector. Since the oscillation spectrum, excited by such discharge arresters, is rather broad and ranges from 50 MHz to 40 GHz [13], TEM-feeds have broad beam pattern at acceptable levels of the reflector shading. As a result, a considerable portion of the excited oscillation energy is dissipated beyond reflector aperture, thus lowering the device operation efficiency and bringing up a high-level electromagnetic background beyond the operating area. The latter circumstance is a major shortcoming for employing devices of this type in certain environmental, geophysical and other applications, mentioned above. In view of the above-said, it is considered expedient to undertake investigation, aimed at development of impulse non-sine waveform generators free from above mentioned disadvantages.

The objective of the study is development and experimental investigation of impulse non-sine waveform generator and radiating element, based on a closed waveguide-horn structure, excited by the gas-filled spark gap and paraboloidal reflector.

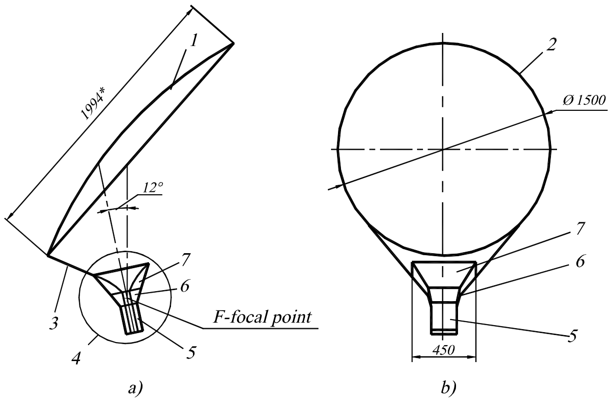

Fig. 1. Impulse Non-Sine Waveform Generator Schematic Diagram: side view (a), front view (b). 1 - paraboloidal reflector; 2 – Aperture plane; 3 – Feed fastening; 4 – H-waveguide feed; 5 – H-waveguide; 6 – Matching junction; 7 – Radiating H-horn.

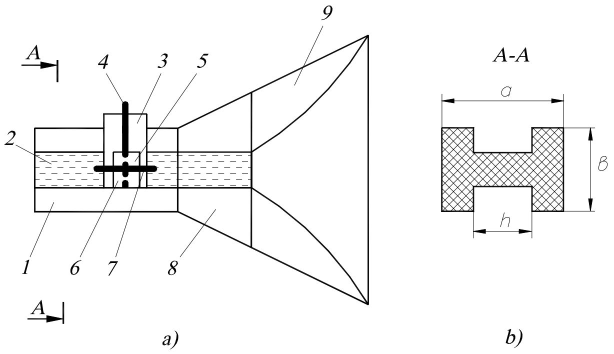

Fig. 2. Schematic Diagram of H-waveguide feed (a) and cross-section of the H-waveguide, used in the feed (b): 1 – Short-circuited H-waveguide section; 2 – Oil; 3 – Double spark gap; 4 – Connection output to capacitor storage; 5 – Peaking spark gap; 6 – Waveguide excitation spark gap; 7 – Correcting capacitor; 8 – Matching junction; 9 – Radiating H-horn.

The closed wave-guide structure permits to narrow beam pattern and thereby reduce the flux of energy, dissipated beyond the reflector aperture. In addition, the waveguide feed can be regarded as high-pass filter, suppressing low-frequency part of the excited oscillation spectrum, which does not contribute to the directed radiation.

2. Description of the Generator

Schematic diagram of impulse non-sine waveform generator design is displayed at the Fig. 1.

Generator contains capacitive energy storage unit with the charger device, H-waveguide-based feed and a paraboloidal reflector.

The feed is designed on the base of H-waveguide, with its dimensions derived by calculations and corrected by means of prototype experiments. The waveguide cutoff frequency is equal 520 MHz for the selected dimensions and reduced down to 344 MHz if the waveguide is filled by liquid dielectric. This feed configuration employs a short-circuited waveguide section, permitting to form impulse, which can be effectively transmitted in view of the permanent component absence.

Schematic diagram of the feed is shown at the Fig. 2.

H-waveguide is driven by the high-pressure double gas-filled spark gap with the correcting capacitor [21]. General view of the spark gap, employed in the design, is shown at the Fig. 3.

