Simulation of Transionospheric Pulse Pairs

Kalpana Singh [(1)], and R. P. Singh [(2)]
[(1)]Department of Physics, Banaras Hindu University, Varanasi-221 005, India. kalpanasingh@myself.com
[(2)] As (1) above, but Email: singrp_03@yahoo.co.in

ABSTRACT

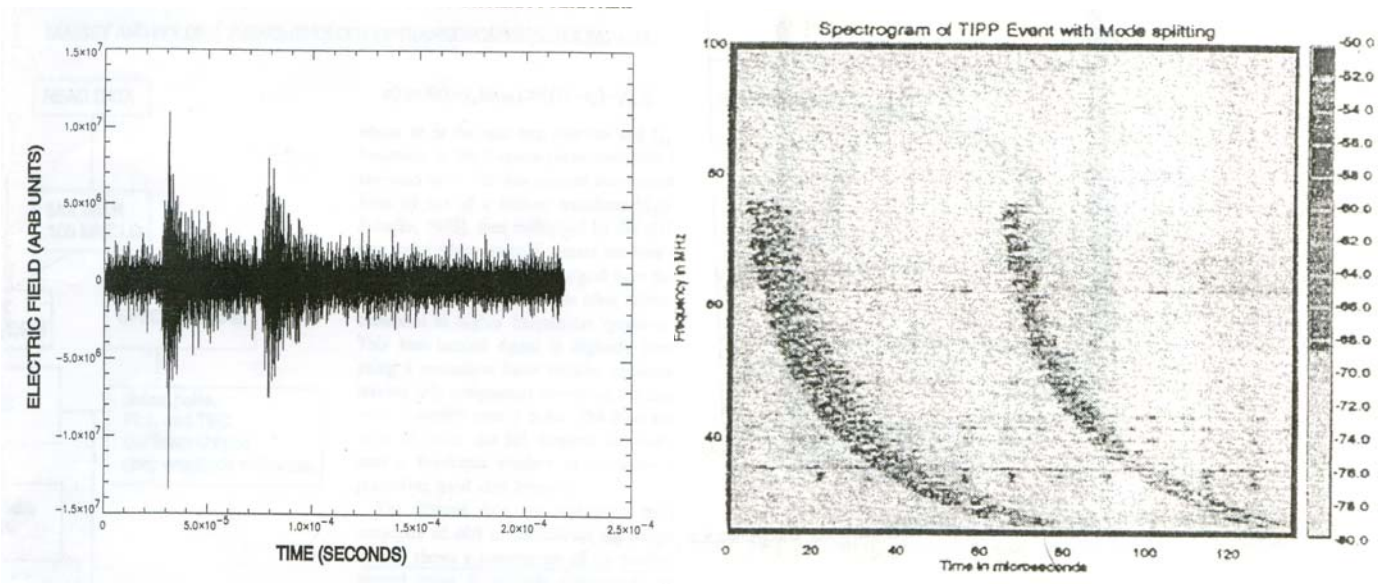
Trans Ionospheric Pulse Pairs are VHF signals consisting of exactly two broadband pulses, each with duration of few microseconds. The time separation of the pulses is typically tens of microseconds. Each pulse exhibits a frequency dispersion indicative of a sub-ionospheric origin. These emissions were distinguished from other naturally occurring radio emissions and were suspected to be associated with thunderstorms; because they were recorded onboard satellite when lightning activity was within the satellite's VHF horizon. In the present paper we try to explain the two pulses of TIPPs by considering the propagation of electromagnetic waves generated during lightning discharge in two different modes. The lightning discharge is represented by the combination of two Dirac delta functions. First one for the ground to cloud discharge current and the other one is cloud to ionosphere discharge. The Maxwell's equations are solved to derive the expression for wave-electric field as a function of frequency and distance. The exact time-dependence of the propagating non-monochromatic signal for the realistic ionospheric (IRI) model is numerically computed alongwith the IGRF model for the variation of gyrofrequency with altitude. It is observed that the separation between two signal pulses depends on the pulse separation of the excitation source; however, the intensity of the signal depends directly on the pulse height of the source current.

