MINISTRY FOR THE DEVELOPMENT OF INFORMATION TECHNOLOGIES AND COMMUNICATIONS OF THE REPUBLIC OF UZBEKISTAN

TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES NAMED AFTER MUKHAMMAD AL-KHORAZMI

FACULTY OF RADIO AND MOBILE COMMUNICATION

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Methodological instructions for performing practical works on "SATELLITE COMMUNICATIONS " discipline

5350100 –"Telecommunication technologies (mobile systems)"

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Methodological guide for the implementation of practical work in the discipline "Satellite Communications"/ TUIT. 2022 y.

Satellite communication systems are in the process of rapid development. The study of these processes, awareness of the principles of building satellite communication systems are very important for the strategy of their implementation in our country. In this regard, this work will be very useful in the preparation of qualified specialists in the field of mobile communications.

This methodological manual is devoted to the study of the general principles of organizing satellite communication systems, organizing satellite television transmission of signals, on-board repeaters of satellite transmission systems, organizing multi-channel satellite communications, ODYSSEY and ICO satellite communication systems, the principles of constructing VSAT earth stations and the principles of constructing the transmitting part of the equipment for time multiplexing of channels.

The manual is designed for use in the educational process in the preparation of specialists in the direction of undergraduate studies: 5350100 - Telecommunication technologies (mobile systems).

Tashkent university of information technologies
named after Mukhammad al-Khorazmi, 2022

PRACTICAL WORK №1
STUDYING THE GENERAL PRINCIPLES OF THE ORGANIZATION OF SATELLITE COMMUNICATION SYSTEMS

1. The purpose of the work

Studying the principles of building satellite communication systems, the composition of earth and space stations.

2. Task

1. Get acquainted with the principle of classification of space and earth stations.
2. Get acquainted with the main indicators of terrestrial and space communication systems.
3. Calculate the parameters of the AP repeater.
4. Construct a signal level diagram over the span.
5. Write a report

3. Report content

1. Purpose and purpose of the work.
2. The main indicators of earth and space stations.
3. A simplified block diagram of the receiving path of a single-barrel AP.
4. The results of the calculation of the parameters of the AP repeater.
5. Building a diagram of signal levels on the span.

4. Brief theory

The composition of any SCS, despite their differences, includes several elements that are identical in purpose:

- space stations (SS), which are a relay (receiver-transmitter) device located on an artificial Earth satellite, with antennas for receiving and transmitting radio signals and support systems: power supply sources, antenna orientation systems (to Earth) and solar batteries (on the Sun), systems for correcting the position of satellites in orbit, thermal control, etc;
- earth stations (ES) of various types.

Let's take a closer look at the types of ESs.

Receiving APs of distribution systems (satellite broadcasting systems) are the simplest type of stations that only receive television programs and (or) other circular programs (Fig. 1), for example, sound broadcasting, images of newspaper pages; Typically, receiving APs are equipped with a small antenna to reduce costs, and the number of such APs in the system is large.

Transmitting ES of satellite broadcasting systems (ES of the feeder line, ES1 – in Fig. 4.1) - stations that transmit on the Earth - AES section of circular programs to be distributed over the network of receiving stations; if the transmitting ES is within the service area and it is possible to receive signals emitted by the satellite of this system, then such reception is usually carried out for quality control, broadcasting; There can be several transmitting stations in the system.

Transceiver ES MSS (ES1, 2, 3 in Fig. 4.1), operating in a duplex telephone network (including with the possibility of transmitting other types of messages over telephone channels or groups of channels - telegraph, data, sound broadcasting programs, etc.), as well as in the television program exchange network: such stations are often equipped with equipment that allows you to work through several trunks at the same time; often the transceiver stations of the telephone system are also the transmitter or receiver stations of the broadcast system; such are many ESs "Orbita" (ES1, ES2 in Fig. 4.1).

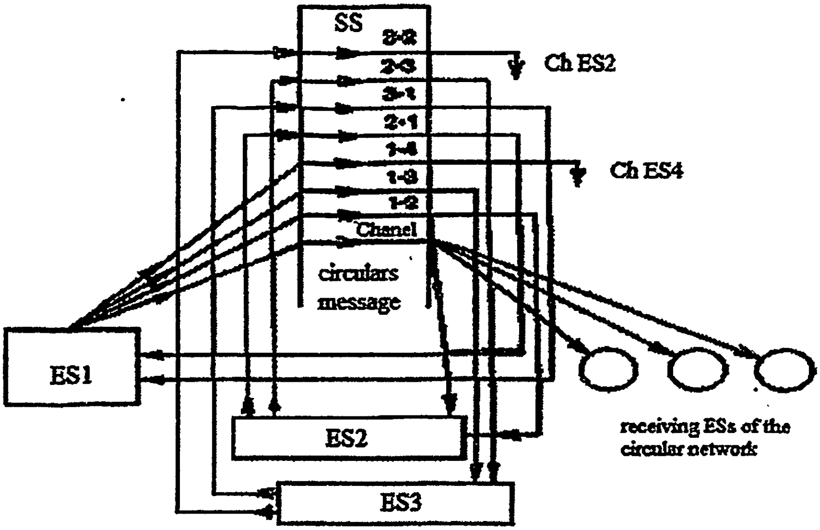


Fig.4.1. Scheme of organization of circular and duplex channels via satellite

Control ES - stations that control the operation mode of the space station repeater, the observance by the earth stations of the network of indicators important for the operation of the entire network - radiated power, transmission frequency, polarization, quality of the modulating signal, etc. The role of control APs in maintaining the normal operation of the system is great. Often the functions of the control station are assigned to one of the transmitting or transceiver stations of the network.

The control and central stations of the network usually have the ability to exchange information with the stations of the network through a specially created intercom subsystem. Usually it is possible to form this subsystem through the same satellite through which the main network operates AES, but in some cases it is necessary to use terrestrial intercom channels.

Earth stations of the AES command and control system - stations that control the operation of the SS and all other subsystems of the AES, monitor their condition, launch the AES into orbit during initial tests and commission the SS.

Connecting ground lines serve to connect ES with sources and consumers of transmitted information, since ES is usually removed from them for reasons of reducing the effects of interference, antenna closing angles, etc. These are connecting lines from a transceiver ES to an intercity telephone exchange (ITE) or another switching node of the telephone network, from the receiving station to the television transmitter, printing house, broadcasting station.

Remote equipment is that part of satellite communication equipment that is located not at satellite communication stations, but at other objects. So, the ITE can be equipped with echo-blockers necessary for the operation of satellite channels, sometimes equipment for sealing, channeling and even modulation, and the output signal of this equipment, having passed through the terrestrial connecting line (usually radio relay), goes directly to the HF path of the satellite communication line.

The communication system control center is a body that manages the operation of the system and its development, i.e. commissioning of new ES and AES, the schedule of their work, the provision of barrels to consumers, maintenance and repair work, etc. The control center is usually connected to the stations of the network by intercom channels. Sometimes the center can be combined with the transmitting station of the satellite broadcasting system or with the control ES.

