Spectral Characteristics of Discharge Phenomena in Artificial Thunderclouds

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ABSTRACT: Results of analysis of characteristics of discharge from artificial thundercloud and electromagnetic radiation created by them in near field are presented. Two kinds of wavelets ("Mexican Hat" and "Morle") have been used for experimental data processing. In such case signal has analyzed in frequency and time field simultaneously. For both wavelets, it was found that maximal intensities in spectral content of the discharge current and displacement current signals are observed during the period of current rise at the final stage of discharge from artificial thundercloud. Characteristic frequency range with maximal intensity for the discharge current was 1-4 MHz, and for the antenna signal – 5-22 MHz approximately. However, it was established that significant part of the wavelet spectrograms for electromagnetic radiation has shown separate range of frequencies of some hundreds MHz. Probably such high frequencies correspond to the discharge processes inside cloud and near its boundaries. It was established correlation between the discharge current parameters and the parameters of its electromagnetic radiation and wavelet characteristic frequencies. The last gives possibility to connect the spectral characteristics of electromagnetic radiation registered by antenna and the lightning current parameters.

INTRODUCTION

The significant part of information about the discharge phenomena in thunderclouds and about the lightning discharge has received by the distant methods. Lightning detection systems designed for lightning stroke place and lightning current parameters determination works on the base of registering of electromagnetic radiation of lightning discharge [Laroche, 2007; Rakov and Uman, 2003; Rakov and Rachidi, 2009; Rakov, 2013]. Registering of the electromagnetic radiation of atmospherics and lightning discharges has been carried out in a wide range of the frequencies [Rakov, 2013]. It is supposed the presence of relation between the characteristic frequencies of a measuring signal and the physical discharged processes being in the thundercloud and the lightning discharge [Rakov and Uman, 2003; Dong and Liu, 2012; Takayanagi et al., 2012].

One of the characteristic problems of lightning detection systems is separation of the intracloud discharges and the ground discharges. It is supposed that intracloud discharges have a spectrum with the higher frequencies. Moreover, it is supposed that development of discharges inside thunderclouds is similar to discharge development in the long air gaps. However, question about threshold frequency value has not been solved nowadays. That could leads to significant errors in determination of the lightning

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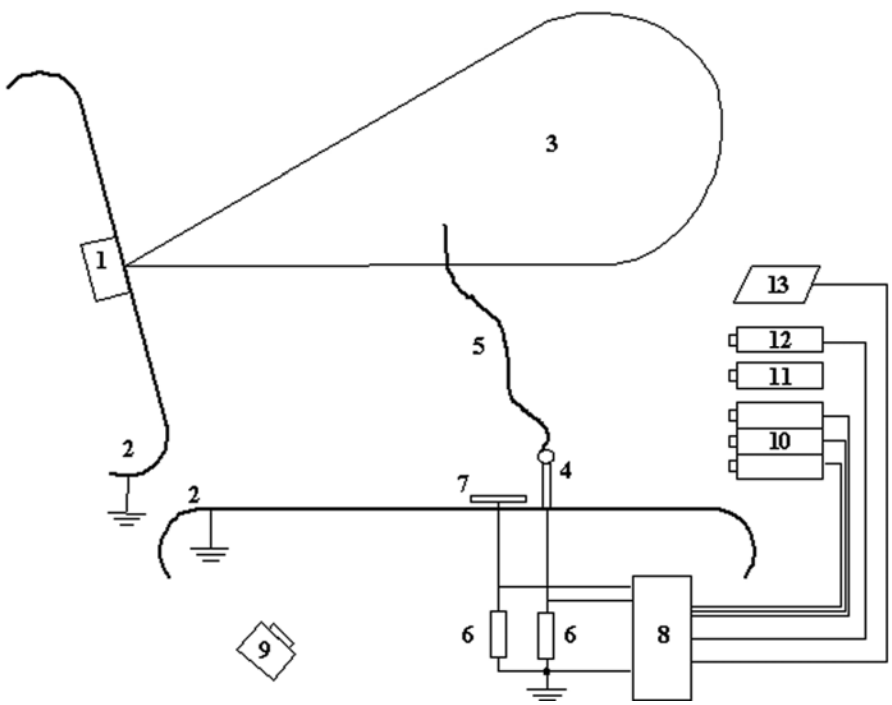
stroke place and its parameters [Rakov and Uman, 2003; Rakov and Rachidi, 2009; Rakov, 2013]. Probably, that is connected with a difference in the processes of discharge development in the thundercloud taking into account its microstructure and in the clear air near the ground [Yoshida et al., 2012; Temnikov, 2012; Babaeva and Kushner, 2009]. Establishment of connections between the parameters and the spectral characteristics of discharge current impulses and its electromagnetic radiation is actual problem too. Using of artificial thunderclouds (specially created clouds of charged water aerosol) capable to initiate discharges inside clouds and between cloud and ground could help on the solving of problem of separation of the lightning intracloud and ground discharges, and establishment of connections between the parameters and the spectral characteristics of discharge current impulses and its electromagnetic radiation.

