FEDERAL SPACE AGENCY

Joint-Stock Company "Institute of Space Device Engineering"

Russia , 111250, Moscow, st. Aviamotornaya, 53, Tel.: +7 (495) 673-34-63, 673-93-03
Tel./fax:+7 (495) 673-47-19, E-mail: fgupniikp@mtu-net.ru http://fgupniikp.ru

Radio link provided compensation of ionosphere and troposphere measurement errors

Valeriy Tyubalin, Deputy Chief Designer

Working Group B, 20 October 2010, Turin, Italy

Initial data

1. The high stable onboard oscillator is necessary

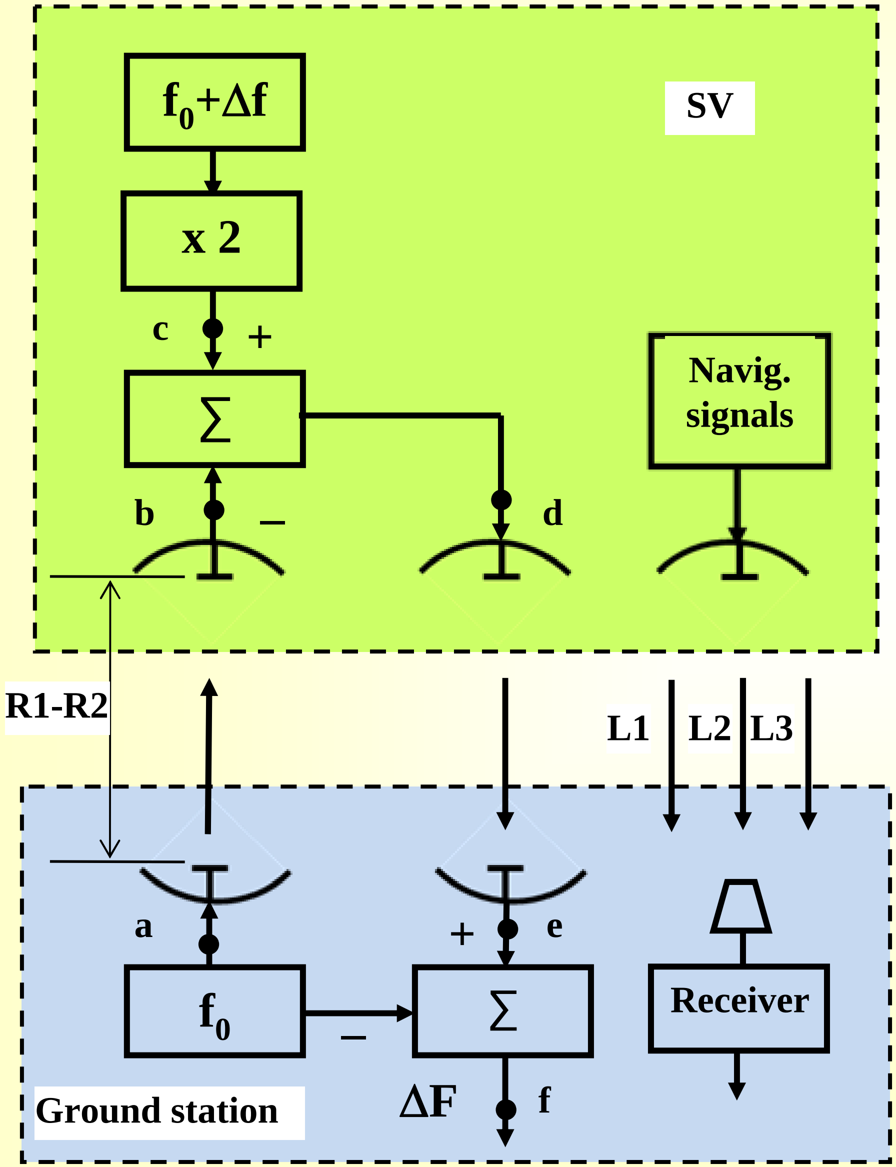
2. Association of compensating radio link with one side (down) radio links in other ranges is expedient

3. Such conditions can be easily executed in onboard navigation SV, if the compensating mode is stipulated in a control radio link