4.1. Key indicators of earth stations

Frequency ranges for reception and transmission, for which the station equipment is designed - antenna, receiving and transmitting equipment; most FCS ES operate in the 4 or 11 GHz bands for receive and 6 or 14 GHz for transmit.

Quality factor of the station for reception G / T - the ratio of the antenna gain (in decibels at the reception frequency) to the total noise temperature of the station (in decibels relative to 1 K); reaches 42 dB / K for the largest antennas used in practice (32 m in diameter) and is 20 ... 31.7 dB / K for the ES of most national and regional systems.

Equivalent isotropically radiated power (EIRP) - the product of the transmitter power and the antenna gain (in the transmission band) relative to the isotropic antenna; is usually in the range of 50...95 dBW. For a simplified calculation of interference created by other communication networks, the maximum spectral density of the emitted ES EIRP (W / Hz) is often indicated, although an accurate calculation of crosstalk requires knowledge of the structure of the signals used in the system (type and modulation parameters, etc.). P.).

Antenna diameter has a decisive influence on the size and cost of the ES; it determines the quality factor and EIRP of the station, as well as its spatial selectivity; if the system uses separation of signals by polarization, it is necessary to know the cross-polarization characteristics of the antenna and indicate with which polarization the station works for transmission and reception. Antennas with a diameter of 1.5 ... 2.5 m to 12 m, sometimes up to 32 m are used on the ES of telephone exchange, from 0.45 to 2.5 ... 4 m on the ES of receiving circular information.

The antenna is also characterized by the indicators of the turntable and the entire system for pointing the antenna to the satellite; distinguish between full-rotary antennas, capable of being directed to any point in the sky, and non-rotary, having a limited area of operational guidance to the signal source; antenna guidance systems are also characterized by the possible speed and acceleration of angular displacement. In recent years, non-rotatable, slow moving and fixed antennas have been increasingly used, suitable for operation only with geostationary AES.

4.2. Main indicators of space stations

Basically, the space station is characterized by the same indicators as the ES: operating frequency range, quality factor, EIRP of each transmitter, polarization of emitted and received signals. However, the values of a number of parameters are significantly different from those indicated for ES. For example, the quality factor of the receiving path of the SS is usually -10 ... + 6 dB / K (which is caused not only by the smaller size of the antenna, but also by the use of a simpler input low-noise amplifier with a higher noise temperature), EIRP, as a rule , does not exceed 23.. .45 dBW, reaching 52.. .58 dBW on direct broadcast satellites.

An important characteristic of a space station onboard repeater is the number of trunks.

Barrel repeater or AP. or the trunk of satellite communications, we will call the transceiver path in which radio signals pass through common amplifying elements (common transmitter) in some common frequency band allocated to the trunk.

The entire frequency range in which the communication satellite operates is usually divided into some bands (27 ... 36, 72 ... 120 MHz wide), in which the signals are amplified by a separate path - the trunk. Several trunks may have common elements - an antenna, a waveguide path, a low-noise input amplifier.

On the other hand, on the ES, the band of one trunk can be separated by filters for the selection and subsequent detection of signals from different earth stations passing through the common AES trunk.

Instead of the term "barrel", the English term "transponder" is often used.

The number of barrels simultaneously acting on AES can be 6-12, reaching 27-48 on the most powerful AES. The signals of these trunks are separated by frequency, space, polarization.The number of trunks, their bandwidth and EIRP mainly determine the most important summary indicator of AES - its throughput, i.e. the number of telephone and television channels, or more generally the number of bits per second, that can be transmitted through a given AES. Of course, one can speak about the throughput of a satellite only conditionally, since it depends on the quality factor of the earth stations used in the system, as well as on the type of radio signals used; throughput is essentially a characteristic of the system, not AES. However, the concept of AES throughput (capacity) is often used in the literature.

Note that the bandwidth of the AES trunk depends to some extent not only on the main indicators - bandwidth and EIRP, but also on other parameters that determine the distortion of the transmitted signals: uneven amplitude characteristics, AM - PM conversion coefficient, uneven GTD features HF in the bore, etc. These parameters affect the mutual interference between the signals of different ESs, the reliability of signal reception and thus the energy losses due to the passage of signals through the non-ideal path of the AES airborne repeater.

Depending on the width of the radiation pattern of the onboard antennas, the satellite (or its separate trunk, if there are several antennas on board and they are different) is characterized by a coverage area - a part of the surface of the globe, within which the signal level from AES is provided, necessary for their reception with a given quality on an ES of a certain quality factor, and the ability to receive signals from ESs with a certain EIRP at the input of the AES is also guaranteed. Obviously, the AES coverage area characterizes the satellite communication system, and not just the AES itself.

The coverage area is determined by the beam width of the AES antenna and is calculated as the intersection of the Earth's surface with the cone of the antenna beam. The shape of this section depends on the location of the AES, the "aiming point" - the point of intersection of the axis of the main lobe of the AES antenna with the earth's surface, as well as on the instability of the position of the AES and the orientation of its antennas. In connection with the instability, the concept of a guaranteed service area is introduced, in which the previously specified reception and transmission conditions are maintained for any combination of deviations of the AES and the AES antenna from the average position.

The location point of the AES in orbit, the aiming point of its antenna, and the instabilities of these parameters are essential not only for calculating service areas, but also for calculating mutual interference between SCSs. For a simplified calculation of mutual interference, the maximum spectral density of the power flux emitted by the AES (W/m2.Hz) is often also indicated.

Finally, the most important AES indicator, which determines not only the reliability and uninterrupted communication, but, above all, the economic characteristics of the entire communication system, is the AES service life - the time to failure of the entire satellite or the allowable number of space station trunks, determined with a high probability - usually 0.9 or more. In modern AES, a service life of 10 ... 12 years or more has been achieved due to the high reliability of the elements, a flexible and branched redundancy scheme.

4.3. Key indicators of satellite communication systems

The system service area is a collection (combination) of service areas of individual AES included in the system (Fig. 4.2); it is somewhat different from the already introduced concept of the coverage area.

The word "aggregation" (rather than "sum") is used because the areas of individual AESs usually overlap (which is inevitable when continuous coverage is achieved and is useful for establishing communication between earth stations located in different areas), and therefore the common area is area is less than the sum of the areas of individual zones.