EXPERIMENTAL COMPEX AND EXPRIMENTAL RESULTS

Experimental complex is designed for an investigation of the fundamental and practical problems of physics of lightning and lightning protection of the grounded objects and aircrafts [Temnikov, 2012]. It allows the creation as the charged aerosol cloud of negative or positive polarity as the system with two charged aerosol clouds of the same or different polarity. One cloud of negative polarity with potential of 1.5 MV has been used in experimental investigation of spectral characteristics of discharges. Scheme of experimental and measurement setup is shown in fig. 1.



1 – charged aerosol generator, 2 – grounded electrostatic screens, 3 – cloud of charged water aerosol, 4 – rod electrode, 5 – spark discharge, 6 – shunts, 7, 14 – plate antenna, 8 – digital oscillscopes, 9 – digital photo camera, 10 – system of photomultiplyers, 11 – CCD-camera, 12 – scintillation sensor, 13 – loop antenna

Fig. 1. Scheme of experimental and measurement setup

Current of discharge between the cloud of charged water aerosol and the grounded rod electrode has been registered simultaneously with its optical, electromagnetic and gamma radiation. Only the experimental results relating to electromagnetic radiation from the discharge phenomena are discussed in this paper.

Electromagnetic radiation of the discharge phenomena has been registered by the plate and loop antennas. One of the plate antennas (antenna 1) was situated on the ground level directly near the place of the cloud to ground discharge formation. Other plate antenna (antenna 2) was situated at the distance of some meters from the cloud at the level of the bottom boundary of the charged cloud. Loop antenna (antenna 3) has been situated near it. Different stages of the discharge development from the streamer corona flash to the final stage have been investigated.

For example, picture of a spark discharge between the charged cloud of water aerosol and the ground, characteristic oscillograms of an impulse current of the final stage of discharge between the charged aerosol cloud and the grounded rod electrode beneath it and of the corresponding electromagnetic radiation registered by the plate and loop antennas situated close to a discharge channel are shown in fig. 2 and fig. 3, correspondingly.

During carried out experimental investigations about three hundreds experimental shots where the discharge current between charged aerosol cloud and ground and corresponding radiation have been registered have been received and processed.

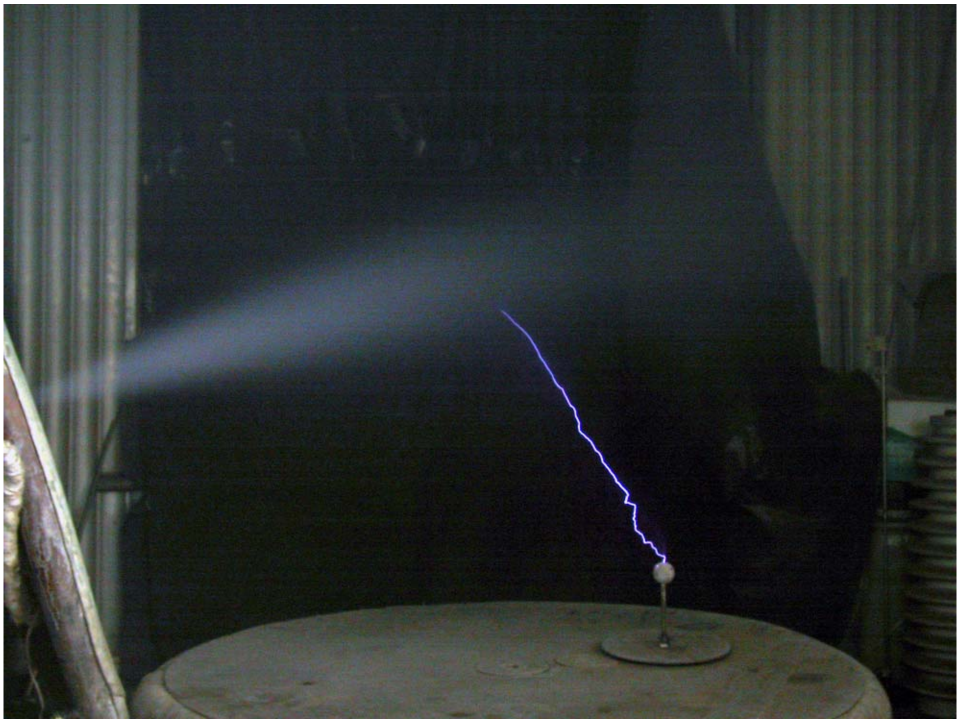


Fig. 2. Spark discharge between the artificial cloud of negatively charged water aerosol and the ground