4. Time of atmospheric fluctuations correlation is more than a signal transmission time

5. Fluctuations are caused by movement irregularity in atmosphere

First-order Doppler effect compensation



$f_a = f_0;\qquad f_b = f_0\left(\dfrac{1-\dot{R}/c}{\sqrt{1-\left(\dfrac{V}{c}\right)^2+2\Phi}}\right)$

$f_c = 2(f_0 + \Delta f)\qquad f_d = f_c - f_b$

$f_e = f_d\left(\sqrt{\dfrac{1-\left(V/c\right)^2+2\Phi}{1+\dot{R}/c}}\right)$

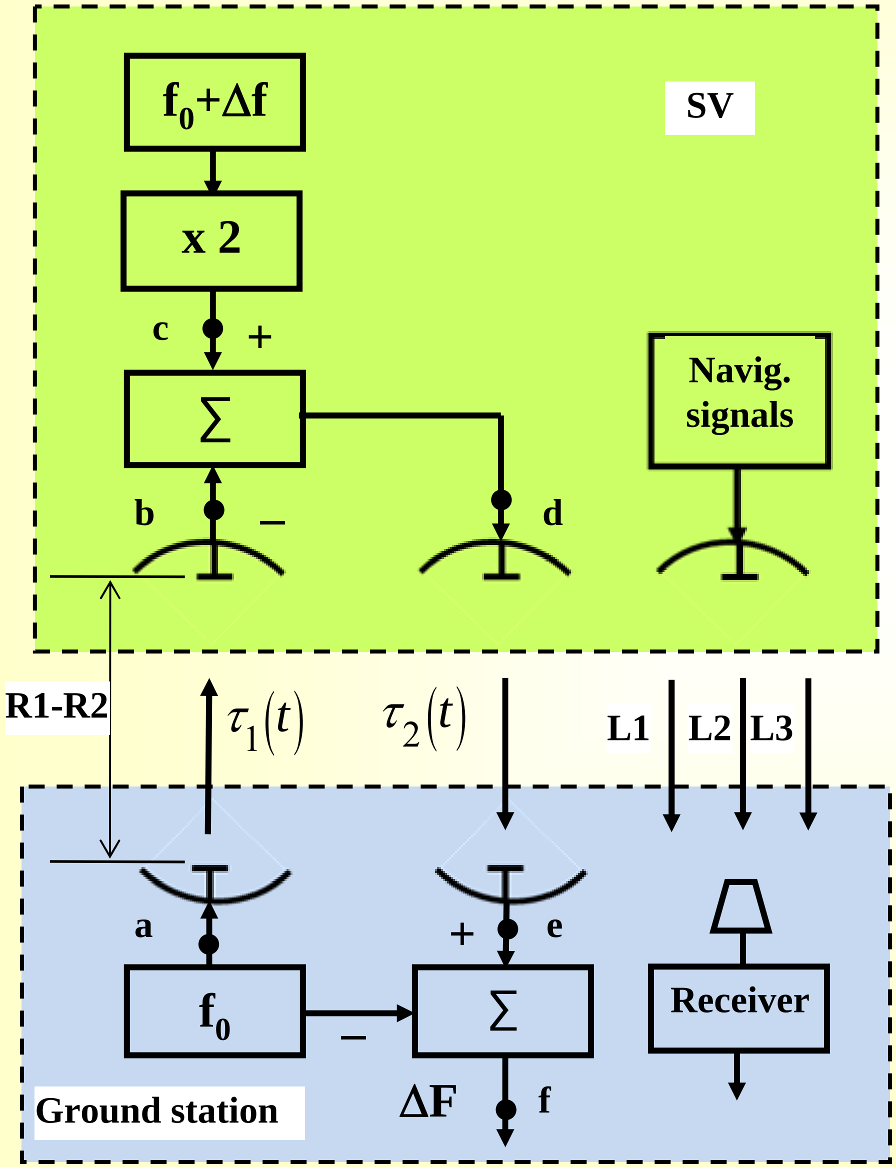
$\Delta F = f_f = f_e - f_0;\qquad \Delta F \approx f_0\left(2\Phi - V^2/c^2\right) + 2\Delta f$

Measured frequency ΔF doesn't contain first order Doppler frequency

$\Phi = \dfrac{\varphi_a - \varphi_b}{c^2} = \dfrac{GM_e}{c^2}\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$

