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Synchronization systems of time scales and frequencies in polar latitudes by meteor radio channel

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Abstract. The necessity of using a meteor communication channel as a backup system for determining the coordinates of moving objects in polar latitudes and transmitting information is substantiated. The necessity of using a time scale synchronization system in the meteor communication channel has been established. The reasons that cause a failure in the transmission of information in the meteor communication channel are presented. A model for calculating the shift of time scales in the meteor communication channel is proposed. A method has been developed to reduce random errors and increase the noise immunity of the meteor communication channel. Recommendations are given on the choice of receiver parameters for synchronization with a given accuracy.

Keywords: meteor radio channel, meteor synchronization, synchronization of time scales, synchronization methods, duplex method, simulation model, noise-like signal, m-sequence, receiver sensitivity, registration threshold

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Системы синхронизации шкал времени и частот в полярных широтах по метеорному радиоканалу

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Аннотация. Обоснована необходимость использования метеорного канала связи в качестве резервной системы для определения координат подвижных объектов в полярных широтах и передачи информации. Установлена необходимость использования системы синхронизации шкал времени в метеорном канале связи. Представлены причины, которые вызывают сбой в передаче информации в метеорном канале связи. Предложена модель расчета сдвига шкал времени в метеорном канале связи. Разработан способ для уменьшения случайных погрешностей и повышения помехозащищенности метеорного канала связи. Даны рекомендации по выбору параметров приемника для осуществления синхронизации с заданной точностью.

Ключевые слова: метеорный радиоканал, метеорная синхронизация, синхронизация шкал времени, методы синхронизации, встречный метод, имитационная модель, шумоподобный сигнал, m-последовательность, чувствительность приемника, порог регистрации

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Introduction

The development of industry and trade, as well as mining, required new developments for communication systems and determining the coordinates of objects [1–10]. The most reliable among communication systems are fiber-optic lines [11–16], which can provide information transmission in difficult conditions. Among the coordinate determination systems, satellite navigation systems are in the greatest demand [1, 5, 6–9, 17–24]. When using satellite systems in northern latitudes (above 70 degrees latitude) to determine coordinates, a number of problems arise [25–27]. They are associated with the attenuation of the amplitude of the GLONASS signal by ionospheric disturbances (for example, the Northern lights, etc.). This creates large errors in determining the coordinates of the object [28, 29].

Under these conditions, navigation is carried out by ground-based pulse-phase radio navigation systems (PPRNS) that emit radio-pulse navigation signals [30-33]. The coordinates of the transmitting stations of the PPRNS are known in advance. The stations serve a certain area of the earth's surface. Transmitting stations work in groups forming a single chain. Each chain includes a master station and several slave stations, whose radio pulse emissions are synchronized with the signals of the master station. The emissions of the leading station of the chain are synchronized, for example, by precise time signals using quantum frequency standards [9, 16, 19, 32]. These standards need to be adjusted during the work. One of the adjustment options is offered in our work.

Meteor synchronization

In northern latitudes, it is advisable to use the meteor radio channel as a backup channel for transmitting the exact time signal. The principle of meteor radio communication is based on the ability of ultrashort waves (VHF) to mirror the ionized traces formed as a result of the combustion of meteoroids in the Earth's atmosphere (Fig. 1) [33, 34].

It is known that the radiometeor communication channel is intermittent. The ionized trace is formed on average for 0.5 second, then it dissipates due to the process of bipolar (ambipolar) diffusion and it is necessary to wait for the formation of the next meteor trail. This disadvantage limits the scope of the radiometeor communication channel.

Due to the random location of the meteor trail in the synchronization systems of spatially remote time scales and frequencies on the meteor radio channel, the time of signal propagation is not known in advance, therefore, it is necessary to use two-way information transmission - the method is called active (two-way, duplex).

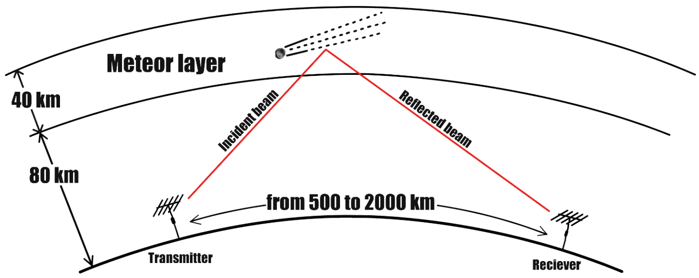

Fig. 1. The principal model of the meteor communication channel

To calculate the shift of the time scales ΔT, it is necessary to calculate the propagation time of the signal tp, for this, in addition to fixing the timestamp $t^{\langle 2\rangle}{}_R$ by the receiver, the time $t^{\langle 1\rangle}{}_R$ is fixed by the transmitter, after exchanging this information, a system of two equations is compiled:

$$\begin{cases} t_R^{\langle 2\rangle} = t_T^{\langle 1\rangle} + \Delta T + t_p, \\ t_R^{\langle 1\rangle} = t_T^{\langle 2\rangle} - \Delta T + t_p. \end{cases} \quad (1)$$

