Investigation of Spacecraft Transmitter VHF Signal Propagation through Exhaust Burns of Approach and Correction Engine Using the Ground-Base Interferometer

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Abstract

In this paper we study features propagation of VHF radiowaves through the ionospheric disturbances generated by exhaust jets of Transport Spacecraft (TSC) "Progress" Approach and Correction Engine (ACE). For solving this problem was created the ground-based interferometric complex comprising of 4 zenith reception antennas. The results of ground-based interferometric measurements showed the effect of ACE run on the onboard transmitter VHF signal characteristics.

1. Introduction

In 2009-2010 were carried out space experiments (SE) by using the TSC "Progress" to investigate gas-plasma formations emerging at the run of the ACE and their effect on the onboard transmitter VHF signal characteristics. One of the SE objectives was to investigate VHF radiowave passing at 121,75 MHz through the ionospheric disturbances generated by exhaust jets of the ACE.

The first reception sessions of radiosignals from a spacecraft were held on October 4, 1957 involving the Earth's first satellite and radio amateurs all over the world. The onboard transmitters emitted radiowaves at two frequencies: 20,005 and 40,002 MHz in the form of 0.3 sec telegraphic premises. It allowed to begin studying the high layers of the ionosphere. Before that, ground-based sounding investigated the domains in the ionosphere lying below the maximum ionization height of ionospheric layers. One of the launch assignments was studies of ionospheric propagation of radio waves emitted by the transmitters passed.

The ground-based interferometric complex comprising of 4 zenith reception antennas, feeder lines and 8-channel receiver with the 1-170 MHz range was deployed at the Tory observation post (OP) (51.8 N, 103.1 E). Figure 1 shows the allocation scheme of the antenna system consisting of four identical antennas placed at the corners of an equilateral triangle with a 34.6 m side. The triangle's one side is oriented towards East-West, the vertex is oriented towards north. The fourth antenna is located at the triangle's center and is 20 m equally remote from the three remaining antennas. A 121,7 MHz "double square" antenna was chosen as a system element. Its peculiarity is that the squares plane is arranged in the horizontal plane and the main lobe is aimed at the zenith. The antennas are anchored on 10.8 m tubular masts. A wide directional diagram of the antennas allows to record the onboard transmitter signal starting with vanishing angles over the horizon to the zenith.

Observations of VHF signal were arranged as follows. At appearing over the horizon (elevation angle 0.5^0 and distance > 2000 km), the TSC control teleoperational system onboard transmitter was actuated in the continuous radiation mode at 121,75 MHz. Figure 2 shows the experiment geometry. At the TSC ephemeris (line with arrow) fat dots denote the site where the ACE was started. During the ACE run, the TSC was flying within the Irkutsk incoherent scatter radar (ISR) coverage [1].

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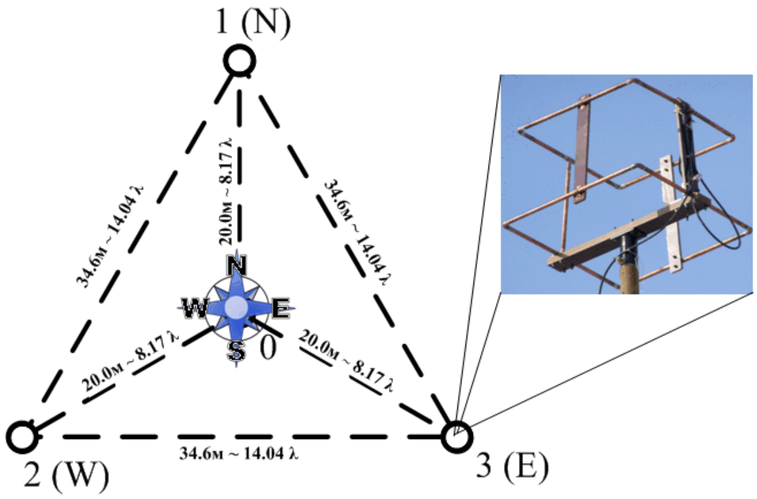

Figure 1. Antenna system orientation and "double square" antenna exterior.

