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Methods for measuring parameters of ultra-wideband microwave radiation

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Abstract. The plasma source of ultra-wideband (UWB) microwave radiation was developed. Operation of this source is based on amplification of the relativistic electron beam (REB) noise. The middle frequency of UWB amplifiers of this type is determined only by the plasma density and does not depend on duration of the high-voltage pulse at the cathode. This allows obtaining rather long signals with durations of about 200–300 ns and tuning the signal middle frequency from 2.2 to 3.8 GHz by means of varying the plasma density. A number of problems were solved, which occur in the course of measuring the UWB microwave signal parameters. In particular, a new method for measuring signal energy was developed, the optimal length of the receiving antenna used for recording the UWB radiation spectra was chosen, and the effective potential of the plasma UWB source was estimated. It was demonstrated that the energy of microwave signal is more than 10 J. The effective potential of the plasma UWB source was found to be approximately 400 kV for the signal with a middle frequency of 3 GHz that is comparable to that of other UWB microwave sources. It was also shown that the spectrum of the plasma UWB source is determined by its amplification band and by the oscillation spectrum of the current generated by the explosive emission cathode.

1. Introduction

The experimental studies of ultra-wideband (UWB) signals meet a number of difficulties, because the standard techniques for receiving and processing the signals are inapplicable for the pulsed UWB radiation. The main diagnostic techniques currently used in the relativistic microwave electronics are the measurements of the electric field time dependence using receiving antennas and high-speed oscilloscopes, as well as the microwave energy measurements using calorimeters. The main problem occurring during measurements of the UWB microwave radiation parameters consists in the fact that the sensitivity of measurement instruments depends on the radiation frequency.

This article describes detection methods used to determine the parameters of the ultra-wideband microwave pulses generated by the plasma UWB microwave amplifier designed at the Plasma Physics Department of the Prokhorov General Physics Institute of the Russian Academy of Sciences.



2. Plasma Ultra-Wideband amplifier of relativistic electron beam noise

The schematic of experimental set-up is shown in Figure 1.

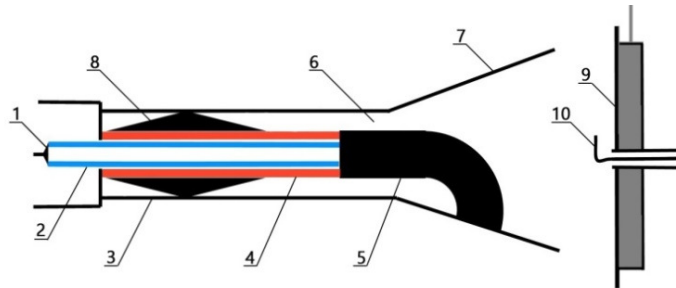


Figure 1. Schematic of plasma UWB microwave amplifier of relativistic electron beam noise and measurement equipment used.

The relativistic electron beam 2 is injected into the cylindrical waveguide 3 pre-filled with the annular plasma 4. The REB is formed in the magnetically insulated diode, inside which the negative high-voltage pulse was applied to the cathode 1. The main facility parameters are as follows: the electron beam energy is 500 keV, the beam current is 2 kA, and duration the voltage pulse applied to the cathode was 600 ns. The lengths of the plasma and electron beams are limited by the length of the coaxial vacuum waveguide 6. The plasma and electron beam currents flow to the collector and are terminated by the metal waveguide. To prevent broadening of the plasma and electron beams, the strong magnetic field with an inductance of $B = 0.45$ T is created around the waveguide. The microwave radiation absorbers 8 are installed inside the waveguide to avoid the transition to the generation mode. The amplified UWB microwave radiation is emitted by the horn 7 and received by the rod antenna 10. Then it is inputted to the high-speed oscilloscope with a bandwidth of 4 GHz through the coaxial cable with an attenuator of 63 dB. The calorimeter 9 with a diameter of 50 cm is used to measure the total microwave energy. The distance between the receiving antenna and the calorimeter surface is 2.5 cm.

