Stability of radio loops covering navigation systems and communication systems

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Abstract. The development of the concept of E-navigation in modern shipping makes it necessary to create very reliable lines for the transmission of information packets and the interchange of data via radio networks to a huge number of consumers, practically all over the world. With such a scale, radio communication must be extremely reliable and stable, which is provided by the planetary system of satellite communication channels. The study proposes a method of signal loops of satellite communication systems for diagnosing the quality of the radio path, which will allow quickly localizing the external causes of the deterioration of the linear stability of communication in the absence of deep diagnostics during the daily operation of radio transmitting equipment. The organization of an external loop will make it possible to make a more accurate spatial adjustment of the antenna system to the zone of stable traffic with an increase in the steepness of the guidance system characteristics according to its own signal returned from the loop from the satellite. The external loop allows for more precise tuning of the antenna system of the stations, relative to the “steepness” of your own signal and to localize the external causes of signal deterioration by applying the method of signal loops.

1. Introduction
The development of the concept of E-navigation in modern shipping makes it necessary to create very reliable lines for the transmission of information packets and the interchange of data via radio networks to a huge number of consumers, practically all over the world. With such a scale, radio communication must be extremely reliable and stable, which is provided by the planetary system of satellite communication channels.

At the same time, the “ground-space-ground” path line is a narrow section of the relay system through orbiting satellites, since the passage of signals through the atmosphere distorts, noises and weakens the radio wave due to instability and disturbing effects of atmospheric electromagnetic fields [1].

2. Materials and methods
Currently, in modern satellite communications, various configurations of channel information transmission are used. In terms of traffic, networks are classified as: point-to-point, the simplest case of a duplex communication line between two remote stations, centralized communication [2].
For multichannel communication and radial transmission of traffic information between the network center and peripheral points, a partially decentralized network is organized.

A peer-to-peer network is an independent fully decentralized system that provides full-duplex communication between two remote points, as a multi-directional radial traffic transmission between the central earth station of the network and remote peripheral points according to the energetically most favorable configuration [3].
Satellite communication via a geostationary satellite, on a terrestrial scale is ultra-long-distance communication with a route length of up to 40 thousand kilometers. According to the phenomenological equation of the propagation range of radio waves, in the theory of satellite communication it has the following form:

$$d = \left( \frac{\lambda}{4\pi L_{add}} \right) \left( \frac{P_{TX_{ES}}(G_i)(G_{RX})}{P_{RX_S}} \right)^{\frac{1}{2}}$$  \hspace{1cm} (1)

where:

- $\lambda$ is the radio signal wavelength;
- $L_{add}$ is additional signal power loss on the ground-space-ground path;
- $P_{TX_{ES}}$ is the effective signal power at the output of an earth station transmitter;
- $P_{RX_S}$ is the signal strength at the input of the satellite repeater receiver;
- $G_i$ is the gain of a transmitting antenna relative to an isotropic transmitter;
- $\eta$ is the transmission coefficient of a wave path depending on the characteristics of the path and transceiver stations on the ground and satellite [5].

From the analysis of signal levels $P_{TX}$ and $P_{RX}$, the features of signal attenuation along the radio wave path appear and are correlated with the coefficient $L_{add}$ [3].

3. Results and discussion

It is investigated that both "up-down" paths for the antenna unit of the transceiver on the satellite and the earth station combined in one design are superimposed in space, and the propagation of radio waves is shifted in time by 250 ms. Therefore, the accuracy of the processes of fine spatial nonreciprocity of the radio path and short processes in the troposphere characterizes the attenuation along the "up and down" path in approximately the same way. Thus, it is possible to conduct a
quantitative analysis of the influence on the quality of the channel of many internal factors acting outside the weak effects from external fast processes in the stratosphere of the earth's atmosphere [4].

In the satellite loop, the radio wave paths pass twice through the troposphere and ionosphere. Then, the full path of the radio signal will be obtained by equating the constant coefficients of the radio path equation of the two sections of the communication line, in the following form:

\[ \left( \frac{4\pi dl}{c} \right)^2 = \frac{1}{f_{UL}^2} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} - \frac{1}{f_{DL}^2} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} \]  

(2)

where:

\( c \) is radio wave propagation speed; \( f_{UL} \) is the radio wave propagation frequency from the ground; \( f_{DL} \) is the radio wave propagation frequency to the ground.

After some transformations, we get an expression some parts of which characterize the specificity of the space route sections by stochastic no more than 250 ms:

\[ \left( \frac{f_{DL}}{f_{UL}} \right)^2 = \frac{P_{TXS}(G\eta)_{TXS}}{(G\eta)_{RXS}} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} = \frac{l_{add,UL}}{l_{add,DL}} \cdot \frac{p_{RXS}}{P_{RXS}} \]  

(3)