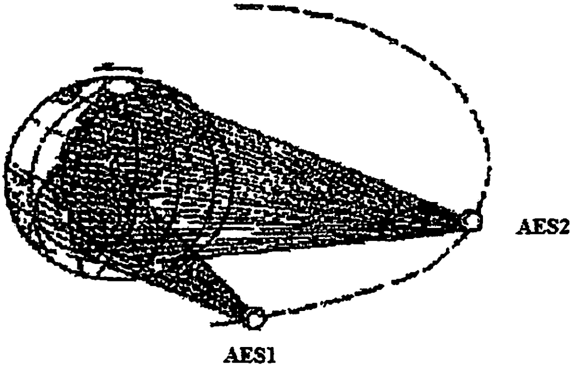


Fig 4.2. To determine the service area of a satellite communication system with multiple AES

The throughput of the system is the sum of the throughputs of the AESs included in the system. In this case, the word "union" (rather than "sum") is given the same meaning. The throughput of the system turns out to be less than the sum of the throughputs of individual AES, since for communication between stations operating through different AES, part of the channels is broadcast by two SSs in series - using two-hop lines (Earth - AES - Earth - AES - Earth) or direct inter-satellite connections (Ground - AES - AES -Ground).

If only one AES is used in the SCS, the service area and capacity of the system and the AES are the same.

System capacity depends to some extent on interference from other SCSs; the role of these interferences increases as the number of satellites in orbit increases.

Further, the satellite communication system is characterized by the number and placement of ES, the number of AES and the type of their orbit, the point of placement in geostationary orbit. The characteristic of the system is also the number of trunks on AES, their bandwidth, the frequency bands of trunks on the Earth–satellite and satellite–Earth sections.

One of the most important characteristics of the system is the multi—station access method - a method of combining signals emitted by various ES for their passage through the common trunk of the onboard repeater of the space station.

Multi-station access (MA) is used because it usually turns out to be uneconomical to create a number of trunks per AES equal to the number of ES in the system. MD is used with the separation of signals by frequency, shape and time. Any MD method leads to a loss of trunk throughput up to 3 ...6 dB, although in the most advanced systems (with time separation — MATS) these losses may not exceed 0.5...2 dB.

The energy characteristics of the communication system, the required frequency band, its electromagnetic compatibility with other systems are significantly affected by the modulation method used; frequency modulation (FM) is the most common when transmitting messages in analog form and phase modulation (PM) when transmitting messages in discrete form. Of the modulation parameters, frequency deviation is of the most important importance in FM, in PM — the number of carrier phases (modulation multiplicity), and in the transmission of television programs — also the method of sound transmission (time or frequency combination with the video signal, the frequency of the subcarrier, etc.). The modulation method and the parameters of the modulated signal must be consistent with the bandwidth and energy of the trunks of the communication system. Another important characteristic of the system is the quality of the message transmission channels organized in it — television, telephone, etc. Usually SCS is used to create international or long-distance long-distance communication channels, and the quality of these channels meets the requirements formulated in the recommendations of the International Telecommunication Union (ITU) or in domestic regulatory documents. However, in some satellite communication systems, based on their specific purpose or for economic reasons, higher or lower quality indicators are achieved or allowed. Thus, in television broadcasting systems with reception of signals by simple collective and especially individual installations, a reduced signal-to-noise ratio is often allowed. Sometimes, in telephone channels, a slightly reduced signal-to-noise ratio or reduced bandwidth is installed compared to those recommended for long-distance channels, if SCS is intended for specialized or intradepartmental (corporate, office) purposes. As in the previous case, in such specialized systems, simplified stations are close to the subscriber, and the quality of the channel for the subscriber remains acceptably high. In some SCS, built on the basis of frequency multi-channel access and transmission of each channel on a separate carrier, noise suppressors (companders) are used, the action of which is based on the peculiarities of noise perception with an audio signal. Companders allow you to reduce the visibility of noise by 10...20 dB and, accordingly, win in the energy of communication lines and the bandwidth of the communication system, but they do not make the channels universal, since this gain is not realized when telegraphic messages, data, etc. are transmitted over the channels of the tonal frequency. On the other hand, it is in satellite systems that the transmission of high-quality high-definition television signals is possible and carried out.

4.4. Composition of Earth and space stations

Consider the simplest Earth station designed to receive unidirectional information — a single-barrel receiving ES. The signals emitted by AES are received (Fig. 4.3, a) by the antenna 1 ES, intercepting electromagnetic radiation and converting it into electrical voltage. Further, the received signal is amplified by a low-noise input device 2 containing a low-noise amplifier, mixer, intermediate frequency pre-amplifier. The oscillations necessary for frequency conversion are formed by the heterodyne path 3. The main signal amplification is carried out in an intermediate frequency amplifier IFA 4, which includes a filter (or filters) that forms the bandwidth optimal for receiving the signal (the band is either close to the trunk band if the received signal occupies the entire trunk, as when receiving television programs, multi-channel telephone messages with temporary multi-station access, etc., or it is only part of the trunk band, for example, when receiving telephone signals in a system with frequency multi-station access). The amplifier is followed by a demodulator 5, which allocates the transmitted message, and terminal channel-forming equipment 6. For example, when receiving television programs in the device 6, synchro mixture regeneration, audio channel allocation, signal declassification, etc. can be carried out. The received information is transmitted via the ground connection line 7 to the consumer of the programs (or to the TV, if it is an individual reception station). In modern receiving devices, double frequency conversion is often used.

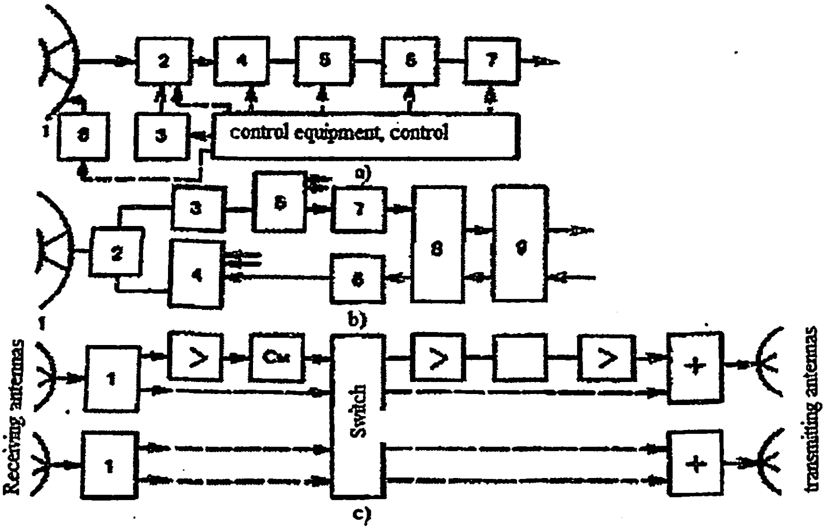


Fig.4.3. Simplified block diagrams of single-barrel receiver (a) and multi-barrel transceiver (b) ES, as well as SS on-board repeater (c)

Complex 8 is used for pointing antennas at AES; it includes a drive that moves the antenna and guidance equipment that controls its movement. In simple receiving stations, the antenna is usually stationary (there is only a mechanism for non-operational initial orientation) or has a mechanism for installation in several fixed positions (positioner).

