Constraint on Discharge Current Parameters and Streamer Speeds of Venusian Lightning. V. R. D. Kumar[1], J. P. Pabari[2], K. Acharyya[2], S. Jitarwal[2], S. Nambiar[2], Rashmi[2] and T. Upadhyaya [1]BITS, Hyderabad-500078, INDIA (f20140771h@alumni.bits-pilani.ac.in), [2]Physical Research Laboratory, Ahmedabad, INDIA, [3]CHARUSAT, Changa, INDIA.

Introduction: Lightning is an energetic phenomenon that emits electromagnetic radiation along with optical emissions. To initiate a lightning event, we require electric fields on the order of the planetary atmosphere's breakdown field. Electric fields of such order are usually generated by charged cloud particles, which acquire charge via triboelectrification [1,2]. Free seed electrons are present in the planetary atmosphere because of the interaction of cosmic rays with the gas molecules in the planetary atmosphere [3]. These seed electrons are accelerated by the large electrical fields produced by charged cloud particles and gain sufficient energy to ionize the gas molecules of the planetary atmosphere. The secondary electrons produced by ionization are further accelerated, start an electron avalanche and form the lightning discharge channels. The lightning sensing instruments observe the radiation emitted by the accelerating electrons and photons emitted from ionization within the discharge channels.

Though the detection of Venusian lightning in the optical domain remains elusive [4], both Venus Express and Pioneer Venus Orbiter made measurements of low-frequency whistler waves of atmospheric origin [5]. The flow of electrons within the discharge channels constitutes electric current and efforts have been made to model these electric currents within the discharge channel [6,7]. Using the electric currents within the discharge channels, it is possible to model the expected time domain and frequency domain characteristics of electric fields generated by lightning [8]. In this work, we constrain the possible limits of peak frequency using streamer speed and use the peak frequency limit to find the plausible range of discharge current parameters.

Method: The electric currents within the lightning discharge channels can be modeled as a biexponential current of the form [6,7]

$$I = I_0(e^{-t/\tau_1} - e^{-t/\tau_2}) \quad (1)$$

where I_0 is the maximum amplitude of the discharge current, τ_1 is the duration of the current waveform and τ_2 is the rise time of the current waveform. The radiation from the discharge channels can be described in terms of Charge Moment (M_q), Current Moment (M_c) and Radiation Moment (M_r). The Current Moment is given by [8]

$$M_c = L_0 I_0(e^{-t/\tau_1} - e^{-t/\tau_2})(1 - e^{-v_0 t/L_0}) \quad (2)$$

where L_0 is the length of the lightning channel and v_0 is the speed of streamers. The Charge Moment and Radiation Moment are simply the integration and differentiation of Current Moment with time, respectively ($M_q = \int M_c\, dt$, $M_r = dM_c/dt$). The electric field observed at a distance 'd' is given by [8]

$$E(t) = \frac{1}{2\pi\varepsilon_0}\left(\frac{M_q(t)}{2d^3} + \frac{M_c(t)}{cd^2} + \frac{M_r(t)}{c^2 d}\right) \quad (3)$$

Fourier transformation of the time domain electric field signal will provide us information on the spectral characteristics of the lightning.

Streamer Speed Calculations. The steady-state concentration of equilibrium plasma at the streamer tip is solved and a reliable estimate of the expected order of streamer speeds (v_s) can be determined using the following relation determined after rigorous treatment of one-dimensional fast ionization wave equation consistent with the streamer physical model [9]

$$v_s = \frac{\nu_{im}(E) r_m}{(2k-1)\ln(n_m/n_0)} \quad (4)$$

where E is the electric field at the tip of the streamer, $\nu_{im}(E)$ is the ionization frequency in the medium streamer is generated and it is a function of the electric field at the streamer tip ($\nu_{im}(E) \propto E^k$), r_m is the radius of the propagating streamer, n_m is the electron density in the wavefront at the point of maximum field and n_0 is the initial seed electron density, which started the ionization wave. Ionization frequency (ν_{im}) can be approximated as the product of electron ionization coefficient (α) and drift velocity (v_d) of electrons if the effects of diffusion are negligible [9,10]. The electric field at the streamer tip is typically about ten times the planetary atmosphere's breakdown field [11].