INTRODUCTION

Transionospheric pulse pairs (TIPPs) were discovered in 1993 with a wide band (~28-166 MHz) transient electromagnetic pulse detector, called Blackbeared, onboard the ALEXIS satellite [1]. Massy and Holden [2] defined TIPPs as VHF signals consisting of exactly two broadband pulses, each with duration of a few microseconds separated by tens of microseconds. Each pulse exhibits a frequency dispersion that an indication of a sub-ionospheric origin. These first investigators suspected that TIPPs are associated with the thunderstorms because they are recorded when lightning activity was within the satellite's VHF horizon. They have also tabulated several parameters of physical interest that constrain possible explanations for these events.

Holden et al. [1] observed bifurcation at lower frequencies as a result of mode splitting. When the signal propagates through the ionosphere, the right circular component travels as ordinary "O" mode, while the left circular component travels as extraordinary, or "X" mode. The "O" mode arrives first, with the separation determined by $\vec{k}.\vec{B}$, where $\vec{k}$ is the propagation vector and $\vec{B}$ is the geomagnetic field. The existence of mode splitting implies that the source emits a liner polarization. The most striking feature of these signals is that each one occurs as part of a pulse pairs. None of the events occurred either singly or in any other multiplicity. In very few cases, the second pulse was very faint so as to make debatable its existence.

The duration of each transient, when the effects of ionosphere are removed, is typically a few microseconds. Another feature of TIPP events is that, the leading edge of the transient is quite sharp while the trailing edge exhibits a more diffuse structure. These signals are dispersed at low frequencies suggesting a source below the ionosphere. As TIPPs are detected at frequencies known to be radiated by cloud electrification processes, it is believed that TIPPs are generated by the electrical activity of clouds [1]. Since the lowest frequencies of TIPPs approaches the plasma frequency of the peak of the ionosphere, the observed dispersion is accounted for a signal passing through the ionosphere; it is proposed that the source of these signals may be below the ionosphere. Figs. 1[a] and [b] show the detailed amplitude-time function and spectrogram of a TIPP event taken from the BLACKBEARD experiment on the ALEXIS satellite [After [1], fig.3].



(a) (b)

Fig. 1 (a) Detailed amplitude-time diagram (b) Spectrogram of a TIPP event taken from the BLACKBEARD experiment onboard the ALEXIS satellite [1]

Roussel- Dupré and Gurevich [3] proposed high altitude discharge hypothesis based on the well-demonstrated fact that a relativistic upward discharge may not terminate in the cloud and under suitable condition may continue upward and eventually terminates in the ionosphere. Thus, we may consider two discharges, one of the usual ground to cloud return stroke and the other discharge in the mesosphere where although the electric stress E is lower, the ratio E/P becomes large (due to exponential decrease of pressure, P). This second breakdown- including electric stress from the cloud (site of the original transient) to the mesosphere propagates at nearly the speed of light. It radiates the second "echo" (i.e., late-arriving) pulse to the satellite however, the first echo is radiated by the return stroke of the cloud to ground discharge. The delay of the echo pulse, relative to the primary pulse is maximum when the satellite is low on the horizon and is roughly given by (mesosphere height-cloud height) / c $\sim 200\mu\,\mathrm{sec}$. In this paper, we have used WKB solution and a computational technique to simulate the amplitude-time functions as well as spectrograms of the TIPPs. Further, the effect of the variation of physical parameters is also studied