In the equation, the first term is a constant value of a particular communication line, the second and third ones characterize the parameters of the earth station and the satellite repeater, with elements of some possible stochastic changes when the object antenna position becomes unstable [5, 6]. The fourth term takes into account the difference in the attenuation of radio waves when propagating along the same path on the ground-to-space and back sections with a time shift, the fifth term characterizes the power ratio of the received signals and modifies the pair of signal-to-noise ratios at the input of the earth station receiver and the repeater:

\[ \left( \frac{f_{DL}}{f_{UL}} \right)^2 = \frac{P_{TXS}(G\eta)_{TXS}}{(G\eta)_{RXS}} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} = \frac{l_{add,UL}}{l_{add,DL}} \cdot \frac{P_{NS}(P_C)_{RXS}}{P_{NS}(P_C)_{RXS}} \]  

(4)

Since the noise generated by various sources (pink noise) [6] in the frequency bands of satellite communication systems is additive in nature, their total power \( P_N \) can be calculated by the following formula:

\[ P_N = kT_{\Sigma}R_N\Delta f_N \]  

(5)

After modification, we get:

\[ \left( \frac{f_{DL}}{f_{UL}} \right)^2 = \frac{P_{TXS}(G\eta)_{TXS}}{(G\eta)_{RXS}} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} = \frac{l_{add,UL}}{l_{add,DL}} \cdot \frac{P_{NS}(P_C)_{RXS}}{P_{N}(P_C)_{RXS}} \]  

(6)

where:

\( k = 1.38 \cdot 10^{23} (J/K) \) is the Boltzmann constant; \( T_{\Sigma} \) is the equivalent noise temperature of the entire receiving system, including internal and external noise (gray noise); \( R_N \) is the amplifier noise impedance (orange noise); \( \Delta f_N \) is the equivalent (power) noise bandwidth of the receiver (red noise).

We transform the expression in the following approximation:

\[ \frac{l_{add,UL}}{l_{add,DL}} \approx 1 \]  

(7)

In the case of the fairness of the boundaries of the equality:

\[ \left( \frac{f_{DL}}{f_{UL}} \right)^2 = \frac{P_{TXS}(G\eta)_{TXS}}{(G\eta)_{RXS}} \cdot \frac{P_{TXS}(G\eta)_{TXS}(G\eta)_{RXS}}{P_{RXS}} \cdot \frac{\Delta f_{NS}}{\Delta f_{NS}} = \frac{l_{add,UL}}{l_{add,DL}} \cdot \frac{T_{ES}R_{NS}(P_C)_{RXS}}{T_{ES}R_{NS}(P_C)_{RXS}} \]  

(8)
If we exclude stochastic changes in the values of the second and third terms of equality, provided that the satellite is stationary, then the entire left side of the equality will become a constant value and characterize a specific satellite line, that is, the satellite loop of this line, or *satellite loop constant* [5] (STC), then the modified formula takes the following form:

$$STC = \frac{T_{ESNS}(\frac{P_C}{P_N})_{RXS}}{T_{ESNS}(\frac{P_C}{P_N})_{RXS}}$$

(9)

Hence,

$$\left(\frac{P_C}{P_N}\right)_{RXS} = \left(\frac{P_C}{P_N}\right)_{RXS} \cdot \frac{T_{ESNS}}{T_{ESNS}} \cdot STC^{-1}$$

(10)

The studies show the dependence of the signal-to-noise ratio at the input of the earth station receiver $\left(\frac{P_C}{P_N}\right)_{RXS}$ on the signal-to-noise ratio at the input of the satellite repeater $\left(\frac{P_C}{P_N}\right)_{RXS}$, and on the ratio of the illuminance temperatures of the receiving antennas and noise impedances with an accuracy to a constant value $STC^{-1}$, which does not take into account the stochastic processes of tuning the antenna system arising during the operation of the satellite tracking system and the virtual conditions of nonreciprocity of radio paths "ground-space", up and down [6].

Thus, studies have shown that the organization of external loops traces the dependence of the quality indicators of the satellite communication channel on destabilizing factors from the antenna mirror, along the radio path on the position of the satellite in orbit and fluctuations in the atmosphere. Diagnostics of external and internal factors affecting the quality of communication is possible.

4. Conclusion

The organization of an external loop will make it possible to make a more accurate spatial adjustment of the antenna system to the zone of stable traffic with an increase in the steepness of the characteristics of the guidance system according to its own signal returned from the loop from the satellite. The external loop allows more accurately tuning the antenna system of the stations, relative to the "steepness" of its own signal and localizing the external causes of signal deterioration by applying the method of signal loops.

References

[1] Baskakov S I 1980 *Radio engineering circuits with distributed parameters* (Moscow: Higher School)
[2] Kondratiev S I, Boran-Keshishyan A L, Popov V V 2018 Optimization of the reliability of data exchange channels in the connected systems of the national concept of the Russian segment of E-navigation of the Azov-Black Sea basin *Marine intelligent technologies* 3 (41) 170-174
[3] Muzyca Z N 1981 *Sensitivity of radio receiving devices on semiconductor devices* (Moscow: Radio and Communication)
[4] Ivakhnenko A G 1969 *Self-learning recognition and automatic control systems* (Kiev: Technika)
[5] Rakov A I 1981 *Reliability of radio relay and satellite transmission lines* (Moscow: Radio and Communication)
[6] Demyanov V V, Popov V V 1999 *Scientific experience in creating large marine information communication systems in the south of Russia* (Novorossiysk: NGMA)