In the addressed device, first spark gap shortens the front of the switched pulse and provides, respectively, high frequency components of current fluctuations in the second spark gap, which acts as the main H-waveguide driver. Experimental measurements show this design solution to provide large share of non-sine waveform oscillations energy in the high frequency spectral area. Gas pressure in the spark-gap for this design did not exceed 3 Torr.

At the open H-waveguide end, which is excited by the above mentioned double spark gap, a matching junction is installed, to match waveguide with the radiating horn input. The horn has sophisticated shape and is designed in such a way that in each cross section it has cutoff frequency, that is equal to that of H-waveguide, filled with liquid dielectric with specified permittivity ε.

This design of generator employs reflector antenna. The reflecting surface is a section of rotation paraboloid with the focus distance equal to 600 mm. The reflector aperture diameter is 1500 mm, with the distance from the center of the aperture to the focal axis equal to 1050 mm.

Energy source in this generator is built around high-voltage storage capacitor. Energy storage unit is charged by the pulsed voltage source, with amplitude not exceeding 25 kV, Charging voltage was varied through the experiments. General view of the impulse non-sine waveform generator assembled with the reflector antenna, is shown at the Fig. 4 (a, b).

Above described design of generator was studied experimentally. The radiation output characteristics and their dependence on the basic parameters of generator were studied in course of experimental study.

3. Measurements Results

Measurements of the radiated impulse output characteristics were taken, using the standard antenna П6-33 with the passband ranging from 0.1 GHz to 1 GHz. Impulse signals from antenna output were registered, using fast oscilloscope C7-19 with the passband equal to 5 GHz.

In process of the experiments, the voltage waveforms were recorded at the receiver antenna

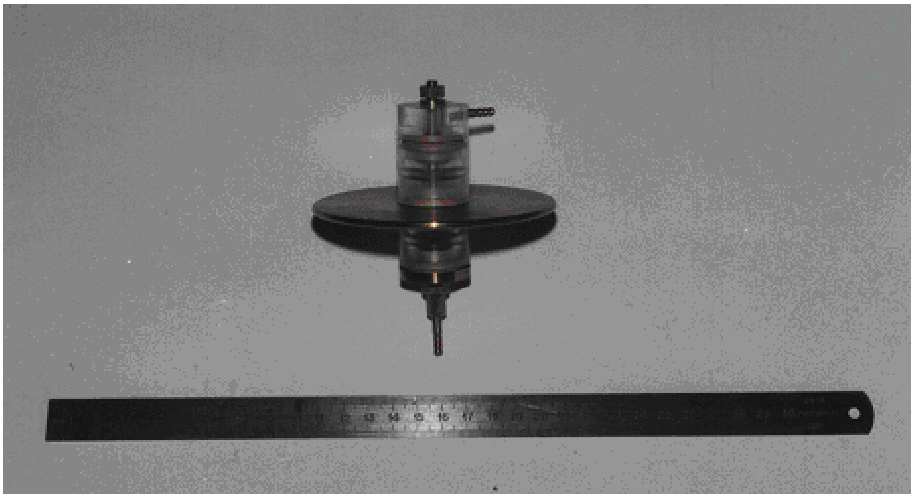

Fig. 3. General view of the high-pressure fast double gas-filled spark gap.

a) b)

Fig. 4. General view of the impulse non-sine waveform generator: front view (a); side view (b).

output together with their peak values. Dependence of impulse amplitudes on the angle of registration was recorder as well, because it is identical to the beam pattern of antenna device. Spectrum of measured impulses was calculated using software for the impulse signal Fourier analysis.

The typical impulse waveform, as taken in the direction of paraboloid axis and its spectrum for one of the generator operation regimes modes are displayed at the Fig. 5 (a, b).