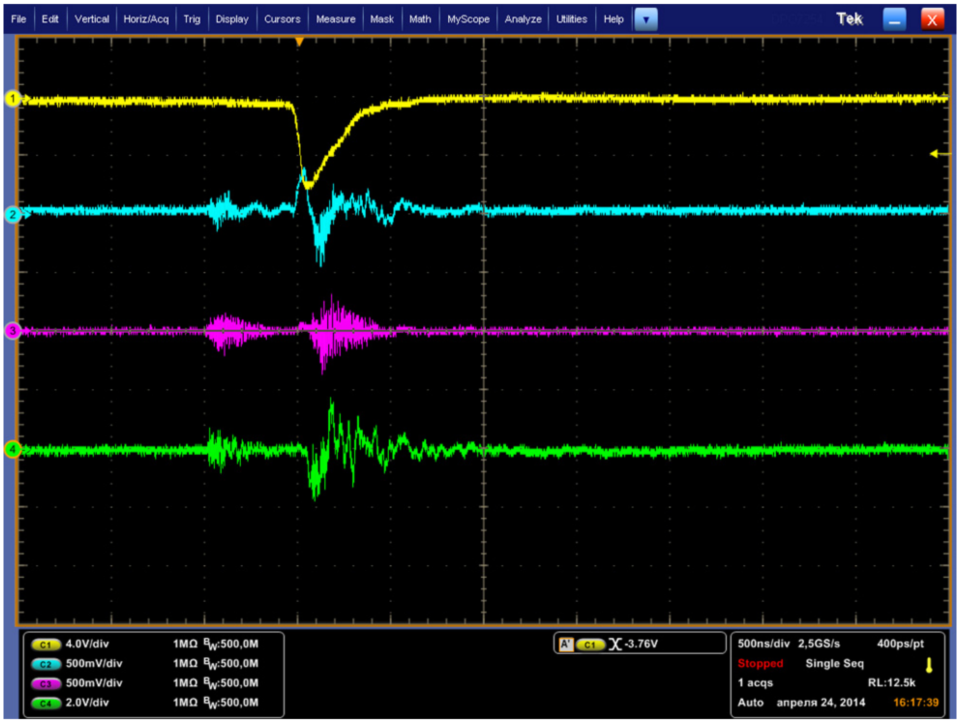


Fig. 3. Oscillograms of the discharge current (curve 1, shunt 0.5 Ohm), the signal registered by the plate antennas (curve 2 – antenna 1; curve 3 – antenna 2), and by the loop antenna (curve 4)

SPECTRAL CHARACTERISTICS OF DISCHARGE PHENOMENA IN ARTIFICIAL THUNDERCLOUD

Fourier and wavelet analysis has been applied for investigation of the spectral characteristics of the discharge current and its electromagnetic radiation. Two kinds of wavelets (“Mexican Hat” and “Morle”) have been used for experimental data processing and analyzing signal in frequency and time field simultaneously. Such types of wavelet probably should be optimal for the analysis of the discharge current and atmospherics signals [Sharma et al., 2011].

Characteristic wavelet spectrums (for example, for the wavelet “Mexican Hat”) of the current impulse and signals registered by the plate and loop antennas during a final stage of discharge between the cloud and the ground are shown in fig. 4-7. On the base of the experimental data processing it was established that wavelet spectrum “Mexican Hat” has shown more high frequencies as for discharge current as its radiation on the plane antenna than wavelet “Morle”. Analysis of spectral characteristics has shown that wavelet “Mexican Hat” is much more fit to the current impulse spectral analysis than wavelet “Morle”. For spectral analysis of signals registered by antennas, both types of the pointed wavelets could be used.

It was found that the ranges of the characteristic frequencies of discharge current depend on a stage of a discharge formation between the charged aerosol cloud and the ground. Upper level of the characteristic frequency range is for impulse streamer corona current from 0.2 MHz (“weak” flash) to 3.0 MHz (“strong” flash), 0.03-0.2 MHz for upward leader current, and 98 MHz (“Mexican Hat”) or 46 MHz (“Morle”) for final stage of discharge. Maximal intensity in the frequency field for final stage is observed in the range of 1-4 MHz.

