GENERATION OF POWERFUL, SUPERBROAD-BAND, SUBNANO-SECOND ELECTROMAGNETIC PULSES

V. G. Shpak, M. I. Yalandin, S. A. Shunailov, and M. R. Ul'maskulov

The excitation of superbroad-band TEM antennas with a high-voltage subnanosecond modulator permitting a pulse-repetition frequency of up to 100 Hz is experimentally investigated. The modulator consists of a RADAN-303B nanosecond driver and a pulse amplifier based on gas discharges. The instrument generates unipolar and bipolar pulses of tunable length and amplitude. The amplitude and power of the pulses sent to the antenna reach 100 kV and 200 MW. Data are obtained on the stability of the parameters of the subnanosecond modulator pulses. Information is given on the electrical strength of the air insulation in the matching interval between the modulator and the antenna. The superbroad-band pulses emitted are recorded at distances of up to 25 m. The characteristics of the instrument permit the spatial resolution of reflections from conducting objects with a shape-inhomogeneity scale of no more than 25 cm. Emitters with increased directionality in the E or H (E and H) planes based on two (four) TEM antenna supplied with split modulator pulses are investigated. In-phase and antiphase antenna configurations are considered.

INTRODUCTION

Nanosecond high-current accelerators of relativistic electron beams (REB) are widely used to generate superpowerful VHF pulses. They are based on a generator of high-voltage pulses transmitted in the form of TEM waves in the accelerator tube of a VHF generator. The total efficiency of the subsequent energy transformation in the generator - REB - electromagnetic-radiation chain is small – usually 10-20% [1]. At the same time, the TEM-wave energy of the high-voltage generator may be converted to electromagnetic radiation without using REB, i.e., by the direct emission of an electromagnetic pulse from a superbroad-band antenna. The characteristics of this pulse are significantly different from those of a radiation pulse of analogous length (\( \tau_p \)) with VHF filling. The relative spectral width in this case may be relatively large (\( \Delta f = f \approx 1/\tau_p \)), and the characteristic radiation frequencies at the pulse lengths accessible to high-current generators (0.1-1 msec) are 1-10 GHz. This determines the conditions in which superbroad-band pulses may be used as probing and test signals [2, 3].

Superbroad-band (SBB) pulses of low-power electromagnetic radiation are successfully used in geological prospecting and elsewhere. One advantage of SBB electromagnetic probing pulses is the possibility of recording reflections from objects that are not visible to ordinary radiolocation systems based on coherent single-frequency microwave radiation, including those with high pulse power. Objects at small angles to the horizon are accessible to probing by short SBB pulses; the emitter may be close to the Earth’s surface. It is relatively simple to create such SBB antennas. A disadvantage of SBB pulses is the difficulty of creating narrowly focused diagrams. The use of a powerful pulsed modulator may significantly increase the energy potential of SBB radiation. Of particular interest is the possibility of generating SBB pulses of electromagnetic radiation with a high power level (0.1-1 GW or more) in conditions of periodic repetition at a frequency of 100 Hz or more.

A powerful SBB-pulse source based on an antenna with shock excitation may be characterized by good reproducibility of the parameters from sample to sample, relative simplicity, and low cost. The stability of its characteristics is completely determined by the stability of the modulator pulses. A single powerful SBB emitter is an alternative to a sectioned system based on synchronized low-power sources. At the same time, the creation of a system of synchronous emitters (even on the basis of


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powerful single SBB elements) is not an absurd concept at this point. Methods of forming high-voltage nanosecond pulses permit parallel sectioning of the nanosecond drivers on which powerful pulsed modulators are based. In addition, research shows [4] that electrically controlled high-voltage gas discharges may now be turned on with subnanosecond precision. This suggests the prospects for synchronizing powerful modulators with a pulse length \( \tau_p \leq 1 \) nsec. To create a sectioned and/or synchronized modulator (i.e., a source for SBB gratings with shock excitation) entails increasing the directionality of radiation with a broad spectrum. The same results may be obtained by splitting the high-voltage pulse of a single superpowerful modulator and connecting several passive emitting antennas with an enlarged spatial base. In the present work, experimental data on the generation of powerful SBB radiation by means of a small high-current subnanosecond pulsed—periodic high-voltage modulator are outlined.