V – orbital velocity;
c – velocity of light
Φ - difference of ground station-SV gravity potentials
$G=6{,}670\cdot10^{-8}cm^3g^{-1}s^{-2}$ - gravitation constant
$M_e = 5{,}98\cdot10^{27}g$ – Earth mass
R_1, R_2 = distance from Earth center to ground station and SV, respectively
$\dot{R}$ – SV radial velocity

Compensation of ionosphere and troposphere fluctuations



$$\tau_1 = \tau_0 + \Delta\tau_1(t); \qquad \tau_2 = \tau_0 + \Delta\tau_2(t)$$

$$\varphi_f = 2\varphi_0(t-\tau_2) - \varphi_0(t-\tau_1-\tau_2)$$

$$\Delta\varphi(t) = \omega\left[\Delta\tau_1(t) - \Delta\tau_2(t)\right] = \Delta\varphi_1(t) - \Delta\varphi_2(t)$$

$\Delta\varphi_1(t); \Delta\varphi_2(t)$ - phase fluctuation in up- and down- radiolinks, respectively

$$\Delta\tau_2(t) = \Delta\tau_1(t-t_0)$$

$$B_{\Delta\varphi}(l,\theta) = <\Delta\varphi(l_1+l, t+\theta)\cdot\Delta\varphi(l_1,t)>$$

$$= B_{\Delta\varphi}\left(\theta - \frac{l}{V}\right);$$ V – irregularity transfer velocity

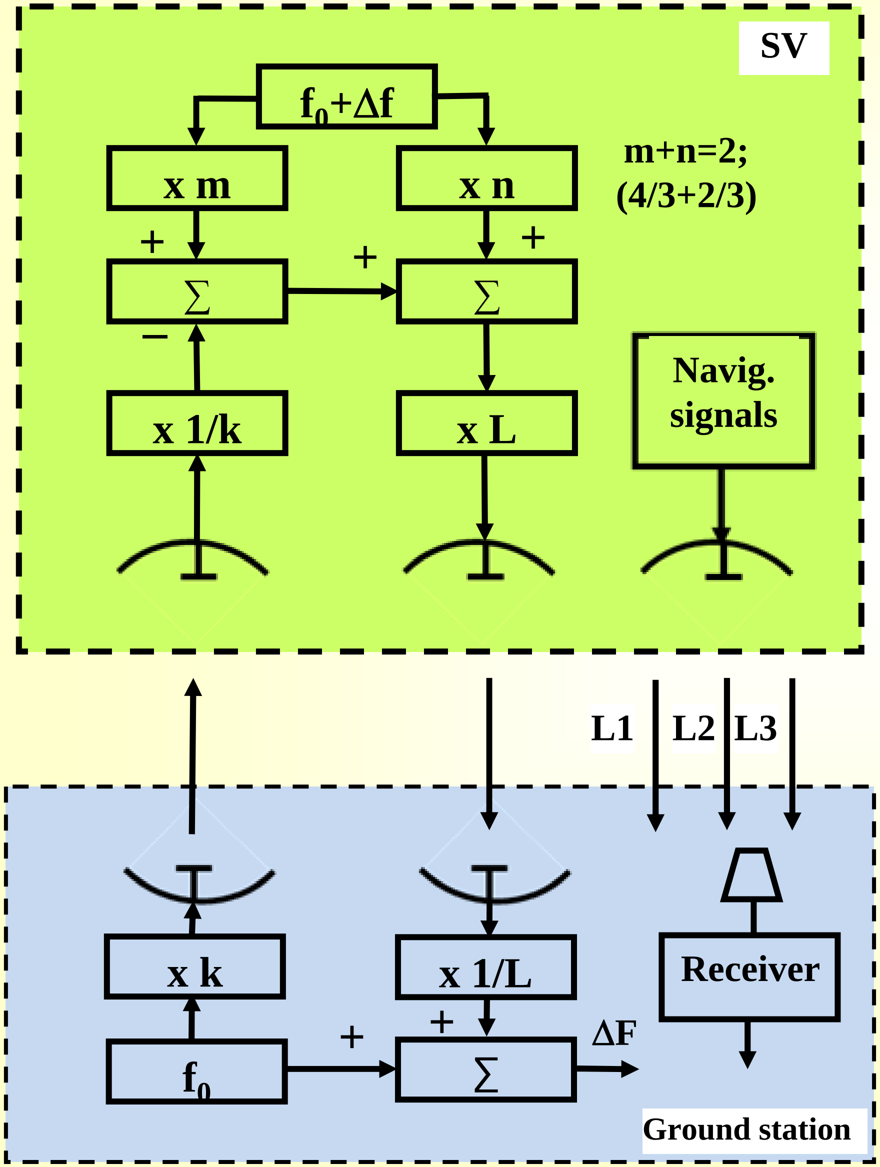
$$\overline{\sigma^2_{\Delta\varphi}} = 2\sigma^2_\varphi\left[1 + \frac{\theta_k}{2\tau_0}\left(e^{-\frac{2\tau_0}{\theta_k}} - 1\right)\right]$$

