

“Solitary” Trans-Ionospheric Pulse Pairs onboard of the microsatellite “Chibis-M”

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Abstract

We present observations of “normal” and “abnormal” (solitary) Trans-Ionospheric Pulse Pairs (TIPPs) recorded by microsatellite “Chibis-M”. Measurements made by Radio Frequency Analyzer (RFA) onboard “Chibis-M” with passband 26–48 MHz and digitization 96 MHz. It is widely supposed that TIPPs appear as pairs of short (up to 10–20 μ s) VHF bursts separated by a few tens of microseconds. Dispersion of the signal indicates on its sub-ionospheric origin. It was proved by previous space-borne missions (ALEXIS and FORTÉ) that doubling of the signal results from the reflection of initial VHF emission from the surface. Nature of the TIPPs source is still under discussion. In this paper we are arguing that “solitary” VHF impulses from the sub-ionospheric source identified also in ALEXIS data represents the coalescence of two separate VHF bursts of TIPP. Observations of this phenomena are possible only for some specific geometrical patterns (low elevation of the source and high observational angle relative to the satellite position). We present some quantitative analysis to verify this hypothesis and found reasonably good correspondence of theory and observations.

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1. Introduction

Almost 20 years passed since the discovery of Trans-Ionospheric Pulse Pairs (or TIPPs) but nature of its source is still unresolved. For the first time new class of VHF emission were reported in 1993 with wideband (28–95 MHz and 108–166 MHz) radioreceiver Blackbeard aboard ALEXIS satellite (Holden et al., 1995). As it was pointed out by authors the phenomenon had some crucial characteristics enabled it to distinguish from other natural radioemissions. First of all, the peak power of the electric field of the event is of the order 100 μ V/(m kHz) referred

to 1 km that is about 10 times stronger relative to the emission from the “ordinary” flash (Holden et al., 1995). In spite of the fact that solitary impulses constituted $\sim 1\%$ of all detected events it was postulated that the VHF signals of new phenomenon occurred in pairs each with duration of few microseconds and time lag of the order of tens of microseconds (Holden et al., 1995; Massey and Holden, 1995). Another feature of TIPP events is related to the onset of signal. The leading edge of the dispersive impulsive structure has a sharp profile while the trailing edge exhibits a more diffusive one (Holden et al., 1995). Each pulse reveals a frequency dispersion indicating on its sub-ionospheric origin. On the basis of these detected features such pairs were called “Trans-Ionospheric Pulse Pairs” (TIPPs).

As recorded from the ground, microsecond-duration, intense, noise-like bursts of VHF radiation accompany

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observations class of waveforms called Narrow Bipolar Pulses (NBP) attributed to lightning discharges (Le Vine, 1980; Willett et al., 1989; Eack, 2004; Jacobson et al., 2000; Zuelsdorf et al., 2000; AzlindaAhmad et al., 2010; Zhu et al., 2010; Liu et al., 2012). It has been suggested that the VHF bursts accompanying NBP represents source of the first pulse in a TIPP (Smith et al., 1999).

What is the mechanism of the signal doubling in the TIPP? The simplest answer to the question is that second pulse in the TIPP is the ground reflection of the first pulse. This prosaic theory implies several consequences that could be easily cross-checked. First issue is the ratio between impulse energies. The reflectivity of the ground is definitely less than unity (some portion of the electromagnetic energy definitely should be absorbed by the soil or oceanic water). Massey and Holden (1995) found that this ratio for almost 70% of all events is less than unity. The second issue is the ratio of the second pulse duration to that supposed to be the first pulse in a pair. If the second pulse was caused by reflection from the roughness surface, one would expect its duration to be at least larger than the difference in transit time of electromagnetic signal across the reflecting area constituting several Fresnel zones. Study of Massey and Holden (1995) revealed that the duration of the second impulse was larger only in approximately 50% of the entire population. Time gap between two pulses (up to 100 μ s) is proportional to the elevation of the TIPP source above surface and was consistent with typical height of the tropopause (up to 15–18 km in tropical region). Therefore Massey and Holden (1995) concluded that “reflection hypothesis for the second pulse is viable only if the Earth’s surface acts as a nearly specular reflector for wavelengths between 4 and 12 m”. Later to test the reflectivity of sand at frequencies of ALEXIS radioreceiver, an electromagnetic pulse generator was flown on one balloon while a second balloon tethered above desert sand held a receiver (Massey et al., 1998). It was found that sand have reflection coefficient around 0.94 ± 0.06 for polarization in the horizontal plane and 0.78 ± 0.09 for the vertical plane polarization. Although this experiment was not carried out for other surface materials its results strongly supported the “reflection hypothesis”.