More complex Earth stations designed for duplex communication and operating in several AES trunks are built according to a more general scheme (Fig. 4.3, b), where 1 is an antenna with a guidance complex; usually used simultaneously for reception and transmission; 2 is a filter for separation of reception and transmission; 3 is a low-noise amplifier; 4 is addition device (addition filter) of signals of transmitters of various trunks; 5— separation device (separation filter) of received signals of various trunks; 6 — transmitting device of the trunk; 7— receiver of the trunk; 8 — channel-forming equipment of the trunk; 9 — connecting line equipment. The diagram does not show the backup kits and switches to backup kits that are usually available on the ES. Let's consider the main elements of the radio engineering complex of the space station, which is part of the satellite communication system. This complex consists of two main parts — antennas and an on-board repeater. On board modern AES communications, several receiving and transmitting antennas are usually installed. This is due to the need to form various service areas in order to align the radiation of antennas with the placement of Earth stations on the Earth's surface, so as not to dissipate energy uselessly to those areas where it is not used. The high directivity of the AES receiving and transmitting antennas also helps to reduce mutual interference with other communication systems — satellite and ground-based, increases the efficiency of using the geostationary orbit. The signal received by the SS antenna goes to the input low-noise device 1 (Fig. 4.3, e), as which mixers, amplifiers on low-noise TWL or transistors are used on AES. The received signal is amplified at the receiving frequency, intermediate frequency and transmission frequency. In modern AES, not two-, but a single frequency conversion is often carried out, directly from the input to the output, while there is no IF amplifier.

The circuit can use devices for separating, switching, and combining signals (switchboard in Fig. 4.3, c), the purpose of which is to send signals addressed to one or another ES to transmitting antennas with the corresponding service area. Systems with high-speed reorientation of the narrow beam of the antenna (with beam switching) are promising, which allows communication with many ES via acutely directional antennas, without increasing the number of antennas on board the AES, repeatedly using the frequency band.

Figure 3 does not show backup elements and devices for switching to a backup; these schemes are usually quite complex, since the degree of redundancy varies for different elements of the path, depending on their reliability, importance for the viability of AES, service life.

In some cases, more complex signal processing is performed on the space station, for example, the conversion of the type of modulation, the regeneration of signals transmitted in discrete form.

5. Calculation of the parameters of the Earth Station repeater

Task:

- Determine the attenuation of the signal in free space.
- Determine radio signal losses in atmospheric gases.
- Calculate the signal level at the receiver input without fading.
- Determine the fading margin.
- Construction of a diagram of signal levels on the span.

Methodological guidelines for the calculation:

1. According to the specified values from Table 1.1 and the characteristics of the MINI-LINK 15th digital equipment, write out the initial data for the calculation.

2. Calculate the gain:

$$G = 20\lg(D) + 20\lg(f) + 17.5, \text{ dB}, \tag{5.1}$$

where **D**- is the antenna diameter, m;
f- is the operating frequency (taken from the presented interval), GHz.

When choosing antennas, it should be borne in mind that in practice, antennas with gain coefficients greater than 45 dB are not used.

3. Determine the attenuation of the signal in free space for different frequency ranges by the formula:

$$L_0 = 20\lg(4.189*104*R_0*f), \text{ dB}, \tag{5.2}$$

where **R_0** - is the length of the RRL interval, km.

4. Determine the linear losses of the radio signal in oxygen atoms lo and in water vapor dn according to the graph (see Fig. 1.6) and calculate the total losses in atmospheric gases:

$$L_g = (l_o + l_{\text{н}})\, R_0, \text{ dB} \tag{5.3}$$

5. Calculate the signal level at the receiver input in the absence of fading:

$$P_{rec} = P_{tr} + 2G - L_0 - L_g - L_{add}, \tag{5.4}$$

6. Determine the fading reserves for different operating frequency ranges, antennas and equipment.

$$M = P_{rec} - P_{rec}\, thr(10^{-3}), \text{dB} \tag{5.5}$$

where P_{res} $thr(10^{-3})$ - is the threshold level of the signal at the receiver input with the error coefficient k_{er} = 10^{-3} (determined from the parameters of the equipment).

7. Build a level diagram on the repeater interval.

1. Initial data: V = 16 Мбит/с; R_0 = 20 км, D = 1,2 м
   Radan Equipment-15
   Frequency range: 14,5–15,3ГГц; P_{tr} = 20 дБ; $P_{thr}(10^{-3})$ = - 83 dBm
2. Calculation of the gain
   $G = 20\ lg(D) + 20\ lg(f) + 17{,}5dB$,
   Where D - antenna diameter,m; f - operating frequency,GHz
   $G = 20\ lg1{,}2 + 20\ lg14{,}5 + 17{,}5 = 1{,}58 + 23{,}22 + 17{,}5 = 42{,}3\ dB.$
   Since $G = 42{,}3 < 45$, then the antenna selection condition is met
3. Determination of signal attenuation during flight.
   $L_0 = 20\ \lg\ (4.189\ 10^4\ R_0\ f), dB$,
   Where R_0 - the length of the RRL interval
   $L_0 = 20\ \lg\ (4.189 * 10^4 * 20 * 14{,}5) = 141{,}69\ dB$.
4. Determination of the linear losses of the radio signal in oxygen atoms $l_o = \gamma_o \cdot R_0$;; in water vapor $l_н = \gamma_н \cdot R_0$ (γ_o and и $\gamma_н$ are determined according to Appendix 1, depending on the operating frequency) and total losses in atmospheric gases.
   $L_g = l_н + l_o$,
   or:
   $L_g = (\gamma_o + \gamma_н)\ R_0$, dB.
   $L_g = (0{,}006 + 0{,}006)\ 20 = 0{,}24$ dB
5. Calculation of the signal level at the receiver input in the absence of fading:
   $P_{rec} = P_{tr} + 2G_1 - L_0 - L_g - L_{add}$,
   Where $P_{пд}$ - transmitter power level, dBm;

$L_{add} = 1\ dB.$

$P_{rec} = 20 + 2 \cdot 42{,}3 - 141{,}69 - 0{,}24 - 1 = -\ 38{,}33\ dB$

6. Determination of stocks for fading

$M = P_{rec} - P_{rec\ thr}(10^{-3}) = -\ 38{,}3 + 83 = 49{,}67\ dB.$

7. Construction of a diagram of signal levels on the span (Fig. 1.4) at the following points:

Point 1: beginning = 0 dB
Point 2: P_{tr} = 20 dB
Point 3: $P_{tr} - L_{add}$ = 19 dB
Point 4: $P_{tr} - L_{add} + G$ = 61,3 dB
Point 5: $P_{tr} - L_{add} + G - L_0$ = - 81,63 dB
Point 6: $P_{tr} - L_{add} + G - L_0 + G$ = - 39,33 dB
Point 7: $P_{tr} - L_{add} + G - L_0 + G + L_{add}$ = - 38,33 dB
Point 8: end = 0 dB