THEORETICAL FORMALISM

We have used this concept of high altitude discharge hypothesis and the source current is represented by a combination of Dirac delta functions, i.e., $J_1(x,t) = I_0[\delta(t) + \delta(t - t_0)]\delta(x)$, where t_0 is the time delay in high altitude discharge. For the simplicity of the calculation, we have considered the same peak intensity of the two discharges (I_0). The wave equations are solved is obtained for the case of weakly inhomogeneous magnetoionic medium using WKB approximation [4] and the field expression for the whistler mode signal is obtained as follows [5]

$$E_w(x,t) = -\frac{Z_0}{4\pi}\int_0^{\infty} I_0 \sqrt{\frac{k_1(x_0,\omega)}{k_1(x,\omega)}}\,\frac{k_0(\omega)}{k_0(\omega)+k_1(x_0,\omega)}\, e^{j[\omega t - \int_{x_0}^{x} k_1(\xi,\omega)\,d\xi]}\, d\omega$$

where, Z_0 is wave impedance for vacuum, ω is the signal frequency, ω_b and ω_p are the space dependent gyro- and plasma- frequencies, $k_0(\omega) = \frac{\omega}{c}$, $k_1(x,\omega) = \frac{1}{c}\sqrt{\frac{\omega\omega_b(x)\omega_p^2(x) + \omega^2(\omega_p^2(x) + \omega_b^2(x) - \omega^2)}{(\omega_b^2(x) - \omega^2)}}$, and x_0 is the starting point of the signal in the interacting magnetoionic medium.

In the above expression, the integration is to be carried out along the path of propagation. For the terrestrial ionosphere, the variation of geomagnetic field is considered to be represented by International Geomagnetic Reference Field (IGRF) model where as, the electron density distribution along geomagnetic field line is taken from the International Reference Ionosphere (IRI) model.

RESULTS AND DISCUSSIONS

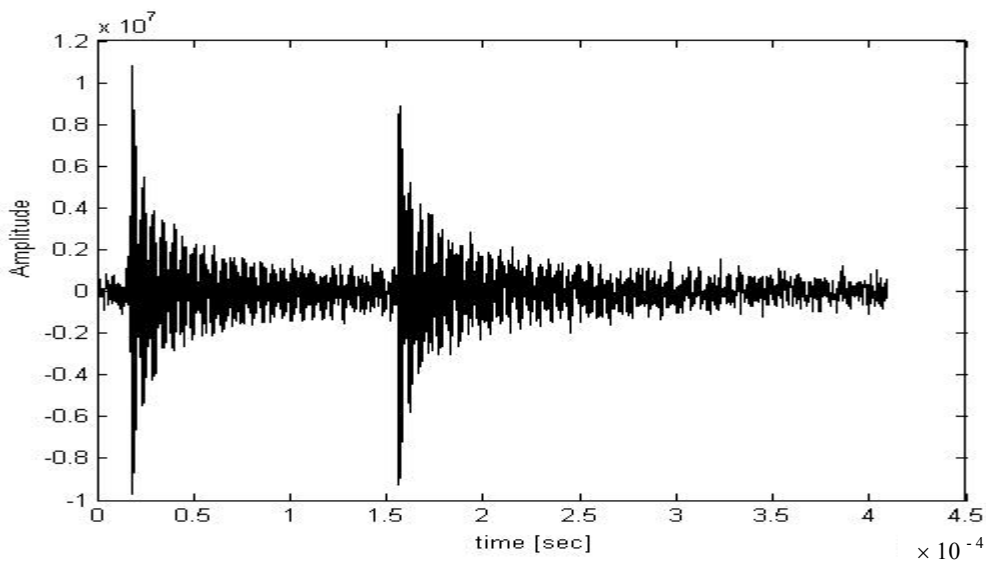


Fig. 2 Calculated amplitude-time function of a Transionospheric Pulse pair with $I_0=10^5$ coloumb/m, t_0 =150 microsecs

The amplitude time function of TIPP is calculated for $I_0=10^5$ coloumb/m, t_0 =150 microsecs. Fig. 2 shows two peaks, the first part of the signal has its origin from the cloud to ground discharge, however, the second part is because of the High altitude discharge current. The order of the amplitude of the signal is same as that of the observed TIPP [Fig. 1(a)], which depends on the I_0. Furthermore, the time delay between two signals depend on t_0 which in the present case is ~ 150 microsecs.

