Technical Physics Letters, 2022, Vol. 48, No. 4

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Stand for research of radio emission of a long electric spark

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Received November 3, 2021
Revised February 7, 2022
Accepted February 7, 2022.

On the created stand, in laboratory conditions, various phases of discharge development characteristic of lightning were simulated using an electric spark in a long air gap. With the help of special radio equipment, the radio emission of a long electric spark was investigated. It is found that at the stages of development of a spark discharge, radio emission is recorded in a long interval up to at least a frequency of 1.4 GHz. Data on radio emission in this range are of great practical importance for such areas as radio communication (during thunderstorm activity), radar, lightning direction finding.

Keywords: Long electric spark, lightning discharge, radio emission, streamer discharge, lead discharge, radio communication.

DOI: 10.21883/TPL.2022.04.53173.19070

Radio-frequency emission from thunderstorm clouds is an actual subject of the atmospheric electricity research because of its great practical importance for such fields as thunderstorm direction finding, radio location, radio communication, including microwave frequency communication. The RF emission of thunderstorm clouds has a long history of research in natural conditions. However, these research activities are very complicated technically, therefore still poorly understood are the mechanisms leading to the radio-frequency emission from the discharge processes in a thunderstorm cloud at both the stage of its initiation and development, and the stage of channel propagation of the lightning leader. In this context the laboratory experimental investigations of the RF emission of long electric spark as an equivalent of lightning discharge provide great opportunities.

The electric spark in a long air gap can be considered as a physical model of lightning discharge. A sufficiently long spark has development stages typical for the behavior of lightning in its initial phase (for the leader movement in the thunderstorm cloud−ground gap, when its streamer zone is still far from the ground, for the achievement of the grounded object by the streamer zone of the leader) and at the phase of return strike. In a similar way, radio-frequency emissions typical for lightning arise in a long electric spark. The sources of radio-frequency emission of a long spark (similar to lightning discharge) are streamers (the streamer zone of the leader) and the leader channel itself (at the phase of free leader development and achievement of a grounded electrode by its streamer zone), as well as the channel of spark discharge at the phase of return strike development.

In the experiments with lightning discharge simulation by spark discharge in a long air gap, all the described phases of the long spark should be clearly defined, i.e. parameters of the long spark should be in conformity with certain criteria. For this purpose, the interelectrode air gap should be sufficiently long and the voltage impulse applied to the gap from a high-voltage source should be of a certain waveform.

In [1,2] the RF emission from streamer discharges was experimentally investigated in megahertz and gigahertz bands for a streamer length of up to 20 cm. In [3–5] the RF emission of real thunderstorm clouds and lightning discharges was studied. In [6] it was found that from discharges in a charged aerosol structure (simulating a thunderstorm cell) a RF emission is generated with a frequency of up to 10 GHz.

The purpose of this work is to describe the created experimental stand that allows forming several-meter-long electric spark with discharge phases typical for the lightning leader, and the measurements performed to study its radio-frequency emission in mega- and giga-hertz bands.

In these experimental research activities a long electric spark was formed using a Marx-type high-voltage generator with on input voltage of up to 6 MV. This generator is included in a unique research setup [7] and located on an outdoor site surrounded by forest. The setup is designed for both research activities in the field of lightning and lightning protection physics and tests activities to determine electrical characteristics of insulation for high-voltage and ultra-high-voltage installations. The generator makes it possible to generate spark electric discharges with a length of up to 50 m simulating a lightning discharge. Measuring

