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Research paper

X-rays and microwave RF power from high voltage laboratory sparks

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ABSTRACT

Lightning flashes involve high energy processes that still are not well understood. In the laboratory, high voltage pulses are used to produce long sparks in open air allowing the production of energetic radiation. In this paper X-rays emitted by long sparks in air are simultaneously measured with the RF power radiation at 2.4 GHz. The experiment showed that the measured RF power systematically peaks at the time of the X-rays generation (in the microsecond time scale). All of the triggered sparks present peaks of RF radiation before the breakdown of the gap. The RF peaks are related to the applied voltage to the gap. RF peaks are also detected in discharges without breakdown. Cases where X-rays are detected presented higher RF power. The results indicate that at some stage of the discharge, before the breakdown, electrons are very fast accelerated letting in some cases to produce X-rays. Microwave radiation and X-rays may come from the same process.

1. Introduction

Productions of X-rays from electrical discharges at atmospheric pressure have been studied for a long time (e.g. Stankevich and Kalinin, 1967). The recent discoveries of the Terrestrial Gamma ray Flashes (TGF) by Fishman et al. (1994) and the high-energy emissions produced by lightning (Moore et al., 2001) promoted the interest of the atmospheric electricity community in the high energy emissions produced by laboratory discharges at air (e.g. Dwyer et al., 2005; Nguyen et al., 2008; Rahman et al., 2008; March and Montanyà, 2010, 2011; Kochkin et al., 2012). One of the interests in high voltage experiments is to understand the mechanisms of the production of energetic radiation that occurs in lightning and may probably share similar properties than the intense TGF to space. Results from laboratory experiments showed the importance of the overvoltage attained in the inter-electrode gap in order to produce X-rays (e.g. Babich and Loiko, 2010 and related references therein). In that way, March and Montanyà (2010) showed how a fast voltage growth lets to higher probability of X-ray production and with higher energies. In addition, the asymmetry between streamer/leader polarities related to the energetic production was studied by March and Montanyà (2011).

Radio Frequency (RF) radiation from lightning at frequencies higher than 500 MHz were first recorded by Takagi and Takeuti (1963) and later by Brook and Kitagawa (1964). They found that most of the RF radiation was associated with stepped leaders, dart leaders and k-changes (recoil leaders). Later, Kosarev et al. (1970) suggested that the radiation at decimetric wave range is different from the dipole emission from the lightning currents. Rust et al. (1979), by measuring at 2.2 GHz, found bursts of radiation during the preliminary breakdown, in conjunction with the initial return stroke and during dart leaders of subsequent strokes. Recently Petersen and Beasley (2013a and 2013b) presented radiation at 1.57 GHz from negative stepped leaders.

Bekefi and Brown (1961) studied bremsstrahlung radiation produced by accelerating electrons. When an electron makes a transition between two continuous states with initial and final energies of $mv_i^2/2$ and $mv_f^2/2$ respectively, it radiates and emits a quantum of $\hbar\omega$. Due to the transitions between continuous states the radiation forms a continuum. Later, Rai et al. (1972) based on the previous reference of Bekefi and Brown (1961), found that the bremsstrahlung process is a possible source of RF emissions in UHF and microwaves measured during some lightning processes. The authors demonstrated how the full ionized plasma in the return stroke does not radiate microwave power since its absorption coefficient lets to an optical thickness much greater than the unity. On the other hand, the partially ionized plasma in the stepped leader, dart leader and k-changes (recoil leader) does emit microwaves. In such cases the estimated optical thickness is lower than the unity due to the negligible absorption. Microwave radiation can be basically due to electron–atom encounters. Bondiou et al. (1987) studied the V-UHF RF emission of laboratory discharges and proposed a model. The impulsive RF radiation was

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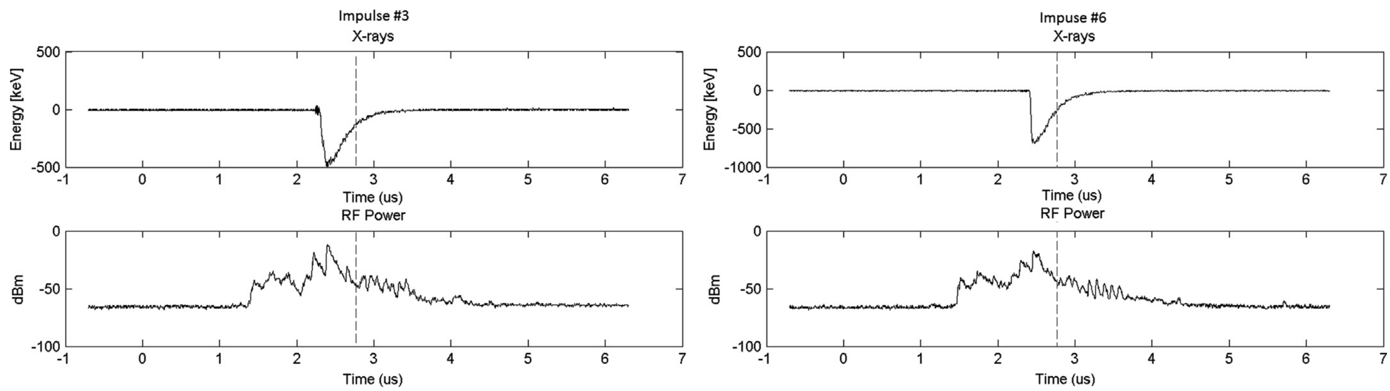

Fig. 1. X-rays and RF power at ~2.4 GHz for two negative voltage impulses. Left plot corresponds to a voltage impulse of −775 kV whereas the right most plot to −786 kV. Vertical dashed line indicates the breakdown time.