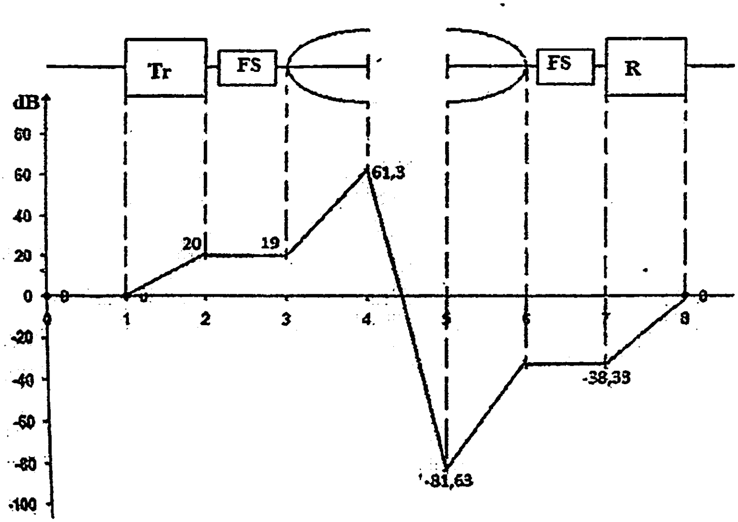


Fig. 4.4. Diagram of the signal levels on the span.

Table 4.1

Initial data on options

The last digit of the magazine number	V, Mbit/s	R_0, km	D, m
1	2	28	1,2
2	4	12	0,9
3	8	10	0,6
4	16	8	0,3
5	34	11	1,2
6	2	30	0,9
7	4	26	0,6
8	8	24	0,3
9	16	20	1,2
0	34	14	0,9

Questions

1. Give a classification of space and Earth stations.
2. Give a description of the earth control stations, earth stations of control and control systems, connecting ground lines, remote equipment and the control center of the system communication.
3. What are the main indicators of Earth stations?
4. List the main indicators of space stations.
5. What is meant by the coverage area and the service life of the satellite?
6. What are the main indicators of satellite communication systems?

PRACTICAL WORK №. 2

STUDY OF THE ORGANIZATION OF SATELLITE TELEVISION SIGNAL TRANSMISSION

1. The purpose of the work

Study of the principles of the organization of satellite television signal transmission.

2. Task

1. Get acquainted with the principle of the organization of satellite television signal transmission.
2. Get acquainted with the sequence of signal processing stages in satellite television broadcasting.
3. Calculate the signal-to-noise ratio of the satellite line
4. Make a report.

3. Report content

1. Purpose and purpose of the work.
2. The sequence of stages of signal processing in satellite television broadcasting.
3. Block diagram of the transmitting part of the digital broadcasting system.
4. Calculation of the signal-to-noise ratio of the satellite line.

4. Brief theory

The twentieth century is marked by huge achievements of mankind in various branches of science and technology, and most importantly – the penetration of one industry into another. When successes in the development of one industry are combined with successes in another, amazing results are obtained. These gigantic achievements made it possible to achieve such progress that even the most sophisticated science fiction writers of the last century could not dream of.

The discovery of radio, the introduction of radio communications and broadcasting, magnetic recording and electronic television, electronics and computer technology into everyday life on the one hand, and a grandiose breakthrough in the field of rocket and space technology on the other, made it possible to implement global television.

Unlike radio broadcasting in the ranges of long, medium and short waves, which are characterized by high "range", television, due to the wide frequency band of the television signal, has to be transmitted in the ranges of ultra short waves (UShW), the reception range of which is limited.

Therefore, to expand the reception area, the retransmission of the TV signal emitted by one transmitter is used by other transmitters (repeaters) located at acceptable distances from the first one. In space retransmission, television repeaters placed on artificial Earth satellites (AES) are used. Thanks to this, today any family has access to an almost unlimited number of TV programs, including those transmitted from the other side of the world. However, the unavoidable features of space retransmission do not allow receiving TV transmissions from the satellite as simply as it is done from a terrestrial television center or repeater. One of the features of a communication satellite is the limited energy potential of a satellite repeater, therefore, satellite broadcasting traditionally uses processing methods that require a minimum signal-to-noise ratio at the receiver input. Satellite television is one of the types of practical use of satellite AES. Currently, in the field of television, artificial Earth satellites are used for the international exchange of television programs, for the distribution of television programs among broadcasting organizations, for the retransmission of terrestrial television transmitters, among cable networks, as well as direct television broadcasting (DTV), the purpose of which is to transmit television programs from satellites in a way that allows direct reception of television broadcasts by individual viewers. In addition, the satellite is used for relaying images of current texts of newspaper strips, long-distance and international telephone communications, audio broadcasting programs and other information.

The satellite placed in orbit around the Earth AES contains electronic equipment that receives a certain amount of information from the Earth via a radio channel. The signals of the received information by the satellite equipment are amplified, converted in frequency and radiated back to Earth (retransmitted). The satellite is equipped with antennas for receiving and transmitting, and solar panels and batteries for powering the equipment.

At first, artificial satellites were used for these purposes, which turned in elliptical orbits, and then geostationary satellites were used, which led to simplification and cheaper equipment, and the round-the-clock illumination of solar panels by the sun made it possible to significantly increase the power of satellite transmitters.

Based on their purpose, according to accepted international agreements, all satellite systems transmitting TV programs are divided into fixed satellite service (FSS), mobile satellite service (MSS) and broadcasting satellite service (BSS).

FSS is a radio communication service through a space station located on the AES, between Earth stations located at certain (fixed) points. In the FSS system, satellite-transmitted TV signals can be received by special ground stations with high quality.

MSS is a radio communication service between mobile Earth stations via one or more space stations.

FSS is a radio communication service in which the signals of space stations are intended for direct individual reception by the population using relatively simple and inexpensive installations with the so–called subscriber quality.

The functions of the FSS include not only the retransmission of TV broadcasts: the bulk of the information of this service is occupied by duplex telephone communication, telegraph, images of newspaper strips, and in the future – video telephone communication. For each of these services, certain frequency bands are allocated, which are different for the Earth-Space and Space-Earth lines. This is necessary for decoupling between transmitters and receivers. The first domestic systems "Orbit" and "Intersputnik", as well as the subsequent "Screen" and "Moscow", which began operating in 1976 and 1980, belong to the fixed service, and "Intelsat" and "Eutelsat" belong to the foreign ones. The radio broadcasting service includes the currently widely used domestic STV-12 system (satellite television broadcasting in the 12 GHz band), as well as foreign TDF, TV-SAT and others systems. It should be noted that the separation between the FSS and BSS systems is not entirely clear. Thus, the Ekran-M system could also be used to receive TV broadcasts by individual viewers using the Screen subscriber receiver manufactured by the industry. This was facilitated by the fact that the television signal was transmitted by a satellite repeater at frequencies of decimeter waves in the range of 702... 726 MHz.

It should also be noted that the power of FSS satellite transmitters, as a rule, is significantly less than that of BSS transmitters, since FSS ground stations are equipped with oversized antennas that have significantly higher gain values. The diameter of the parabolic reflectors of the antennas of the ground stations of these services sometimes reaches 24 meters. This makes it possible to use satellite transmitters with a power of about tens of watts, unlike the power of BSS transmitters, which reaches 200 watts.