1. HIGH-VOLTAGE SUBNANOSECOND MODULATOR

The range chosen for the exciting pulse lengths is determined by the requirements on the spectral characteristics of the SBB pulses in terms of the information content provided in reflected-signal analysis [3]. Subnanosecond pulse lengths (from hundreds of psec to 1 nsec) correspond to the short-wave region of the decimeter-wave range. Resonant scattering of probing SBB pulses by the surface relief of small objects occurs in this range.

The subnanosecond generator is based on a nanosecond driver, which determines the operational characteristics of the instrument. The pulsed—periodic nanosecond driver adopted is a compact RADAN-303 generator [5], the basis element of which is a binary shaping line (BSL) or Blumlein line. It allows pulses with \( t_d \sim 4 \) nsec and with a controllable amplitude (up to \( U_d \sim 150-200 \) kV, depending on the repetition frequency, which may reach 100 Hz) to be obtained with a matched 50-\( \Omega \) load. Hence, the pulsed power at the matched driver output is \( \sim 450-800 \) MW. It is important that the charging unit of the BSL based on a Tesla transformer (TT) permits increase in the voltage from 500 V to 200 kV. Thus, in a nanosecond energy-compression system, intermediate capacitive stores and additional switchgear are eliminated and a high-speed thyristor is used in the low-voltage high-current TT circuit. As a result, the driver’s weight is no more than 30 kg, and the power it draws from the grid is 1000 W at a pulse-repetition frequency of 100 Hz.

Since we want to generate powerful high-voltage pulses of length less than 1 nsec, a special subnanosecond shaping unit based on amplification and cutoff discharges is connected to the driver. The design of the shaping unit permits simple regulation of the pulse length over a relatively wide range [6]. The first detailed investigation of such subnanosecond generators was conducted around 20 years ago [7]. The operation of such a shaping unit — called a slicer — is based on the subnanosecond delay time between the triggering of the amplification and cutoff discharges. This delay determines the length of the output pulse. In pulsed—periodic conditions at voltages above 30 kV and repetition frequencies of tens of Hz or more, high-pressure gas discharges are most suitable. Our instrument employs nitrogen at a pressure up to 60 atm. The special electrode configuration permits regulation of the amplifier gap over a wide range, with insignificant variation in wave resistance of the coaxial channel. Smooth regulation of the voltage and the length of the output pulse may be ensured directly in the course of generator operation. Slicers with different numbers of amplifying discharges (1-3) have been experimentally tested [6]. In all cases, the rate of voltage growth in the first amplification gap is \( \sim 0.5 \cdot 10^{14} \) V/sec.

In a slicer with a single-gap amplifying discharge, a pulse of \( \sim 160 \) kV with a length at halfheight of \( \sim 300 \) psec is obtained. Shorter pulses may be obtained on reducing the amplitude. The rate of voltage growth of such a subnanosecond pulse is \( dU/dt \sim 5 \cdot 10^{14} \) V/sec. The value of \( dU/dt \) for the trailing front is twice as large. This makes sense, since the cutoff discharge operates in traveling-wave conditions (i.e., without prebreakdown voltage doubling) and at higher prebreakdown voltage growth rates. Consequently, the gap of the cutoff discharge may be much less than that in the amplifying discharge. As a result, low inductance of the switch unit is ensured. Taking into account that the voltage growth rate and the electrical strength of the gas increase with each additional spark gap, a \( \sim 150-200 \) kV pulse with a length at halfheight of 150 psec is obtained with a three-gas amplifying discharge. The cutoff length recorded (50 psec) agrees with the transient characteristic of the measuring system, which is limited by the KOI-3 oscillograph employed.

In multigap discharges, only the first gap permits external regulation. Therefore, in the basic experiments of SBB-pulse generation, a simplified two-electrode amplification unit is employed. A Tektronics TDS820 stroboscopic oscilloscope with a 6-GHz recording band is used for detailed analysis of the stability of the subnanosecond-pulse characteristics. This instrument is distinguished by high sensitivity and stability of triggering by the test signal. In the experiments, the signals are digitized with a total of 500 counts at 10-psec intervals. Correspondingly, the oscillograms obtained represent the overall pattern for 500