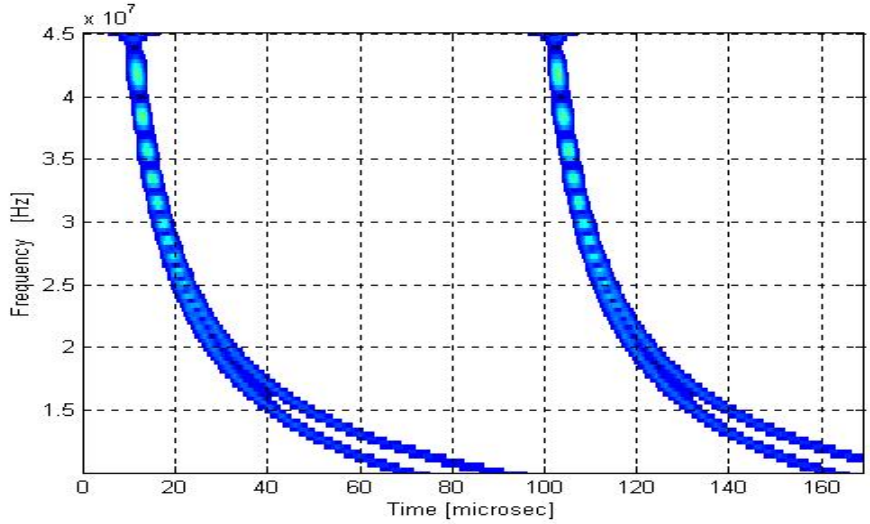


Fig. 3 Dynamic spectra of the simulated TIPPs with $I_0=10^3$ coloumb/m, t_0 =150 microsecs, NmF2 = 8.8×10^4 cm^{-3}

We have simulated the dynamic spectra of the TIPP for $I_0=10^3$ coloumb/m, t_0 =150 microsecs, NmF2 = 8.8×10^4 cm^{-3} [Fig. 3] where NmF2 is the peak in the number density of the F_2 layer in the terrestrial ionosphere. In the low frequency range spectral splitting in both the simulated traces is obtained. This arises due to the presence of two (left- and right hand rotating) modes. The left- hand polarized mode, depending on the plasma parameters can or cannot penetrate into the plasma and propagate in ELF~ VLF bands, but both modes propagate in the high frequency range even in a lossless magnetoplasma. This effect results in the Faraday rotation for a given frequency, the time-shifting between the two modes can be used in the determination of electron content of the path of propagation of the signal.

In this work we have quantitatively estimated the spectrograms of TIPPs, which depends on the high-altitude current, time lag in high altitude discharge and NmF2. Thus, variation in the dispersion of the dynamic spectra of TIPPs for a given ionospherical model may be used to study variation in NmF2.

REFERENCE

[1] D. N. Holden, C. P. Munson, and J. C. Devenport, Satellite observations of Transionospheric Pulse Pairs, *Geophys. Res. Lett*., vol.22, pp. 889-892, 1995.

[2] R. S. Massay, D. N. Holden, Phenomenalogy of transionospheric Pulse Pairs, *Radio Sci*., vol. 30, pp. 1645-1656, 1995.

[3] R. Roussel-Dupre, and A. V. Gurevich, On runway breakdown and upward discharges, *J. Geophys. Res.*, vol. 101, pp. 2297-2311, 1996.

[4] C. Ferencz, O. E. Ferencz, D. Hamar, and J. Lichtenberger, *Whistler Phenomena*, The Netherlands: Kluwer Acdemic, 2001.

[5] Kalpana Singh, and R. P. Singh, Excitation of electromagnetic waves in inhomogeneous magnetoplasma, *IEEE plasma science*, 2005, (communicated).