The measurements showed the radiated impulse waveform and, appropriately, its spectrum to depend on the voltage, applied to the double spark gap, spark gap width and gas pressure. Optimal gap width exist for any given pressure of gas in the spark gap. Experiment results prove that the optimal ratio of peaking and driving spark gap width is equal to 2.5 mm for the voltage at the double spark gap 25 kV,

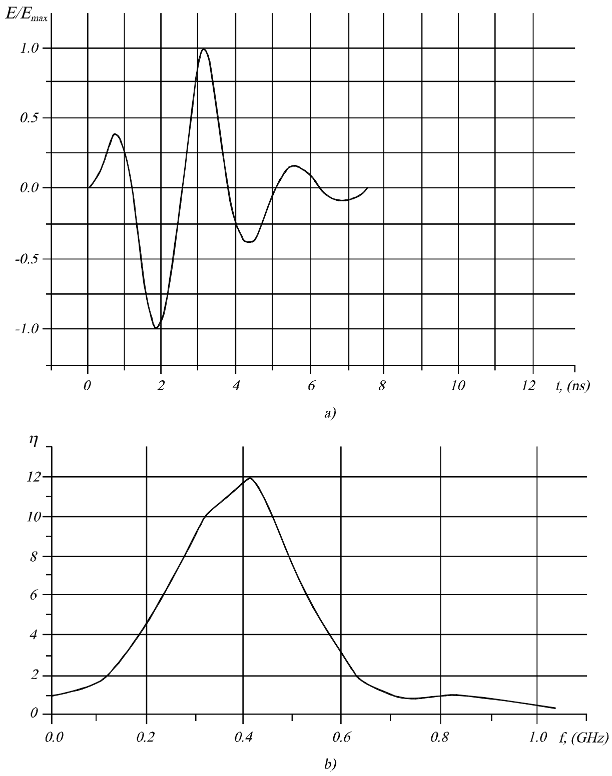

Fig. 5. Typical impulse waveform, as registered, (a) and its spectrum (b). η — the signal amplitude in relative units.

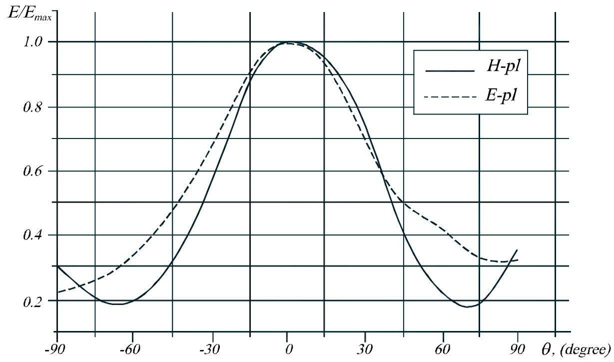

Fig. 6. Amplitude of normalized E-component field strength for the field, radiated by feed, as a function of registration angle in E- and H-planes.

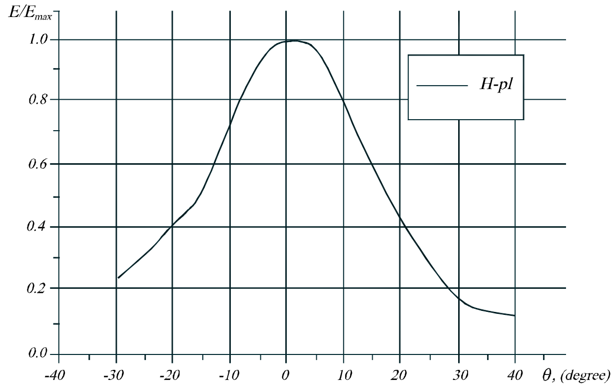

Fig. 7. Amplitude of normalized E-component field strength for the field, radiated by reflector antenna, as a function of registration angle in H-plane.

gas pressures 2 Torr and given storage capacitance.

Note that employed in the current design solution of H-waveguide excitation by the double spark gap with the corrector capacitance is not susceptible to the inductance of discharge circuit. In order to verify this experimentally, a auxiliary 100 nHn inductor was interconnected in the circuit between the storage capacitor unit and spark gap. Generated impulse amplitude did not decrease by more than 15 % and the impulse waveform remained virually unchanged.

Beam pattern of the generated radiation, provided by the feed and reflector antenna, was found according to the measurement results of radiated field E-component amplitude as a function of registration angle. Variation of registered pulse wave-form wasn't taken account in course of experiments.

Results of angular field strength distribution measurements for the feed are given at the Fig. 6, while those for the reflector antenna, are presented at the Fig. 7.

Presented plots can be treated as a substitute for beam pattern in case of harmonic signals. Estimates for the feed and reflector apertures, made in this approximation , indicate that the relationships shown at the Figs. 6 and 7 correspond to the harmonic signal frequency 500 MHz. This value agrees well with the measured oscillation period of a radiated impulse, the oscillogram of which is shown at the Fig. 5 (a).