In recent years, thanks to the successes achieved in the development of UHF technology, it has become possible to create relatively simple and inexpensive installations with antennas of acceptable sizes for individual reception of television broadcasts not only of broadcasting, but also of fixed service.

Therefore, many viewers from different countries purchase installations for receiving TV broadcasts from FSS satellites. In this regard, the most interesting are those FSS satellites whose transmitters operate at frequencies adjacent to the VSS frequencies (11.7 ...12.5 GHz). These are the frequency bands 10.7...11.7 and 12.5...12.75 GHz. Within these frequency bands, transmitters of satellites of the international satellite communications Organization IntelSat, the European Satellite Communications Organization EutelSat, as well as satellites belonging to the commercial associations Telecom (France), Kopernicus (Germany), Astra (Luxembourg), etc. operate.

In television systems, the television radio signals emitted by satellite transmitters differ significantly from the signals emitted by ground centers.

Another feature is the use in satellite systems of direct television broadcasting of a carrier frequency located in the centimeter wave range, which includes the 12 GHz band, unlike terrestrial television, which broadcasts only on meter waves. At such high frequencies, the transmission of the received signal from the antenna to the television receiver using a coaxial cable, as is customary in terrestrial television, is simply impossible. These features require the appropriate construction of a circuit of a television receiver or an additional device (set-top box) to a standard TV intended for receiving terrestrial television.

The creation of an effective algorithm for digital TV signal processing has become possible on the basis of great achievements in the development and production of ultra-large integrated circuits (ULIC). The MPEG standard has become the main encoding algorithm. The algorithm underlying MPEG standards includes a certain basic set of sequential procedures.

The RGB component TV signal is used as the source, then it is matrized into a YUV signal; sampling, as in the digital standard "4:2:2", is carried out with clock frequencies of 13.5 MHz for the brightness signal and 6.76 MHz for color-difference signals. At the preprocessing stage, information that complicates encoding, but is insignificant from the point of view of image quality, is removed. Usually a combination of spatial and temporal nonlinear filtering is used.

The main compression is achieved by eliminating the redundancy of the TV signal. There are three types of redundancy - temporal (two consecutive image frames differ little from each other), spatial (a significant part of the image consists of monotonous equally colored areas) and amplitude (the sensitivity of the eye is not the same to light and dark elements of the image). Temporary redundancy is eliminated by transferring the image of its differences from the previous frame instead of the frame. Simple frame subtraction was significantly improved when it was noticed that most of the changes appearing in the image can be interpreted as the displacement of small areas of the image.

By splitting the image into small blocks (16x16 elements) and determining their location in the previous frame, you can find a set of parameters for each block showing the direction and value of its displacement. This set is called a motion vector, and the whole operation is called a prediction with motion compensation.

Only the motion vector and a relatively small difference between the current and predicted block are transmitted over the communication channel. At this stage, spatial redundancy is eliminated - the difference signal is transformed from the spatial to the frequency domain, carried out using a two-dimensional discrete-cosine transformation (DCT). The DCP converts an image block from a fixed number of elements into an equal number of coefficients. This has two advantages. Firstly, in the frequency domain, the signal energy is concentrated in a relatively narrow frequency band (usually on the LF) and a small number of bits is sufficient to transmit insignificant coefficients. Secondly, the decomposition in the frequency domain maximally reflects the physiological features of vision.

The next stage of processing consists in adaptive quantization of the obtained coefficients. The set of coefficients of each block is considered as a vector, and the quantization procedure is performed over the set as a whole (vector quantization). The evaluation shows that the described compression procedure is close to the theoretical limit of Shannon information compression.

The amplitude redundancy of the original signal is eliminated at the stage of encoding the message before feeding it into the communication channel. Not all values of the motion vector and block coefficients are equally probable, so statistical coding with variable codeword length is used. The shortest words are assigned to the events with the highest probability. Additional compression is achieved by encoding in the form of an independent symbol of groups of zeros. A distinctive feature of MPEG1 and MPEG2 standards is their flexibility. They can work with the image decomposition parameters of 525 lines at 30 frames per second and 625 lines at 25 frames per second, are suitable for image formats 4:3, 16:9, etc., allow the encoder to be improved without changes in already stopped decoders. For satellite television, MPEG2 is certainly more promising, designed for processing the input signal with interlaced scanning and different digital stream speeds (4...10 Mbit/s or more), each of which corresponds to a certain resolution.

According to this parameter, four levels are defined in the standard: low (at the level of a household video recorder), basic (studio quality), high-definition television with 1440 elements per line and full HDTV with 1920 elements. According to the complexity of the processing algorithm used, the standard contains four profiles: simple - according to the algorithm described above; basic - with the addition of bidirectional prediction; improved basic - with an improvement in either the signal-to-noise ratio or spatial resolution and promising - with the possibility of simultaneous processing of color-difference signals.

It can be calculated that in a satellite channel with a bandwidth of 20...25 Mbit/s can transmit four to five programs of good quality corresponding to the main channels of program delivery, or 10...12 programs with quality corresponding to a VHS video recorder.

An integral part of the MPEG1 and MPEG2 standards includes algorithms for transmitting audio signals with digital compression, which allow reducing the speed of the digital stream by six to eight times without subjectively degrading the sound quality. One of the widely used methods is called MUSICAM.

The initial signal is an PCM sequence obtained by strobing the original audio signal with a clock frequency of 48 kHz and converting it to digital form with an accuracy of 16 bits/count. It is recognized that such a digital signal corresponds to the sound quality of a CD (CD-quality). To use the spectrum effectively, it is necessary to reduce the maximum speed of the digital stream.

The new coding technique uses the properties of human perception of sound associated with spectral and temporal masking. Quantization noises dynamically adapt to the masking threshold, and only those details of the sound that can be perceived by the listener are transmitted in the channel. This idea is implemented in the encoder. Here, with the help of a block of filters, the signal is divided into 32 partial signals, which are quantized in accordance with the control signals of the psychoacoustic model of human hearing, which uses an estimate of the masking threshold to form these control signals. At the output of the encoder, a set of code words is formed from partial samples, which is then combined into a frame of a given duration. The output speed of the encoder, depending on the quality requirements and the number of programs in the channel, can be 32, 48, 56. 64, 80, 96, 112, 128, 160 or 192 Kbit/s per monoprogram. The speed of 32 Kbit/s corresponds to a normal voice channel, 48 Kbit/s corresponds to terrestrial AM broadcasting. At a speed of 256 Kbit/s per stereo pair, the quality of the CD is not only ensured, but there is also a significant margin for subsequent processing.