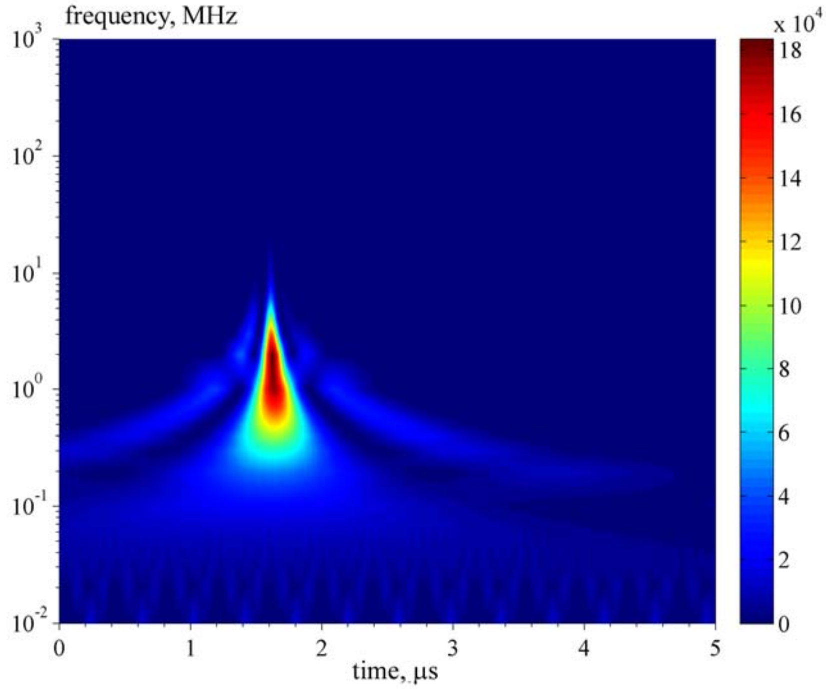


Fig. 4. Wavelet spectrum of the current impulse for the final stage of discharge between the charged aerosol cloud and the grounded rod electrode (wavelet "Mexican Hat")

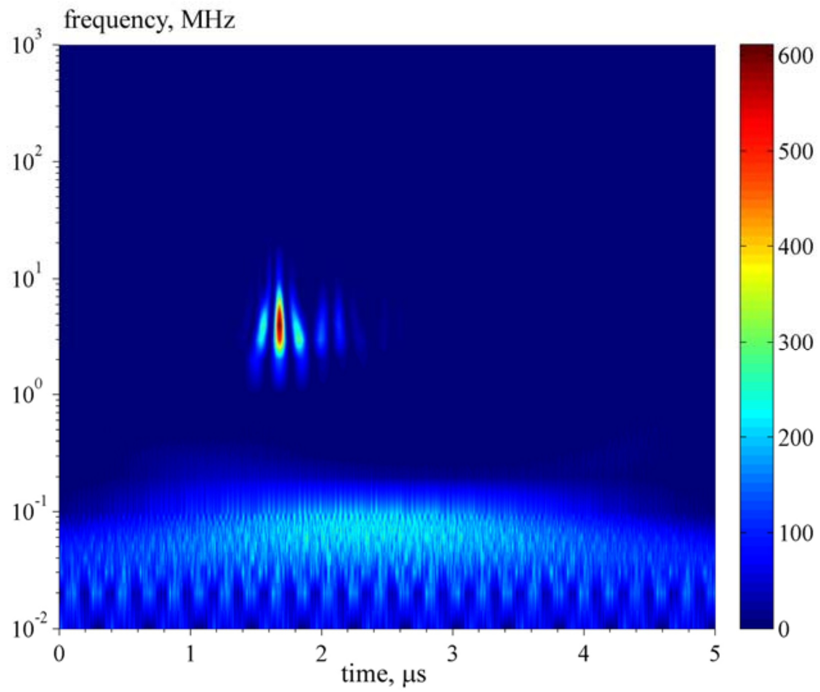


Fig. 5. Wavelet spectrum of the signal registered by the plate antenna (antenna 1) for the final stage of discharge between the charged aerosol cloud and the grounded rod electrode (wavelet "Mexican Hat")