In total, we solve a system of two equations (1) with two unknowns:

$$\Delta T = \frac{1}{2}\left[\left(t_R^{\langle 2\rangle} - t_R^{\langle 1\rangle}\right) + \left(t_T^{\langle 2\rangle} - t_T^{\langle 1\rangle}\right)\right]. \quad (2)$$

In this case, both simultaneous transmission of the timestamp (counter method) and alternate transmission is possible. Alternate transmission is suitable for a communication range of less than 500 km.

Simulation model of time stamp transmission via meteor channel

Equation describing the power of the received signal reflected from an under-compacted trace [6]:

$$P_r(t) = A \cdot q^2 \cdot e^{-\frac{t}{\tau}}, \quad (3)$$

where A is the coefficient, q is the linear electron density, τ is the attenuation constant, t is the time elapsed since the appearance of the trace.

All formulas for generating random distribution parameters are obtained by the inverse function method.

A random time for the appearance of a meteor trail t_0:

$$t_0 = -\frac{\ln(1-R)}{\lambda}, \quad (4)$$

where R is a random variable from a standard uniform distribution.

A random lifetime of the trail t_{life}:

$$t_{life} = -T_{mean} \ln(1-R), \quad (5)$$

where R is a random variable from a standard uniform distribution.

The experience of operating the COMET system has shown that the average lifetime of the trace is 0.5 seconds [8].

A random value of the linear electron density Q:

$$Q = \frac{q_{\min}}{1 - R + R\frac{q_{\min}}{q_{\max}}}, \quad (6)$$

where R is a random variable from a standard uniform distribution.

Simulation results

The potential accuracy of measuring the arrival time of the timestamp directly depends on the signal-to-noise ratio and the width of the signal spectrum [9-10]:

$$\sigma_t = \frac{\alpha}{hF_{eff}}, \quad (7)$$

where $\alpha = \frac{\sqrt{3}}{\pi}$, h – maximum signal-to-noise ratio at the output of the matched filter, F_{eff} – effective spectrum width.

We express from (7) the minimum value of the signal power at the receiver input to ensure the specified measurement accuracy (and hence synchronization):

$$P_r = \frac{\alpha^2 P_n}{2B(\sigma_t 2\Delta f)^2}. \quad (8)$$

Using (8), we calculate the minimum values of the signal amplitude U_r at the input of the receiver for a given accuracy.

A study of the dependence of the average waiting time of a meteor trail suitable for synchronization t_{wait} on the distance to the receiver showed that with an increase in the distance to the receiver, the waiting time increases, that is, the efficiency of the synchronization session decreases. In addition, an increase in the waiting time occurs when the power of the transmitter decreases (Fig. 2).

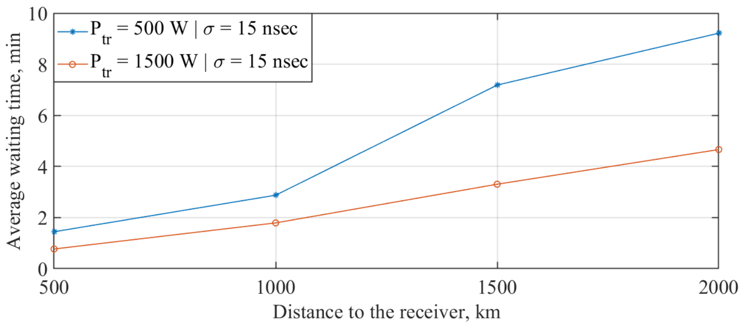

Fig. 2. The dependence of the average waiting time on the distance to the receiver or the different power of the transmitter

As can be seen in Fig. 2, the average waiting time does not exceed 40 minutes, which means that the transmission of a noise-like signal as a timestamp over a distance of 2000 km with a transmitter power of 1500 Watts and a given accuracy of 15 ns is possible, while it is necessary to have a receiver sensitivity of the order of 1.26e-08 V or less.

Conclusion

Transmission as a timestamp of the m-sequence allows to increase the noise immunity and secrecy of the meteor radio communication system, as well as to reduce the random error. The use of highly stable quantum generators (frequency standards) in meteor communication channels makes it possible to further reduce the random error during channel synchronization.

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