In a similar manner, it is feasible to introduce a substitute of antenna gain with respected to radiated signal peaking power, as compared to the isotropic radiating element. Experimentally measured gain for the above device gonstitutes $40 \div 50$.

Fig. 8 shows variations of the absolute peak field strength value lengthwise the axis that is perpendicular to the antenna aperture as a function of distance.

The measurements were taken at the height of 150 cm above ground (moist soil).

As seen from the relationship, shown at the Fig. 8(a), beginning from the distance from the antenna aperture $R \approx 9$ м, the field strength diminishes according to the law $1/R$, which is appropriate for the far zone of an antenna. Certain oscillations, seen at the E-component field strength vs. distance relationship plot are accounted for by measurement errors and underlying surface effects (moist soil).

The measured radiation characteristics were employed to calculate the radiated power, as generated by H-waveguide based feed. Power value constituted 185 kW.

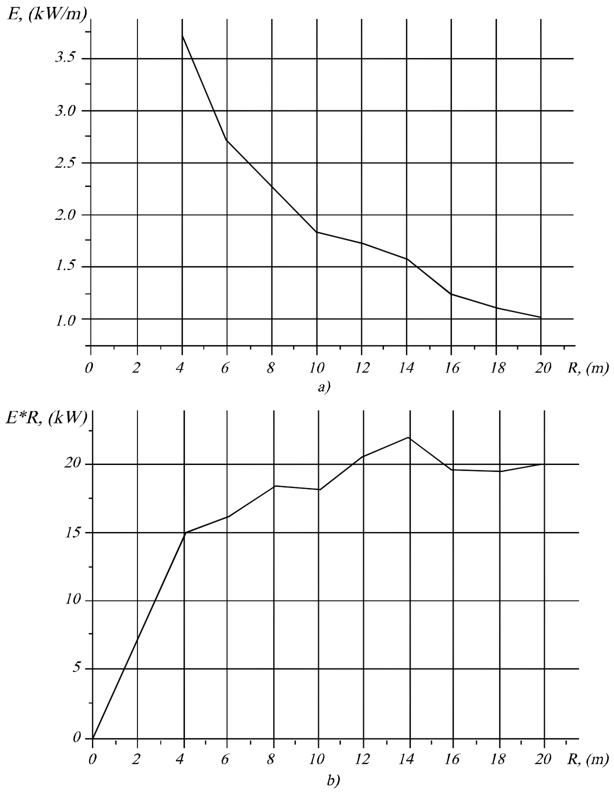

Fig. 8. Peak radiated pulse field strength lengthwise the axis that is perpendicular to the antenna aperture (a) and $*R$ (b) as a function of distance.

4. Discussion

Results of experimental investigation of impulse non-sine waveform generator, based on H-waveguide are presented. In the presented generator design, H-waveguide is driven by double spark gap with the correcting capacitor.

Designed generator employs a offset reflector antenna with the horn feed to provide required beam pattern.

Obtained results along with comparison with other impulse non-sine waveform generators characteristics, published openly, indicate that waveguides of sophisticate configuration can be regarded as alternative to TEM-structures. Their employment should allow, in particular, development of impulse sources with reduced radiation level beyond the working sector limits.

Manuscript revised December 1, 2000.

References

[1] Cook C.E. Proposed monocycle-pulse very high frequency radar for airborne ice and snow measurements // Trans. AIEE Commun. Electron. - 1960. - V. 79. - P. 588-594.

[2] Harmuth H.F. Radio communication with ortogonal time function // Trans. AIEE Commun. Electron. - 1960. - V. 79. - P. 221-228.

[3] Walton E.K. and Gunawan S. Comparative Analysis of UWB Underground Data Collected Using Stop-Frequency, Short Pulse and Noise Waveforms // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London, 1997. - P. 511-516.

[4] Laurence Carin and Stanislav Vitebsky Short Pulse Scattering and the Resonances of Three-Dimensional Buried Targets // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London, 1997. - P. 499-510.

[5] Leopold B. Felsen. Analytic Methods for Pulsed Signal Interaction with layered, Lossy Soil Environments and Buried Object. // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 485-498.