3. Selection of the receiving antenna length

The REB noise spectrum in vacuum and the spectra of noise signals obtained at three different plasma densities are shown in Figure 2.

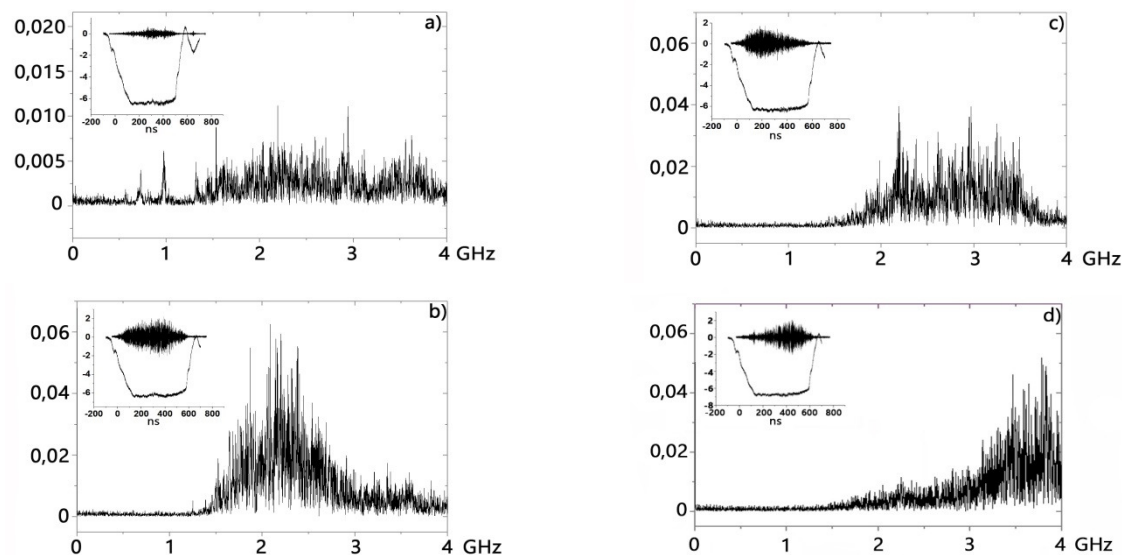


Figure 2. Spectra of the plasma UWB amplifier signals: a) $n = 0$, b) $n = 8$, c) $n = 11.4$, d) $n = 16$ relative units. In the upper left corner of each plot, the waveforms of microwave and cathode voltage pulses are shown.

As can be seen in Figure 2a, the lower edge of the REB self-noise spectrum is approximately 1.3 GHz and the upper edge exceeds 4 GHz. Figure 2 also shows that the middle signal frequency increases with increasing plasma density and the amplification band is approximately 1.5 GHz.

To detect radiation in the frequency band from 1.5 to 4 GHz, the receiving antenna of optimal length was chosen. The optimal length was obtained by means of performing model measurements. The geometry of the model experiments coincided with the geometry of the main experiments, but a standard low-power microwave generator was used as the microwave source. The dependences of the output signal amplitudes on the receiving antenna length were measured for different lengths of the receiving antenna at three frequencies of the input signal: 2.62, 3 and 3.845 GHz.

For all three frequencies of the standard generator, the amplitude of the receiving antenna signal reached its maximum when the length of the rod antenna was 3.5 cm. This result was confirmed by the numerical simulations performed using the “KARAT” code [1]. According to the calculations, the electric fields of the plane waves, polarized in the plane containing the antenna, with an electric field strength of 1 kV/cm and frequencies of 2, 3 and 4 GHz create voltages of 0.98, 0.75 and 0.72 kV, respectively, in the 3.5-cm-long cable of the receiving antenna. Taking into account that the signals are reduced by the 63-dB-attenuator at the oscilloscope input and damped in the 20-m-cable, the voltages recorded by the oscilloscope are 0.49, 0.335 and 0.32 V.