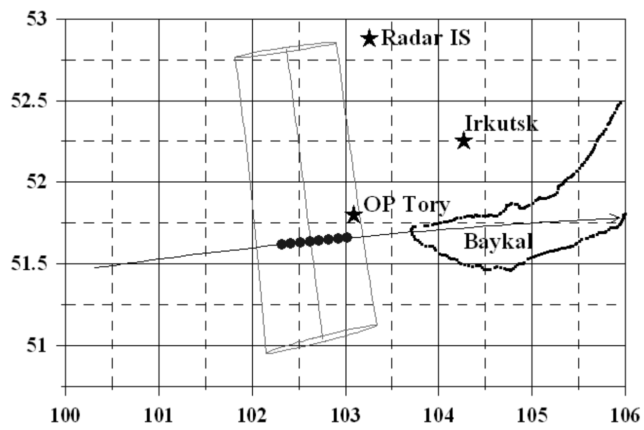

Figure 2. SE geometry

2. Experimental Data Analysis

The full signal waveform of the received VHF signal is recorded in the form of quadratures $a(t)$ and $b(t)$. The observational result is the recorded N-sequence of VHF signal complex envelope samples:

$$q(t) = a(t) + ib(t) \tag{1}$$

The signal analysis is built on the analysis of its quadratures. To define the signal characteristics we need the recorded VHF signal analytical model containing the characteristics of the TSC travel relative to the given antenna system. As first approximation, one may present the signal complex envelope, provided the harmonic wave is radiated (f_0=121,75 MHz), in the view:

$$q_j(t) = \mu_j(t) \cdot \exp\{i(\varphi(t) + \Delta\varphi_{j0}(t))\}, \tag{2}$$

where j is the antenna number in the system, μ is the VHF signal amplitude, $\varphi(t) = \varphi_0 + kR_0(t)$ is the phase, $R_0(t)$ is the distance to the TSC in the coordinate system with the origin at the central antenna location, $\Delta\varphi_{j0}(t)$ is the phase difference between *j* and central antennas.

Since the distance between the antennas is much less than the distance to the TSC, the phase differences between antennas n and m can be associated with the TSC angular position relative to the central antenna as follows:

$$\Delta\varphi_{mn} = k(R_n - R_m) \cong k\cos(\theta)[\rho_n \cos(\alpha - \alpha_n) - \rho_m \cos(\alpha - \alpha_m)], \quad (3)$$

where $k = 2\pi/\lambda$, $\lambda = c/f_0$, θ and α are the elevation angle and TSC azimuth, respectively, ρ and $\alpha_{n,m}$ are the distance from the central antenna and azimuths of antennas n and m. For the antenna pair under consideration, the phase difference can be defined as follows:

$$\Delta\varphi_{mn} = \arg(q_m q_n^*) \quad (4)$$

Since the TSC ephemeris is known precisely enough, i.e. we know $R(t)$, $V_R(t)$, $\theta(t)$, $\alpha(t)$, we will introduce a reference signal to neutralize the regular component of the signal phase difference for the antennas pair under consideration:

$$\Delta q_{mn} = \exp(i\Delta\varphi_{mn\_efem}(t)), \quad (5)$$

where $\Delta\varphi_{mn\_efem}(t)$ is defined from (3) accounting for the estimated $\theta(t)$ and $\alpha(t)$.

Then the phase difference variations between the antennas already accounting for the TSC travel along the estimated ephemeris can be defined as follows:

$$\delta\varphi_{mn} = \arg(q_m q_n^* \Delta q_{mn}^*). \quad (6)$$

Defining amplitude $\mu(t)$ and the Doppler frequency drift (DFD) $f_D(t)$ is carried out by 2^{11} samples, the corresponding time interval is 0.1 sec. Over the given interval, using FFT, we define a frequency to which the amplitude maximum corresponds in the spectrum; such a frequency is assigned $f_D(t)$, and its amplitude value is assigned $\mu(t)$.