Results: The electric current waveform expected in a thunderstorm's discharge channels and the resultant spectral characteristics of the emitted electric field signal is shown in Figures 1 and 2. The position of peak frequency is primarily dependent on the τ_1 and τ_2. There is only a small decrease in peak frequency due to an increase in the total length of the discharge channel. The expected streamer speeds in Venus middle clouds are on the order of 10^6 m/s when the electric field at the streamer tip is about ten times the breakdown field. If the field at the streamer tip is higher, then the streamer speeds can reach speeds as high as 10^8 m/s. For these streamer speeds, the expected peak frequency of the

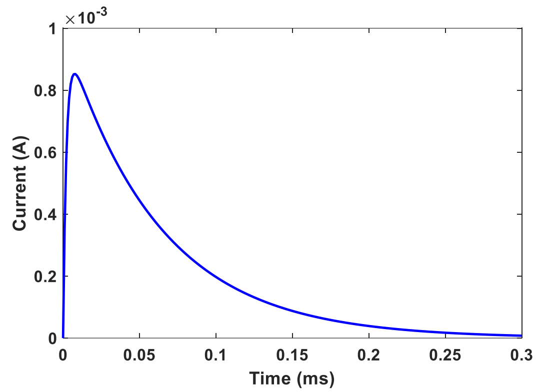

Figure 1: Current waveform with normalized current amplitude (I_0 = 1), τ_1 = 60 μs and τ_2 = 20 μs.

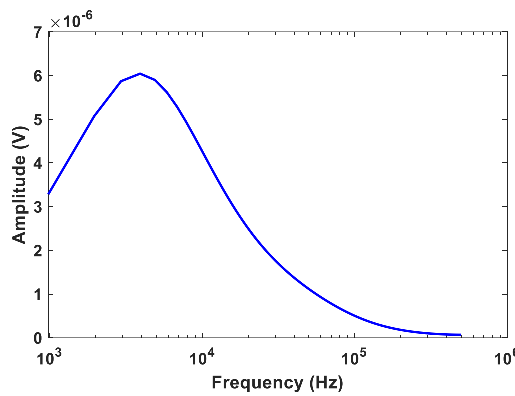

Figure 2: Lightning Frequency Spectrum due to biexponential current waveform in Fig 1.

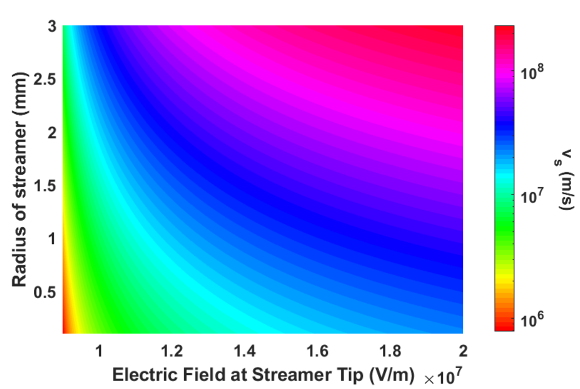

Figure 3: Streamer speeds expected in Venus middle clouds. Typically, the electric field at the tip of a self-sustaining streamer is ten times the breakdown field [11] (E_{br} ~ 10^6 V/m in Venus middle clouds)

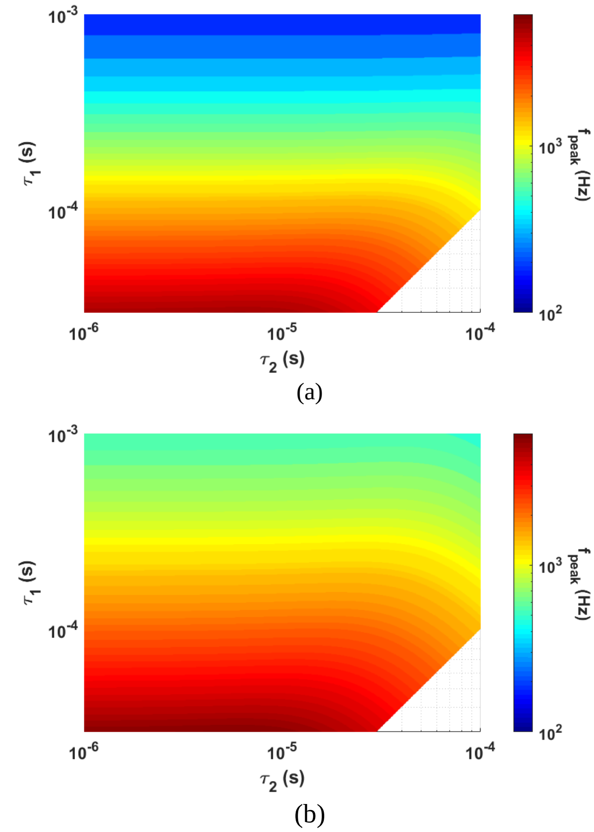

Figure 4: Variation of peak frequency with current parameters and streamer speeds: (a) 10^6 m/s and (b) 10^8 m/s. In both cases, discharge channel length is 10 km

lightning spectrum is between 1 kHz and 11 kHz [12,13]. Using a normalized current amplitude and a given streamer speed, we calculate the expected peak frequency for different electric current rise time and total duration combinations. With increasing streamer speeds, the peak frequency increases. For the expected streamer speeds in Venus middle clouds and peak frequency constraints, τ_1 is about 30 to 100 μs and τ_2 is about 1 to 30 μs.

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