The system part of the MPEG2 standard describes the integration into a single digital stream of individual streams of image, sound, synchronization, data of one or more programs. For transmission in an environment with interference, a "transport" stream is formed, including means to prevent errors and detect lost packets. It contains fixed-length packets (188 bytes) containing a start byte, a prefix (3 bytes) and a payload area. Before being fed into the communication channel, the signal is subjected to additional noise-resistant coding and enters the modulator. These operations are not included in the MPEG standard and can be performed in different ways in different satellite systems, which deprives these systems of hardware compatibility. European countries have managed to solve this problem by developing an MPEG2-based standard for multi-program digital TV broadcasting DVB, which normalizes the weight of the operation on the transmitting side up to the signal input of the UHF transmitter.

The DVB standard uses cascade noise-tolerant coding. The external code is a shortened Reed-Solomon code (204.188) with t =8, providing an "error-free" reception (the probability of an error at the output is less than 10-10) with the probability of an error at the input less than 10-3. The internal code is ultra-precise with a relative speed of 1/2, 2/3, 3/4, 5/6 or 7/8 and a code limit length of K= 7, decoding is carried out according to the Viterbi algorithm with a soft solution.

On the receiving side, the decoder performs all the above operations in reverse order, restoring the output image very close to the original one.

Another specific feature of a satellite broadcast repeater is its operation in a non–linear mode near the saturation point of the output amplifier stage, since it is in this mode that it is possible to obtain the maximum output power.

In this mode, the digital currents of several programs are combined into a common stream and modulate a single carrier frequency. Angular modulation methods are used to reduce nonlinear distortions.

The method of using one or more channels per carrier is also used, which requires switching to a linear output power mode, which is inefficient in satellite broadcasting.

Satellite television broadcasting is carried out in the DVB-S standard. The sequence of processing steps is shown in Fig.4.1.

The transport packets with a length of 188 bytes received at the input of the modulator contain a synchro byte and 187 bytes of data. An internal synchronization cycle is formed in the modulator, which includes 8 packets - the first packet with an inverted starting sync group, the rest with an uninterted one. The purpose of synchronization is to eliminate uncertainty during data transmission.

Symbolic synchronization is performed by the clock frequency of transport packets, cyclic synchronization is performed by inverted starting synchro groups.

To prevent unauthorized reception, the traffic flow enters the scrambler.

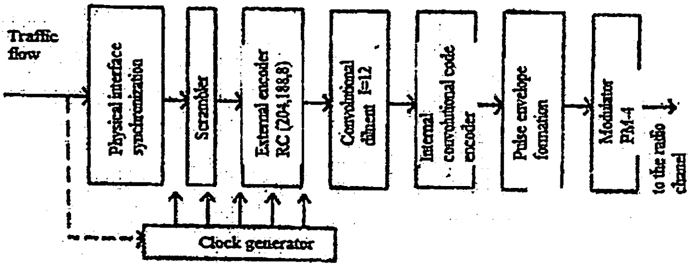


Figure 4.1. Sequence of signal processing stages in the satellite TV broadcasting

After scrambling, the data of the transport stream is subjected to noise-resistant encoding by a cascade code, in which the Reed–Solomon code is used as an external one, and the convolutional code is used as an internal one.

Such a high requirement for the error rate is due to the concept adopted by DVB, according to which a digital channel should be universal and suitable for transmitting not only television, but also any other digital streams.

To protect against long-duration batch errors, convolutional data interleaving is performed in the encoder. In the decoder, the movement is restored.

The convolutional code decoder implements the first level of the protection code and must operate at the error rate of the input signal, reducing the error rate in the output signal to an acceptable value required for the operation of the PC code. The decoder performs direct error correction.

Switching from the base speed of ½ to other values is carried out by selectively striking out – punching – some characters. This somewhat reduces the correcting ability of the code, but at the same time reduces its redundancy, allowing you to free up capacity for useful data.

The main type of modulation in the DVB-S standard is FM4, although in some cases FM-8 is used. The bandwidth of a radio channel operating according to the DVB-S standard depends on the bandwidth of the trunk, the type of modulation and the relative encoding speed.

Depending on the required quality of the transmitted information, the data transfer rate of the digital TV signal can vary in the range from 1.5 to 15 Mbit/s. To transmit an image that has the quality of a studio analog video signal, a speed of 6 to 8 Mbit/s is required. The stereo audio signal, depending on the required quality, is transmitted at a transmission rate of 128-256 kbit/s.

Consider, for example, a set of equipment for digital compression of a television signal of the MPEG/DVB-S satellite standard. This equipment has the ability to connect a TV signal source with various interfaces - composite (dialog) and digital at the output of fiber-optic communication lines of the Central Earth Station.

If there are analog interfaces at the output of the dedicated line, then analog-to-digital converters (ADCs) of the video signal and the audio signal are installed at the input of the compression equipment. The video signal ADC performs an 8-bit conversion of the input composite analog signal of the SECAM standard into a digital signal of the SDI format (Serial Digital Interfuse — serial digital interface).

The audio signal ADC converts analog audio signals of two stereo pairs into two digital AES/EBU streams (a two-channel digital audio signal used as a source for encoders (MPEG-2 standard).

Prepared TV programs in SD1 format are received at the input of a video encoder that provides information compression and the formation of digital transport streams (Fig. 4.2). AES/EBU audio data are elements of an audio compression encoder.

Compression encoders, on the stable operation of which the quality and reliability of the entire system largely depends, are the most important component of the digital broadcasting network complex. To increase reliability, compression encoders are provided with a "hot" backup with automatic switching to a backup set.

The input signal is switched using a high-speed matrix switch. In the backup encoder, the necessary initial settings are automatically set — flow rate, resolution, etc. Each encoder, as a rule, has two equivalent compressed signal outputs in the format of a packaged elementary stream (PEP), which are connected to the inputs of the main and backup multiplexers.

The choice of the sound transmission method is connected with another aspect of network construction - the choice of the location of digital compression equipment. Modern broadcasting complexes, as a rule, are located in several spatially spaced buildings, in particular, the program preparation complex and the transmitting center (especially in satellite broadcasting systems) can be spaced for many tens of kilometers.

Compression occupies an intermediate position between the preparation of programs and their transmission, therefore, compression equipment can be successfully placed both in the program preparation complex and in the transmitting center.

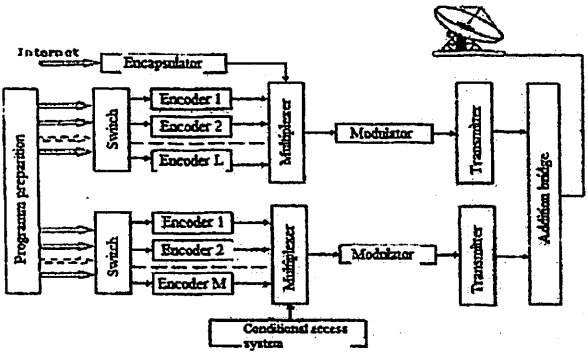


Figure 4.2. Block diagram of the transmitting part of the digital broadcasting system

With a large distance to the transmitting center, the placement of compression equipment as part of the program preparation complex is more economical, since in this case it will not be necessary to transmit the original TV programs over the communication lines, but digital streams compressed several times. If the compression equipment is located on the transmitting center, then the transmission of embedded sound will certainly be a more economical solution than the separate transmission of video and audio data.