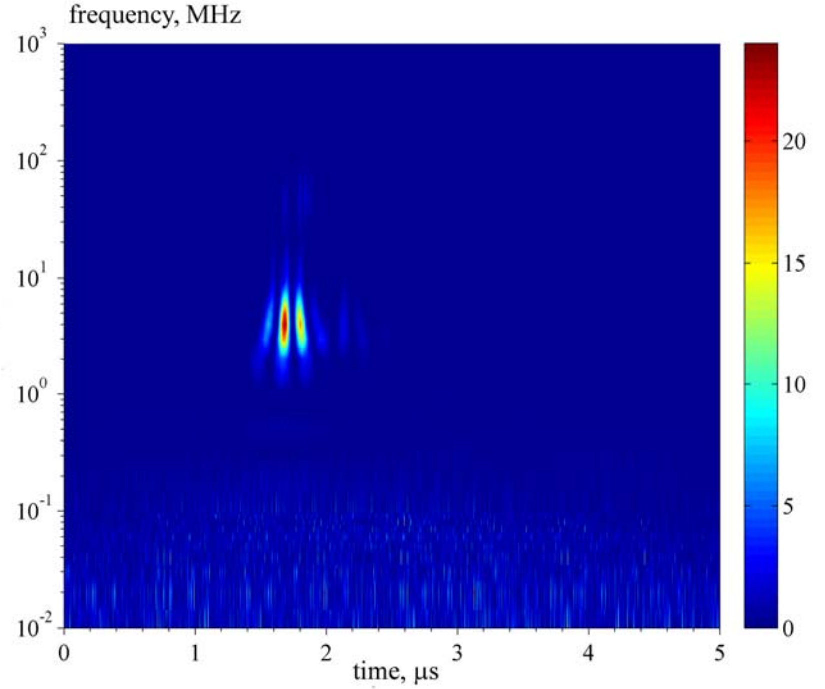


Fig. 6. Wavelet spectrum of the signal registered by the plate antenna (antenna 2) for the final stage of discharge between the charged aerosol cloud and the grounded rod electrode (wavelet "Mexican Hat")

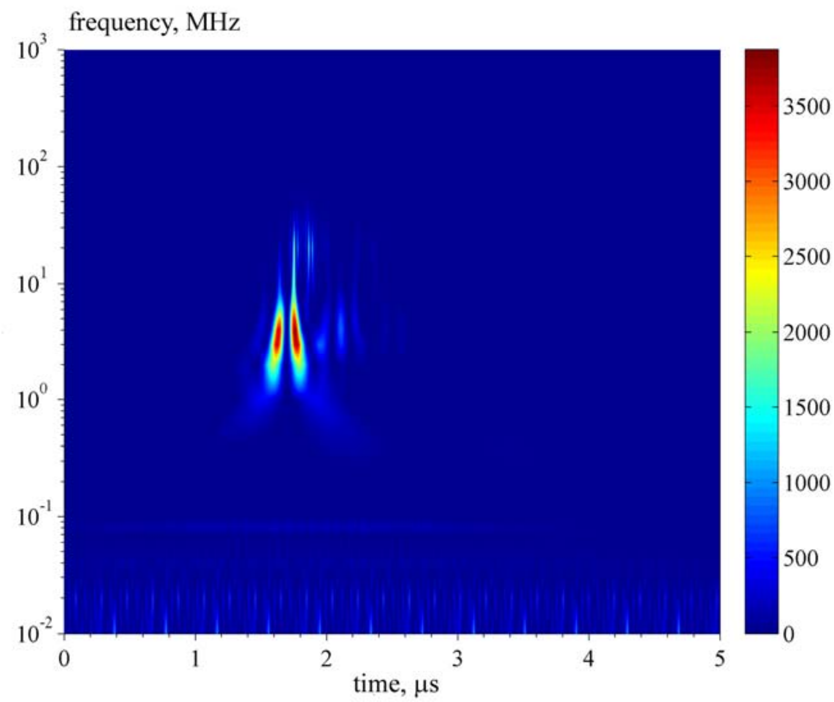


Fig. 7. Wavelet spectrum of the signal registered by the loop antenna (antenna 3) for the final stage of discharge between the charged aerosol cloud and the grounded rod electrode (wavelet "Mexican Hat")

Upper level in wavelet spectrum for electromagnetic radiation of discharge registered with the antennas is 11 MHz for streamer corona flash, 0.02-0.04 MHz for upward leader. For final stage of discharge from the artificial cloud of charged water aerosol it was found that there are one or two characteristic frequency ranges in the wavelet spectrum of the signals registered with the antennas. First characteristic frequency range is obviously in all signals and have the upper level up to 80 MHz (wavelet “Mexican Hat”) or 50 MHz (wavelet “Morle”). Maximal intensity in wavelet spectrum in this range is observed on the frequencies from 5 MHz to 22 MHz. Upper level of the second characteristic range is approximately 250-450 MHz (for plate antennas) or 120-300 MHz (for loop antenna). For both wavelets, it was found that maximal intensities in spectral content of the discharge current and displacement current signals are observed during the period of current rise at the final stage of discharge from artificial thundercloud.

As a result of processing of the received experimental data, presence of the dependences between the characteristics of the discharge from artificial cloud of charged water aerosol and their corresponding spectral characteristics were established. In particular, correlation between the discharge current parameters and the parameters of its electromagnetic radiation and wavelet characteristic frequencies has been found. Among them, it is necessary to point the following dependences (fig. 8-10).