[6] Loubriel G. M., Buttram M.T., Aurand J.F., Zutavern F.J. Ground Penetrating Radar Enabled by High Gain GaAs Photoconductive Semiconductor Switches // Ultra-Wideband, Short- Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 17-24.

[7] Andreev Yu. A., Buyanov Yu. I., Efremov A.M., Koshelev V.I., Kovalchuk B.M., Plisko V.V., Sukhushin K.N., Vizir V.A., Zorin V.B. Gigawatt-Power-Level Ultrawideband Radiation Generator. // Proc. 12th International Pulse Power Conference. - 1999. - V. II. - P. 1337-1340.

[8] Andreev Yu. A., Buyanov Yu. I., Efremov A.M., Koshelev V.I., Kovalchuk B.M., Plisko V.V., Sukhushin K.N., Vizir V.A., Zorin V.B. High-Power Ultrawideband Electromagnetic Radiation Generator // Proc. 11th International Pulse Power Conference. - 1997. - V. I. - P. 730-735.

[9] Mikheev, O.V., Sakharov, K.Yu., Sokolov, A.A., Turkin,V.A., Kockin E.N., Radchenko, V.M. Radiators of Short Ultra-Wideband Electromagnetic Impulses// Proc. 10th Int. Crimean Conf. "Microwaves and Communication Technologies", Sevastopol, Ukraine. September 11-15, 2000.
- P. 469-470.

[10] Davanloo F., Borovina D.L., Korioth J.L., Krause R.K., Collins C.B., Agee F.J., Hull J.P., Schoeneberg J.S.H. and Kingsley L.E.

High Power, Sub-Nanosecond Rising waveforms, Created by Stacked Blumlin Pulsers. // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 31-38.

[11] Giri D.V. and Carl E. Baum Pemporal and Spectral radiation on Boresight of a Reflector Type of Impulse Radiating Antenna (IRA) // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 65-72.

[12] Skulkin Sergey P. and Turchin Victor I. Transient Fields of paraboloidal Reflector Antennas // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 81-88.

[13] Bowen L.H., Farr E.G., Elizondo J.M., Lehr J. High-Voltage, High Rep-rate, Low Jitter, UWB Source With Ferroelectric Trigger. // 12th IEEE International Pulsed Power Conference. - 1999. - P. 1137-1140.

[14] Gubanov, V.P., Korovin, S.D., Pegel' I.V., Rostov, V.V., Stepchenko, A.S., Tarakanov, V.P. Generation of High-Power Ultra-Wideband Electromagnetic Impulses from the System with the Coaxial TEM-Horn. // Izvestia Vyschikh Uchebnikh Zavedenii, Series "Fyzica". - 1996. - N 912. - P. 110-118.

[15] 15. Liu D.W., Carr P.H. Optically Excited Photocunducting Antennas for Generating Ultra Wideband Pulses // Ultra-Wideband, Short-Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 9-16.

[16] Baum C. E., Sadler J.J. and Stone A. P. Coplanar Conical Plates in Uniform Dielectric Lens with Matching Conical Plates for Feeding a Paraboloidal Reflector // Ultra-Wideband, Short- Pulse Electromagnetics 3. Edited by Carl E. Baum; Laurence Carin; Alexander P. Stone. Plenum Press N.Y. & London. - 1997. - P. 73-80.

[17] Farr E.G., Baum C. E. Impulse Radiating Antenna With Two Refracting or Reflecting Surfaces // Sensor and Simulation Notes. - May 1995. - Note 379.

[18] 18. Farr E.G., Frost C.A. Compact Ultra-short Pulse Fuzing Antenna Design and Measurements // Sensor and Simulation Notes. - June 1995. - Note 380.

[19] Prather W. D., Baum C. E., Lehr J.M., O' Loughlin J. P., Tyo S. at al. Ultra-Wideband Sours Research // 12th IEEE International Pulse Power conference. - 1999. - P. 185-189.

[20] McGrath D.T. Numerical Analysis of Planar Bicone Arrays // Sensor and Simulation Notes. - December 1996. - Note 403.

[21] Akhanzyan, T.M., Gavrilov, L.E., Mischenko, B.G. Fundamentals of Nanosecond Pulsed Technology. Moscow, Atomizdat. - 1976. - 376 p.