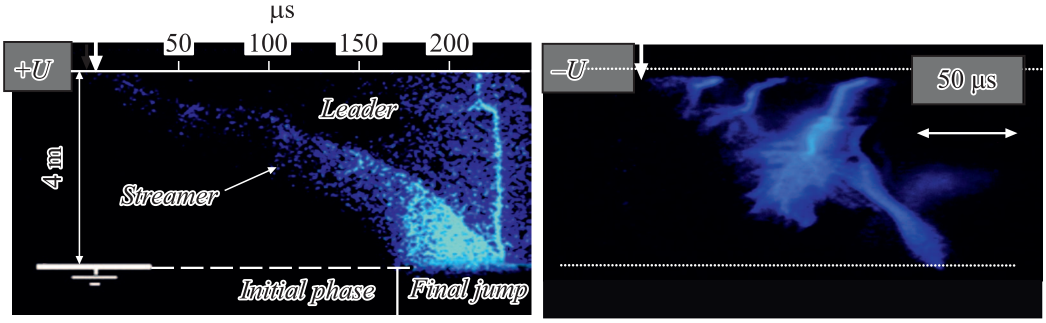

Figure 1. Optical scans of discharge development in time in the rod–plane spark gap with a length of 4 m. On the left — positive pole, on the right — negative pole of the voltage pulse.

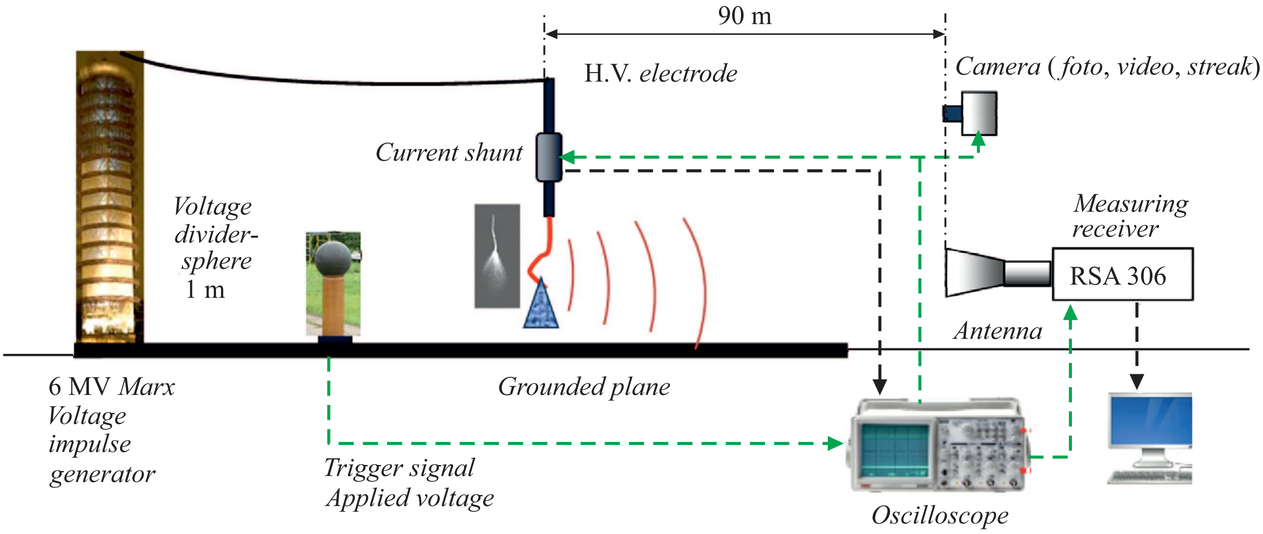

Figure 2. General diagram of test setup with measuring systems.

systems of the setup allows experimental investigations of spark discharge parameters and recording their RF emission in a band of up to 6 GHz. The Marx-type generator in the experiments had the following main technical parameters: output voltage up to 3 MV, stored energy up to 0.6 MJ, output capacitance 50 nF, impulse leading edge 100 μs, impulse length 7500 μs. The height of the generator structure was 45 m. The distance from the generator to the rod–plane discharge gap was 50 m.

Fig. 1 shows time scans of the optical pattern of the long spark development with positive (left image) and negative (right image) polarity recorded by FER-14 streak camera. Photoshots of streamer zone of the leader in the process of its development in the gap were recorded by 4 Picos fast camera with short exposure time. In the experiments, the length of the rod–plane discharge gap was 4–6 m, and a voltage impulse with positive or negative polarity was applied to the gap.