4. Measurements of the effective potential of the plasma UWB microwave source

One of the main characteristics of UWB microwave sources is the effective potential U_{eff} . The effective potential is the product of the electric field strength E in the given point and the distance z between this point and the emitting antenna. The effective potential should be measured in the far-field region, where the electric field strength is inversely proportional to the distance from antenna.

The edge of the far-field region for the antenna emitting radiation with the wavelength λ is determined by the formula:

$$z > \frac{2D^2}{\lambda} \quad (1)$$

where D is the diameter of the emitting horn. To measure the effective potential in the far field region of the plasma UWB source, the diameter of the emitting horn was reduced to 16 cm. In this case, for the signals with a middle frequency of 3 GHz, the far-field region is located at the distance of $z = 50$ cm from the emitting horn.

The electric field near the antenna increased 1.8 times when the distance between the horn and the receiving antenna was reduced twice (from 80 to 40 cm). This means that the region located at distances of $z = (40-80)$ cm from the horn can be considered as the far field region for the plasma UWB source. When the rod antenna was placed at a distance of $z = 80$ cm from the horn, the oscilloscope recorded the signal with a middle frequency of 3 GHz and an amplitude of approximately 1.7 V. With allowance for the attenuation in the cable and at the oscilloscope input, we obtain that an amplitude of $U = 1.7$ V at the oscilloscope output corresponds to a voltage of 3.8 kV at the antenna. According to the results of numerical simulations, the 3.8 kV voltage at the antenna should occur when it receives signals with a frequency of $f = 3$ GHz and an electric field strength of $E = 5$ kV/cm. Thus, the effective potential of the plasma UWB source is $U_{eff} = 400$ kV, which is comparable to that of the utilized ultra-wideband microwave sources of video pulses with single emitting antenna [2].

5. Measurements of the UWB microwave pulse energy

At large distances from the horn, the microwave front becomes plane. “Cold” measurements have shown that, under conditions of normal wave incidence onto the calorimeter surface, the microwave power reflection coefficient is 10%. This makes it possible to determine the microwave radiation energy by means of measuring the energy absorbed by the calorimeter. But at large distances from the horn, because of the strong divergence of the microwave beam, the calorimeter measures only part of the microwave pulse total energy. If the calorimeter is installed closer to the horn, the fraction of microwave energy falling on the calorimeter will increase. But at the same time, the microwave front

becomes not plane and the reflection coefficient will increase up to some unknown value. Therefore, in previous experiments, the measurements of the energy absorbed by the calorimeter were performed at large distances from the calorimeter, and the total energy of the microwave pulse was calculated using the numerical simulation methods.

A new scheme for measuring the total energy of microwave pulses was proposed. In this scheme, an additional horn with a length of 60 cm and an output diameter of 44 cm was installed outside the vacuum chamber between the main emitting horn and the calorimeter (with a diameter of 50 cm) installed at a distance of 80 cm from the main horn. If we use this new scheme, it becomes possible to deliver full energy of the microwave pulse to the calorimeter, as well as to reduce the angle of microwave radiation incidence onto the calorimeter surface. The total energy of the noise microwave pulse with a middle frequency of 3 GHz measured using the new scheme turned out to be 13 J. In previous experiments, in which the microwave pulse energy was measured without the additional horn at a distance of 80 cm from the emitting horn and the numerical simulations were used, the total energy of the microwave pulse was found to be 15 J. Thus, the direct measurements have confirmed the results obtained previously: the plasma UWB source allows generating microwave pulses with durations of 200–300 ns and energy of ~15 J.

6. Autocorrelation functions

The noise radiation can be judged by analyzing the autocorrelation function (ACF) of the signal. Figure 3 shows the autocorrelation functions of the signals obtained in experiments on the REB injection into vacuum and into the plasma with a density of $n = 11.4$ relative units.