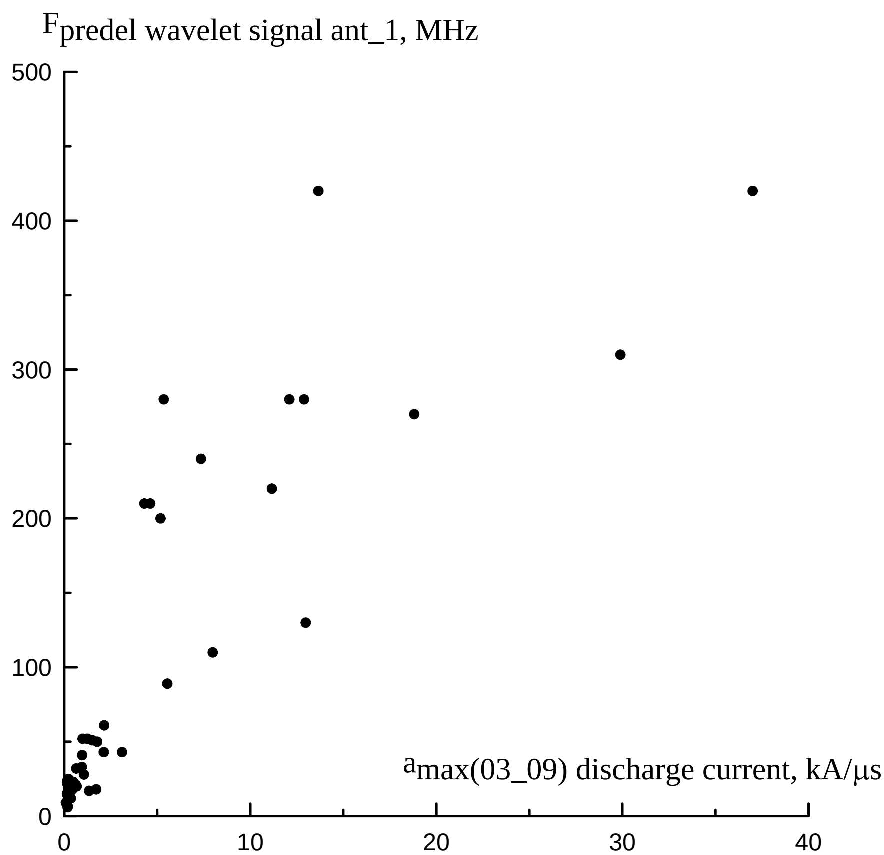


Fig. 8. Dependence of the upper frequency in wavelet spectrum of signal registered by plate antenna 1 from the maximal current rise velocity for main stage of discharge

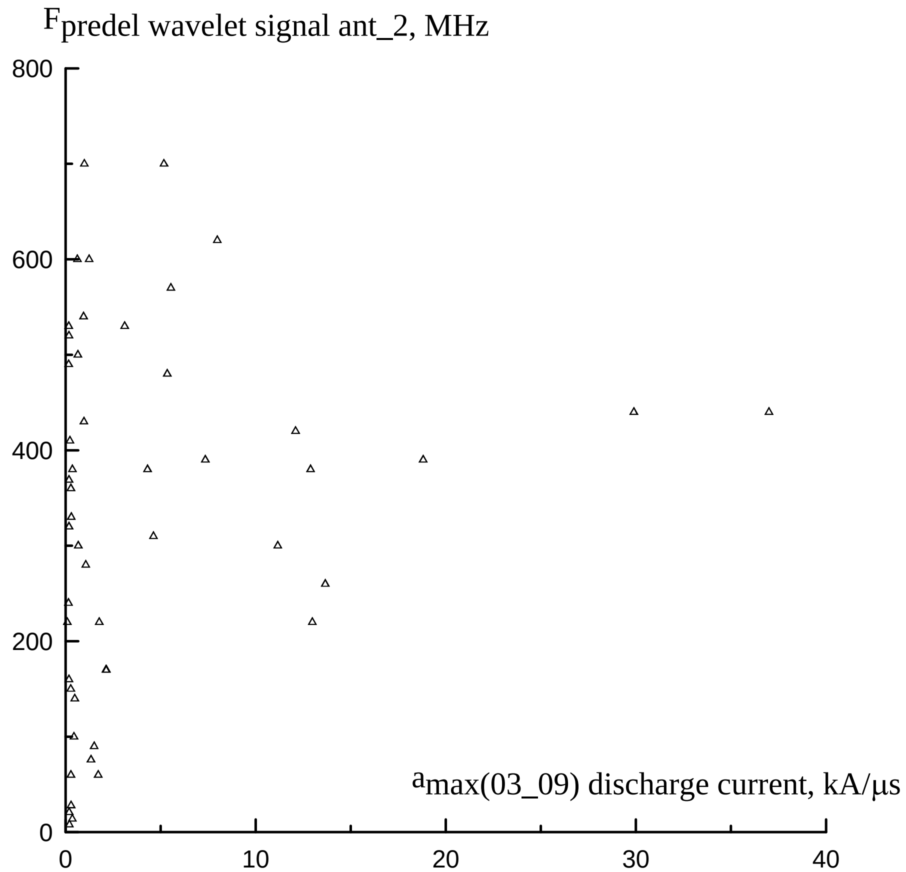


Fig. 9. Dependence of the upper frequency in wavelet spectrum of signal registered by plate antenna 2 from the maximal current rise velocity for main stage of discharge

For plate antenna (antenna 1) situated on the ground immediately near the place of cloud to ground discharge formation, clear correlation the upper frequency in the wavelet spectrum of signal registered by the plate antenna from the maximal current rise velocity for main stage of discharge has been established (fig. 8).