Fig. 2 shows diagrams of measuring systems used in experiments. Waveform of the impulse varied using a capacitive voltage divider (in the form of sphere with a diameter of 1 m installed at a distance of 50 m from the generator). Amplitude of the applied voltage was evaluated on the basis of the generator charge voltage and calibrated using known values from previously obtained discharge characteristics of the voltage impulses used (with given front edge and length of the impulse).

The discharge current on the high-voltage electrode (rod) was recorded using a low-inductance resistive shunt, an oscilloscope and an analog-to-digital converter, which signal was transmitted via a Wi-Fi channel to the recording equipment at the grounded plane. The recorded oscillograms of discharge current from the potential electrode were transmitted after the end of discharge, thus the required noise immunity was provided during measurements. To dynamically record the discharge trajectory and its parameters, optical diagnostic equipment was used (a digital photo camera, a 4 Picos fast camera, a FER 14 streak camera) being installed in a shielded cabin at a distance of 30 m from the discharge gap. To record the RF emission, a receiving (horn or whip) antenna was installed at a distance of 90 m from the discharge gap with a Tektronix RSA 306 measuring receiver (frequency band from 10 kHz to 6.2 GHz, channel bandwidth up to 40 MHz)

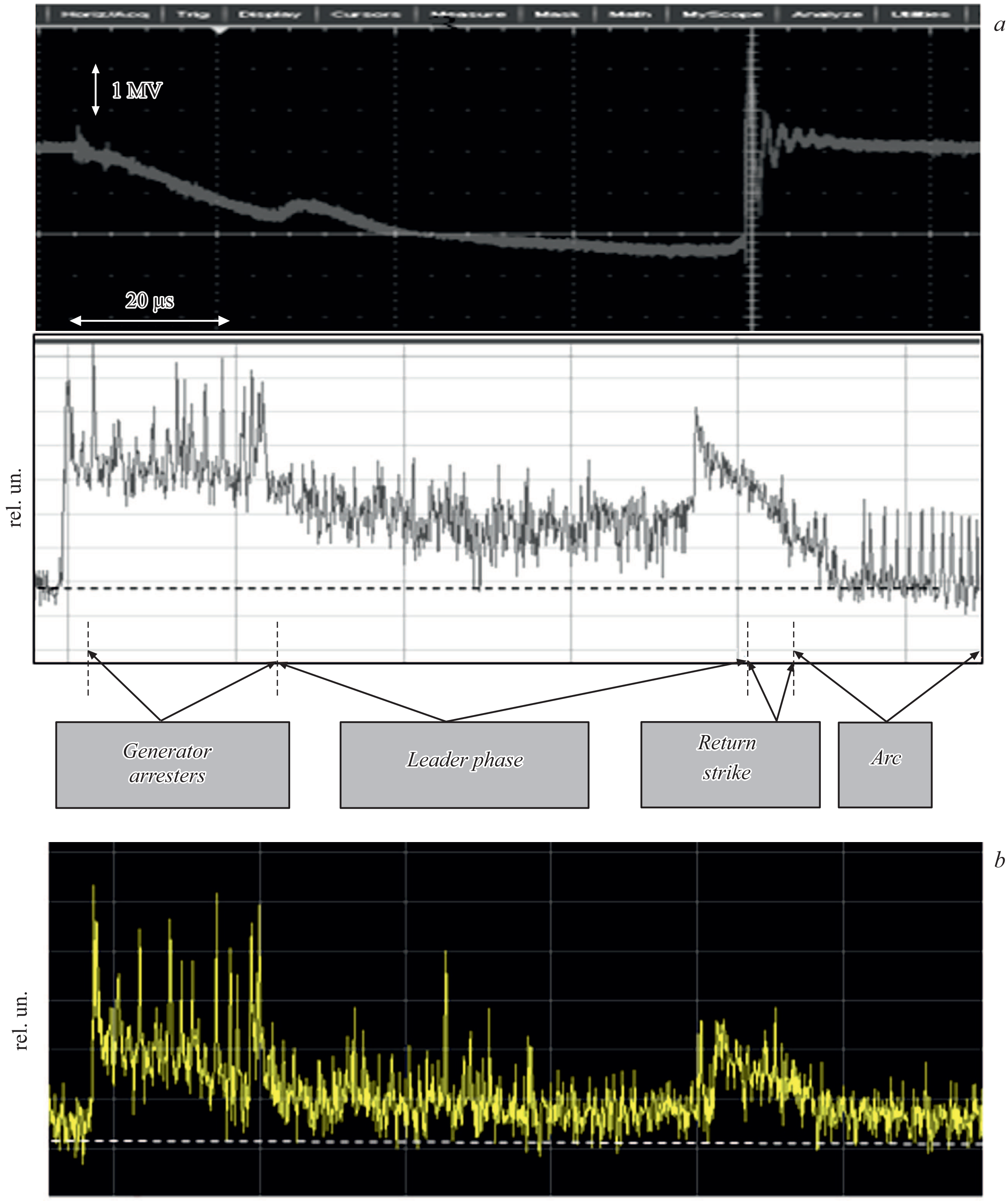

Figure 3. Oscillograms of the radio-frequency emission recorded by RSA 306 measuring receiver (bandwidth - 40 MHz) from a long negative spark in a rod–plane gap with a length of 6 m. *a* — synchronous measurements of RF emission at a frequency of 300 MHz. Top curve — voltage over the gap, bottom curve — oscillogram of the RF emission in various phases of the discharge. *b* — example of oscillogram record of RF emission of a discharge at a frequency of 1000 MHz. Division value of the time scale is 20 μs/div.

connected to the antenna. To perform measurements in the ultra-high-frequency band, a horn antenna of P6-23M type was used having uniform frequency response in the band from 850 MHz to 17.44 GHz. To record signals at lower frequency, a 1 m long rod antenna was used. The sufficiently large distance between the receiving antennas and the discharge gap (90 m) provided measurement to be carried out in the far-field zone. Signals from the measuring systems of current and voltage in the gap were supplied to the input of the Tektronix DPO 7104 storage oscilloscope with a bandwidth of 1 GHz. The measuring systems were synchronized using an impulse standard signal (TTL) generated by the Tektronix DPO 7104 digital oscilloscope. The oscilloscope itself was triggered by a signal from the voltage divider arising in case of actuation of high-voltage generator's arresters.