The most convincing arguments have been received onboard satellite FORTÉ. It was launched on 1997 into circular orbit at 800 km altitude. Detailed description of the project and its performance was done by, e.g. (Jacobson et al., 1999; Jacobson et al., 2000; Jacobson, 2003; Jacobson and Light, 2012). Here we would like to mention only some important features of this radio instrument. The receiver consisted of two passbands having 25-MHz bandwidth, whose center could be tuned anywhere in the range 20–300 MHz. But for the most of studies only two ranges were used 26–51 MHz and 118–134 MHz. The main feature of this instrument was the multi-channel-coincidence system that sampled the transient power on eight different sub-bands and required typically five of the eight sub-bands to be triggered within

160 μ s of each other to generate trigger. The antenna was crossed-par, dual-polarization log-periodic on a 10-m boom directed at nadir. New advantages of this instrument were applied to investigate the “ground reflection” theory. The ratios of the energy in the second pulse to that in the first pulse of a TIPP were examined and compared to what might be expected from common land and oceanic reflecting surfaces (Tierney et al., 2002). This study used the 38-MHz band, and identified 2467 geolocated VHF TIPP, including 481 over land, 1038 over sea, and 948 over “coastal regions”. The energy ratios observed were 0.39 ± 0.27 for the land and 0.94 ± 0.62 for the oceanic lightnings. About 25% of the recordings had the second pulse stronger than the first one, and most of these 25% belonged to the oceanic and coastal events. Tierney et al. (2002) noted that radiation from a linear dipole could produce pulse-energy ratios >1 ; e.g., the extreme occurs if the satellite was in line with the dipole axis (the beamlobe’s null) and the specular reflection was on the dipole’s equator.

As it was mentioned above Blackbeard instrument among “normal” TIPP registered only $\sim 1\%$ “solitary” waveforms while the FORTÉ team did not mentioned existence of such phenomena at all. At first glance it could be supposed that the presence of the “solitary” waveforms contradicts to the “ground reflection” theory. In this paper we would like to scrutinize typical VHF event corresponding to the “solitary” TIPP obtained onboard microsatellite “Chibis-M”. It is worth to mention that similar to the Blackbeard data solitary waveforms constitute the same 1% of the total recorded TIPP events.

2. Scientific instrumentation

First “academic” microsatellite “Chibis-M” was constructed on the platform originally designed at the Special Engineering Department of Space Research Institute of Russian Academy of Sciences in 2011. Spacecraft was placed in orbit on 25 January 2012 under the auspices of the Russian Academy of Sciences and S.P. Korolev Rocket and Space Corporation “ENERGIA”. The main goal of the “Chibis-M” project was the investigation of lightning phenomena in Earth’s atmosphere. The principal idea underlying design of the scientific payload of the microsatellite “Chibis-M” was the joint observations of the lightning emission at different parts of the electromagnetic spectrum. To realize this idea the following set of instruments was installed onboard: Radio Frequency Analyzer (RFA), UV and IR detectors (DUF), Roentgen and Gamma detector (RGD), Plasma Spectrum Analyzer (PSA) and Fast Optical Camera (FOC). We could provide here only a brief sketch of the scientific payload onboard “Chibis-M”, more detailed description of the launching scheme and spacecraft by itself was given in a special paper, e.g. (Zelenyi et al., 2014). In following papers we plan to introduce the capabilities and performance of the UV and IR payloads and

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