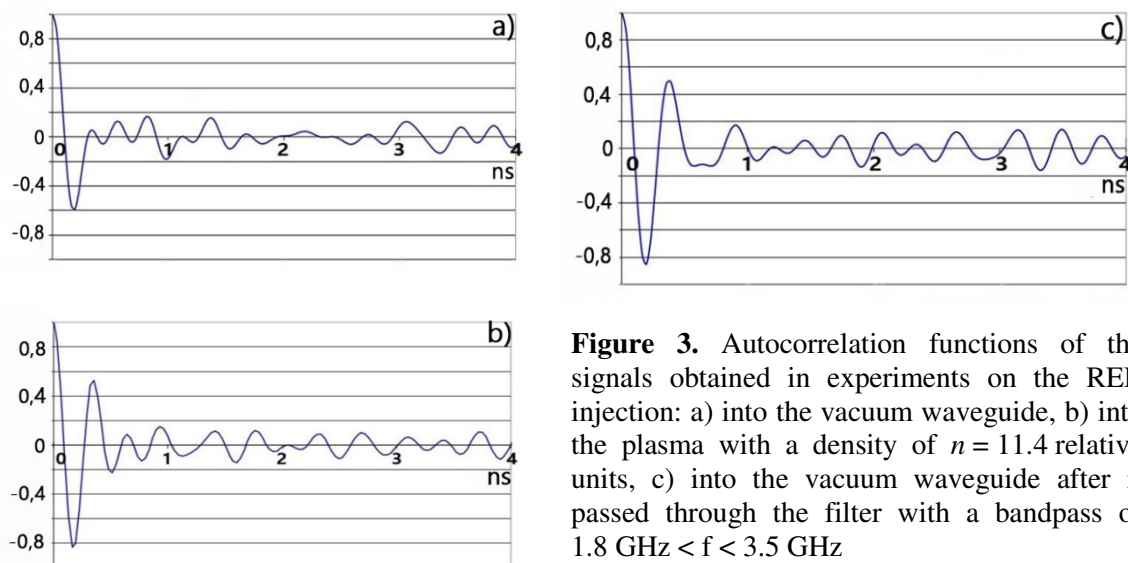


Figure 3. Autocorrelation functions of the signals obtained in experiments on the REB injection: a) into the vacuum waveguide, b) into the plasma with a density of $n = 11.4$ relative units, c) into the vacuum waveguide after it passed through the filter with a bandpass of $1.8 \text{ GHz} < f < 3.5 \text{ GHz}$

The comparison of Figures 3a and 3b shows that the signal obtained in experiments on the REB injection into the plasma is more regular, because its ACF has longer correlation time. Figure 3c shows the ACF of the signal obtained in experiments on the REB injection into vacuum after it passed through the filter with a bandpass of $1.8 \text{ GHz} < f < 3.5 \text{ GHz}$. This bandpass corresponds to the frequency range of the signal obtained at a plasma density of $n = 11.4$ relative units. The correlation times for autocorrelation functions represented in Figures 3b and 3c are equal. Thus, the difference between the ACFs shown in Figures 3a and 3b can be explained by the reduction of the amplification band of the plasma UWB microwave source: only a part of the REB noise is amplified by the plasma amplifier. The autocorrelation analysis of microwave signals confirms that the observed signals are the amplified REB noise signals, and the spectra of this noise signals are the same in both cases when the REB is injected into vacuum or into the plasma. Therefore, one can conclude that the processes on the explosive emission cathode are the sources of REB noise.

Acknowledgments

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References

- [1] Tarakanov V P 2003 *Mathematical Modeling. Problems and Results* (Moscow: Nauka) [in Russian]
- [2] Koshelev V I, Buyanov Yu I, Belichenko V P 2017 *Ultrawideband Short-Pulse Radio Systems* (Boston/London: Artech House)