In the process of experiments several tens of measurements of RF emission were carried out for negative and positive polarity of the impulse voltage of the generator. A rod antenna was used for receiving in the megahertz band. RF emission at ultra-high frequencies was measured by a horn antenna. Fig. 3, *a* shows an example of the measured RF emission at a frequency of 300 MHz (channel bandwidth is 40 MHz) as a function of time for negative voltage polarity on the discharge gap. Fig. 3, *b* shows the record of RF emission at a frequency of 1000 MHz.

The performed experiments have shown that the top limit of the RF emission spectrum in the ultra-high-frequency band is at least 1.4 GHz. No any RF emission at higher frequencies was observed in the experiments, perhaps due to insufficient sensitivity of the measuring system. It was found that in this RF band the most strong emission is observed at the phases of discharge development when a strong streamer process is formed. With this measuring system it is difficult to determine the lower limit of the RF spectrum (below 10 MHz) of the discharge in the form of long spark because of band restrictions of the rod antenna. It should be noted, that in these experiments the role of current source in the spark was played by an impulse generator loaded by the discharge circuit — a loop with typical dimensions of 40×50 m. At frequencies of about 10 MHz and below, the electromagnetic field formed by transient processes and natural oscillations in a large-scale loop can not be considered independently from the emission field of the discharge gap itself, which length is not more than 10% of characteristic dimensions of the discharge loop.

The performed experimental study has shown that the created experimental stand with a Marx-type generator of long spark can be used to simulate processes resulting in the generation of radio-frequency emission of lightning at different phases of its development. It is shown experimentally that at some phases of long electric spark development a radio-frequency emission is generated in a band of at least up to 1.4 GHz. The obtained results match with both the published natural data on radio-frequency emission of lightning [4] and the theoretical calculations [3] and measured parameters of RF emission of long streamers [6].

Funding

The study was supported by a grant from the Russian Science Foundation (project № 19-19-00501).

Conflict of interest

The authors declare that they have no conflict of interest.

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