In 2009, we held 4 SE sessions during which the VHF signal was received by one antenna. In April 2010, we held 5 sessions with the reception by three antennas. In September 2010, we held 7 sessions with the reception by all four antennas. As a result of the measurements taken, we obtained the characteristics ($\mu(t)$, $f_D(t)$, $\delta\varphi_{mn}(t)$) of the radiosignal passed through the ionospheric disturbances generated by the ACE exhaust jets.

Figure 3 shows the results of measuring the phase difference of the signals received by various antennas during the 4/25/2010 session. The time in seconds on the abscissa axis is counted off from the onboard transmitter actuation. The ACE exhaust fume velocity vector in the given session was aimed at the IISR. Red rectangle shows the ACE run time.

After the ACE start, the phase difference variation amplitude increased to 100 degrees, whereas the phase characteristic variations do not usually exceed 30 degrees. It is obvious that the phase differences between the antenna pairs, western (W) - central (0) and W-east (E), behave almost identically differing from the dynamics of the phase difference between antennas 0-E. Such a behavior is due to both the TSC flyby geometry practically perpendicular to the base of antennas 0-E and anisotropy of the generated ionospheric disturbances where the radiosignals [2] propagated.

3. Conclusion

We carried out interference measurements for the TSC transmitter VHF signal characteristic during the ACE run. The analysis showed that the amplitudes of variations in the phase difference of radiosignals received by various antennas increase owing to the effect of the ionospheric disturbances generated by the ACE exhaust jets after the ACE start.

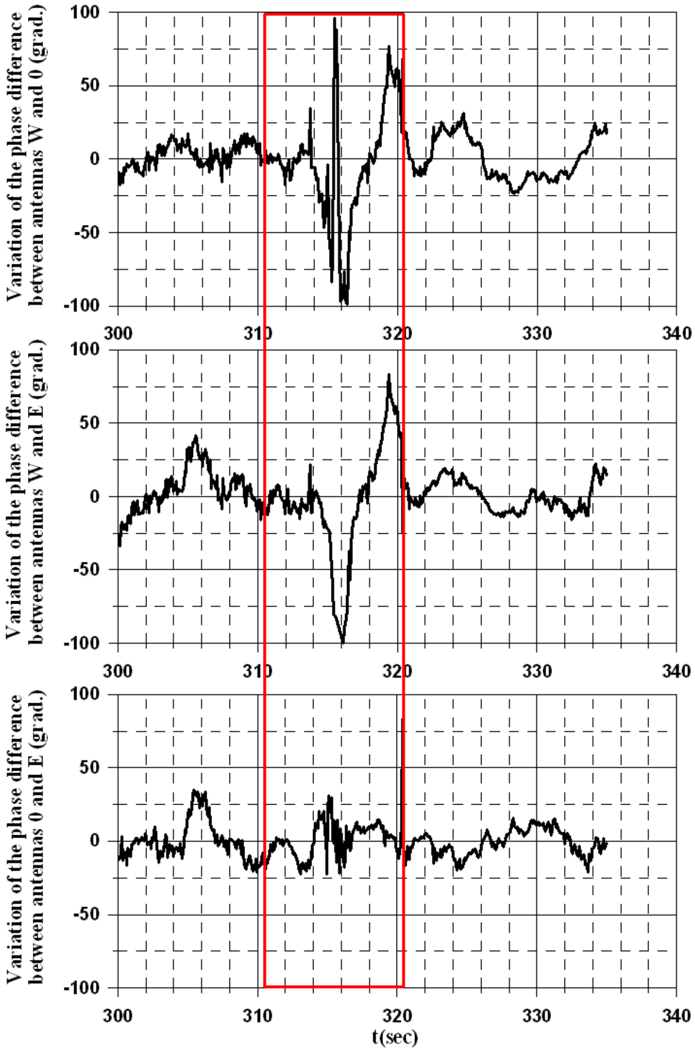

Figure 3. Measurement results for the phase difference between the signals in antennas on 4/25/2010

4. Acknowledgment

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5. References

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