Such clear dependence for other plate antenna (antenna 2) situated laterally at the cloud level has not been found (fig. 9). As we can see, in the wavelet spectrum of the signal registered by the plate antenna 2 there are many cases with very high upper frequency level in comparison to the wavelet spectrum for plate antenna 1.

Probably, that is connected with the discharge processes near the charged aerosol cloud boundaries. For example, it could be the development of powerful streamer discharges from the final stage channel near the cloud boundaries (fig. 11) or the formation of the cloud discharge channels that practically have only weak contact with an upward discharge (fig. 12). The lasts could give the significant contribution to the signal registered by this plate antenna.

For loop antenna (antenna 3), in difference of plate antennas clear correlation the upper frequency in the wavelet spectrum of signal registered by the loop antenna from the amplitude of current impulse for main stage of discharge has been established (fig. 10).

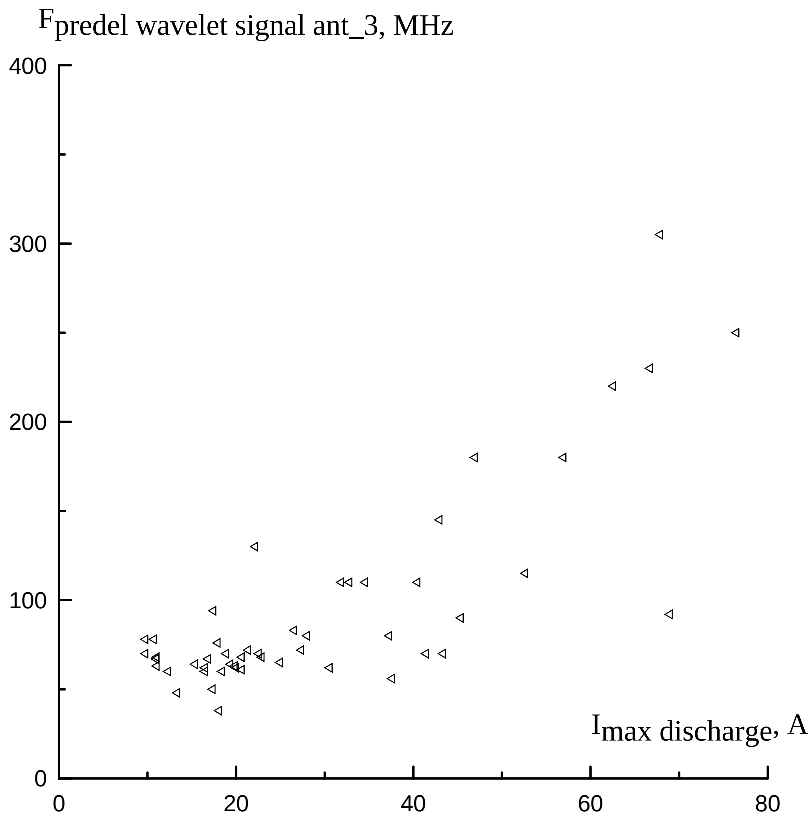


Fig. 10. Dependence of the upper frequency in wavelet spectrum of signal registered by loop antenna 3 from the amplitude of current impulse for main stage of discharge