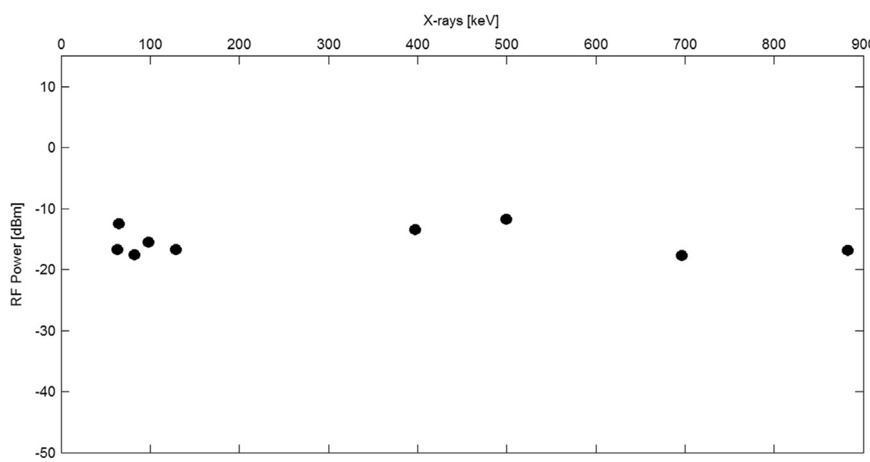

Fig. 2. Energy of the detected X-rays versus RF power.

associated with the processes during the formation of the transient arc and could be similar to the produced by lightning. The called transient arc phase in the breakdown takes place between the streamer phase and the development of the conductive channel with duration between 5 and 10 ns. Recently, Cooray and Cooray (2012) calculated the radiation of electron avalanches showing that can radiate in the microwave region.

In this paper, we present simultaneous measurements of X-rays and microwave RF power emissions at 2.4 GHz from high voltage sparks. The simultaneous occurrence of the X-rays and the absolute RF peaks are presented and discussed. The emission of microwave RF is studied for negative and positive discharges with different gap voltage. A discussion of the obtained results and the possible mechanism is addressed.

2. Experimental setup

The geometries studied in this paper corresponds vertical rod–rod and rod–plate setups. In both cases, the lower electrode was grounded whereas the rod on top was connected to the output of a 1.2 MV Marx generator. The rod was round terminated with a diameter of 16 mm and made from stainless-steel. The gap varied from 60 cm to 1 m. The adjusted waveform presented and average rise time of 0.55 μs. The instruments where placed within an EMI shielded cabined. The measurement cabinet was placed

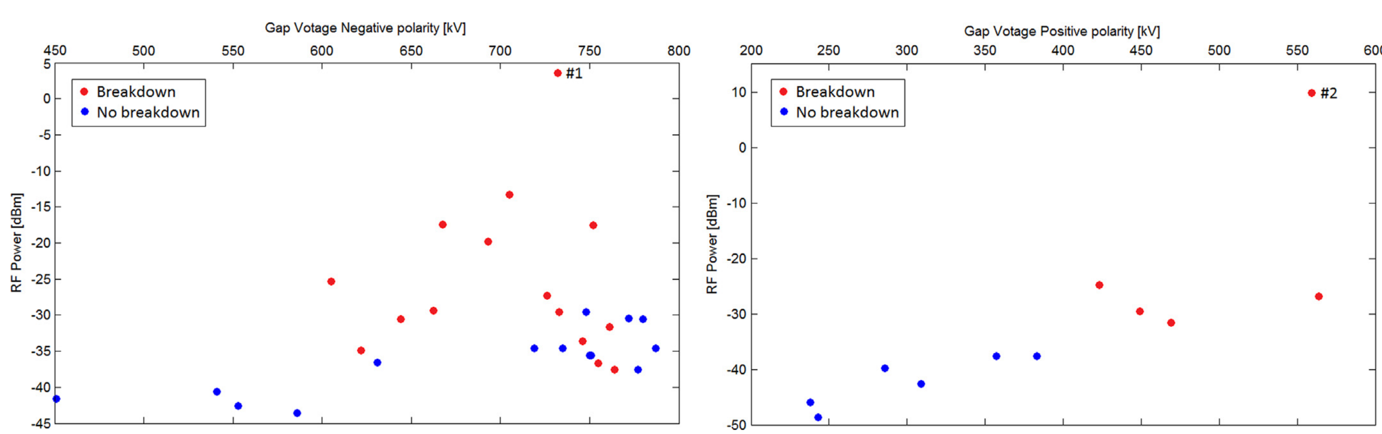

Fig. 3. Peak voltage applied to the gap versus RF power at ~2.4 GHz for positive and negative impulses.