$$\sigma^2_\varphi = 2k^2\sigma^2_{\Delta n} l_0 L; \qquad k = 2\pi/\lambda; \qquad l_0 = V\theta_k$$

$\sigma^2_{\Delta n}$ – refraction coefficient dispersion

L - path length in irregular environment

Radio link architecture



Compensation errors:

- **First order Doppler frequency**

$$\delta F_d = f_0\left(2\Delta\Phi - \frac{\Delta V^2}{c^2}\right);\ \Delta\Phi \le 10^{-13}\ \text{for}\ h_{orbit} \ge 300\,\text{km}$$

$$\Delta V \le 0.1\,\text{km/s};\ \frac{\Delta V^2}{c^2} \le 10^{-13};\ \delta F_d = f_0 \cdot 10^{-13}$$

- **Ionosphere and troposphere fluctuations**

$$\delta\varphi_{I,T} = 2\sigma_\varphi^2\left[1 + \frac{\theta_k}{2\tau_0}\left(e^{-\frac{2\tau_0}{\theta_k}} - 1\right)\right]$$

Quiet troposphere:

$$V = 1\ m/c;\ l_0 \approx 60\,m;\ \tau_0 \approx 0.07\,s\ \left(R_0 = 2\cdot 10^4\,km\right);$$

$$\theta_k = 60\,s; \qquad \delta\varphi_T = 2.4\cdot 10^{-3}\sigma_\varphi^2$$

Disturbed troposphere: cumulonimbus clouds

$$V = 12\ m/c;\ l_0 \approx 6\,m;\ \tau_0 \approx 0.07\,s;\ \theta_k = 0.5\,s;$$

$$\delta\varphi_T = 0.26\sigma_\varphi^2$$

Quiet ionosphere:

$$V = 27\ m/c;\ l_0 \approx 2\,km;\ \tau_0 \approx 0.07\,s;\ \theta_k = 75\,s;$$

$$\delta\varphi_I = 1.9\cdot 10^{-3}\sigma_\varphi^2$$

Disturbed ionosphere: strong solar activity

$$V = 420\ m/c;\ l_0 \approx 1\,km;\ \tau_0 \approx 0.07\,s;\ \theta_k = 2.4\,s;$$

$$\delta\varphi_I = 6\cdot 10^{-2}\sigma_\varphi^2$$

Summary

The considered radio link can be applied for the various purposes:

1. Measurements of gravitational frequency shift.
2. Compensation of atmospheric fluctuations.
3. Operative frequency control of the onboard frequency standard.

Listed above functions are realized on the USSR SV Cosmos №97, Cosmos №145 in 1965 – 1967 years.

4. Automatic synchronization of the remote generators (onboard - ground, ground - ground, onboard - onboard).

References

1. R.S. Badessa, R.L. Kent, T.C. Nowell, C.L. Searle. Proceedings of the IRE, 1960, v.48, 4, p. 758.
2. N.G. Basov, O.N. Krokhin, A.N. Oraevskii, G.M. Strakhovskii, B.M. Chikhachev. Soviet Phisics-Uspekhi, 1961, 75, 1, 3.
3. B.M. Chikhachev, N.E. Ivanov, G.M. Fedorenko and others. “Space Research”, 1975, v. XIII, 3, p.381.