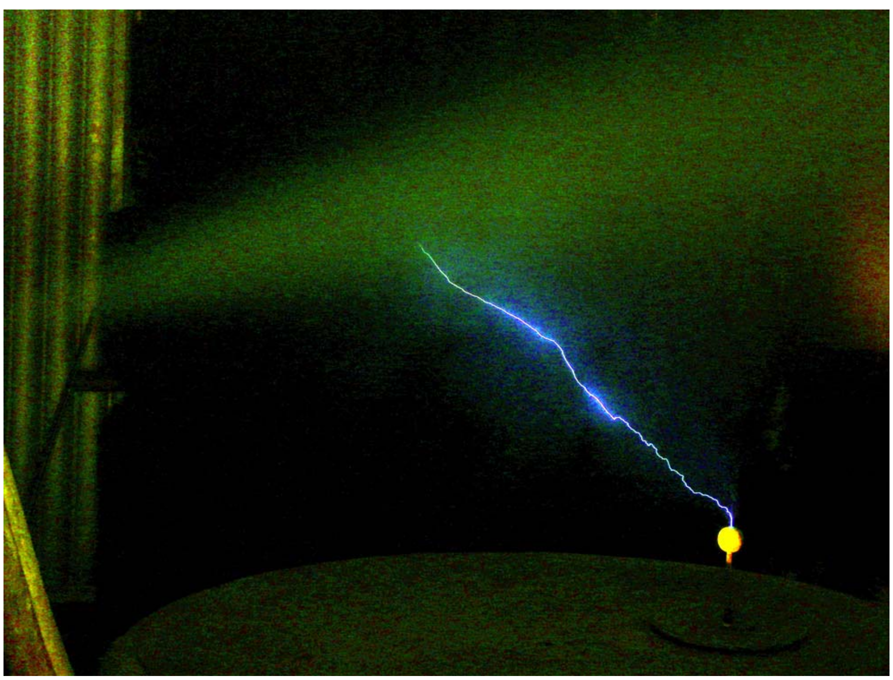


Fig. 11. Formation of powerful radial streamer corona from the final stage channel

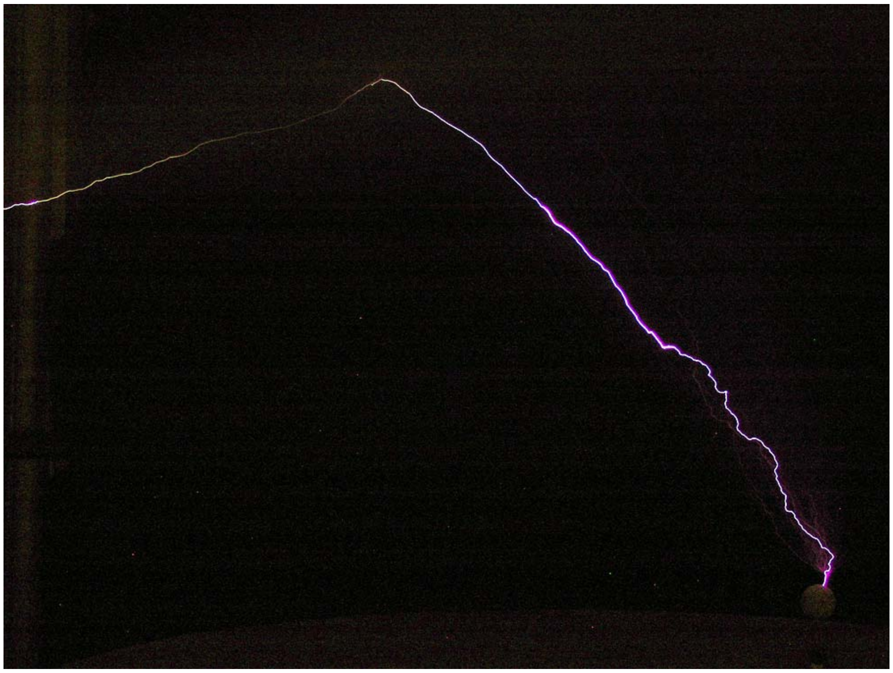


Fig. 12. Formation of cloud part of discharge

Also clear dependence between maximal intensity in wavelet spectrum (for both wavelets) of the signal registered by the antennas and the impulse current amplitude has been found.

CONCLUSIONS

Wavelet analysis of characteristics of discharge from artificial thundercloud and electromagnetic radiation created has shown that maximal intensities in spectral content of the discharge current and displacement current signals are observed during the period of current rise at the final stage of discharge from artificial thundercloud. Characteristic frequency range with maximal intensity for the discharge current was 1-4 MHz, and for the antenna signal – 5-22 MHz approximately. However, it was established that significant part of the wavelet spectrograms for electromagnetic radiation has shown separate range of frequencies of some hundreds MHz.

These frequencies were much more high than the characteristic frequencies determined on the base of a wavelet analysis of the electric field strength signal registering in the place which was situated in the distance of tens kilometers from the lightning discharge [Sharma et al., 2011]. As it is mentioned above, such high frequencies in wavelet spectrum for signals registered with the antennas for final stage of discharge in the artificial thundercloud could be connected with powerful streamer corona from the upper parts of the final stage channel and with formation of the cloud discharge channels. Antennas were situated relatively close to the place of discharge formation in the artificial thundercloud. So, more high frequencies probably exhibited in the wavelet spectrum in comparison with the results of [Sharma et al., 2011]. That correlates with results [Maslowski et al., 2007] where it has been shown that the frequencies up to 50 MHz could be in the signal registered from cloud discharges.

Dependences between the parameters of the impulse current of final stage of discharge from the artificial thundercloud (current amplitude, maximal velocity of current rise, role of cloud part of discharge and processes of interaction of the final stage channel and the charged cloud boundary region) and characteristic frequencies in the wavelet spectrum in the corresponding signal registered with the antennas of different types probably could help to connect the spectral characteristics of electromagnetic radiation registered by antenna and the lightning current parameters.

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