Compressed signals are sent to the input of the multiplexer. Here the total transport flow of the DVB/ASI standard is formed.

Asynchronous Serial Interface - asynchronous serial interface) in accordance with the requirements of the 1SO/IEC13818 standards with a packet length of 188 bytes. In addition to audio and video signals, the package also includes special software and service information in the form of PSI/SI (Program Specific Information/Service Information) tables, conditional access system messages, electronic program guide signals, etc.

Conditional access equipment must be located in the immediate vicinity of the multiplexer.

User data usually arrives at Earth Stations in the IP (Internet Protocol) format and is translated into the transport stream format (most often DVB-ASI). It can be placed near the multiplexer or connected to the multiplexer by a connecting line allowing the passage of signals in the ASI format (150...250 m for coaxial cable or 20...40 km for an optical line). The device for entering Internet information into the transport stream can be located both at the Internet provider and at the transmitting center.

The configuration of the transmitting equipment assumes the presence of redundancy.

5. Calculation of the signal-to-noise ratio of the satellite line.

Task:

- Determine the signal-to-noise ratio at the RF input of the receiver.
- Determine the VTB (FM) gain in relation to the signal – fluctuation noise provided by the TV receiver.
- Determine the signal-to-noise ratio at the low-frequency end of the satellite line (in dB) with the old and new filter.

Methodological guidelines for the calculation:

1. According to the specified values from Table 5.1, write out the initial data for the calculation.

2. Calculate the gain in relation to the signal – fluctuation noise provided by the TV receiver:

$$B_{TV}(FM) = \frac{1{,}5\Delta f_n \cdot (f_g)^2}{F_{up}^3} \tag{5.1}$$

where f_g is the peak frequency deviation allocated to the TV signal;
$f_g = f_{g0} + \Delta f_g$
$F_{up} = 6$ MHz – the upper frequency of the TV signal spectrum;

3. Calculate the signal-to-noise ratio at the input and output of the receiver when transmitting TV by FM method (separately for the old and new type filter):

$$\left(\frac{P_c}{P_n}\right)_{out} = \left(\frac{P_c}{P_n}\right)_{in} + B_{tv}(FM) + B_{up} \cdot \alpha + k \tag{5.2}$$

where Vtv(FM) is the gain in relation to signal – fluctuation noise provided by the TV receiver;

B$_v$ – visometric coefficient;

α – gain in thermal noise from the introduction of thermal linear pre-distortion;

k=8 – conversion of the sinusoidal signal span into an effective value.

B$_v$·α =18,1 dB (for the old type filter);

B$_v$·α =14,3 dB (for a new type of filter).

Calculation example:

1. Initial data:
Frequency deviation $f_{g0} = 11{,}5$ MHz.
Instability of the heterodyne frequency $\Delta f_g = 0{,}5$ MHz.
Effective frequency band $\Delta f_n = 36$ MHz.
The total signal-to-noise ratio on the satellite line
$(P_s/P_n)_{in} = 16$ dB

2. Calculation of the gain in relation to the signal-fluctuation noise provided by the TV receiver:
$B_{tv}(FM) = 1{,}5 \cdot 36 \cdot 10^6 \cdot (11{,}5 + 0{,}5)^2 \cdot 10^{12} / 6^3 \cdot 10^{18} = 36$ *Hz*

With values of $B_{TB}(ЧM)$ 30-40 Гц, the winnings amount to~15,56 dB

3. Determination of the signal-to-noise ratio at the input and output of the receiver when transmitting TV using the FM method for an old-type filter.

$$(P_s/P_n)_{out} = 16 + 15{,}56 + 18{,}1 + 8 = 57{,}66\ dB.$$

4.Determination of the signal-to-noise ratio at the input and output of the receiver when transmitting TV by the FM method for a new type of filter.

$$(P_s/P_n)_{out} = 16 + 15{,}56 + 14{,}3 + 8 = 53{,}66\ dB.$$

Table 5.1.

Initial data on options

The last digit of the magazine number	f_{g0}, MHz	Δf_g, MHz	Δf_n, MHz	$(P_s/P_n)_{in}$, dB
1	12	0,3	32	10
2	11,7	0,4	33	12
3	11	0,5	34	13
4	11,2	0,6	35	15
5	11,5	0,3	36	16
6	12	0,4	36	11
7	11,7	0,5	35	14
8	11	0,6	34	13
9	11,2	0,3	33	15
10	11,5	0,4	32	12

Security questions

1. The principle of the organization of satellite television signal transmission.
2. Types of satellite services.
3. A characteristic feature of signal generation.
4. The need to compress information in the traffic flow.
5. Block diagram of the transmitting part of the digital broadcasting system.

PRACTICAL WORK №. 3

STUDY OF ON-BOARD SATELLITE REPEATERS TRANSMISSION SYSTEMS

1. The purpose of the work

Study of the principles of construction of on-board repeaters of space radio communication systems.

2. Task

1. Familiarize yourself with the structural diagram of the on-board transmitting device.
2. Get acquainted with the element base used in high-power output amplifiers.
3. Familiarize yourself with the purpose of the on-board repeater input receiver.
4. Calculate the communication session and the flight paths of the satellite
5. Make a report.

3. Report content

1. The purpose of the work.
2. Block diagram of the BRTR transmitter (power addition) on the teacher's assignment.
3. Advantages and disadvantages of solid-state BATR transmitters.
4. Three main ways of adding a signal in the microwave path.
2. Calculation of the communication session and the flight path of the satellite

4. Brief theory

The main parameter of the on-board repeater (OBR), which determines the resource and quality characteristics of the communication system, is the power of the transmitter, the maximum value of which is limited by a number of factors:

- the maximum power of the primary power sources of the satellite;
- the ability to remove dissipated heat outside the satellite;
- reducing the durability and reliability of electronic devices while increasing their power.

The transmitters of most of the heterodyne-type BRTRS are built according to the traditional scheme (Fig. 4.1), consisting of a powerful frequency converter and a powerful amplifier with the necessary set of filtering and matching elements.

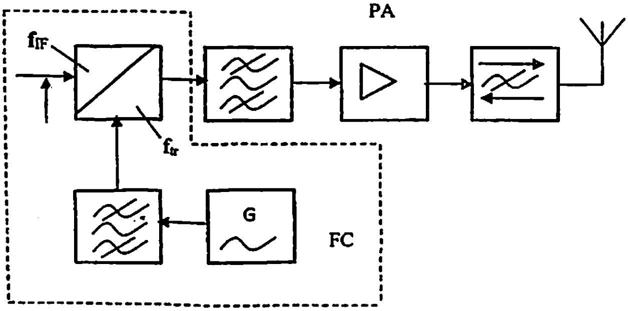


Fig. 4.1. Block diagram of the OBR transmitter

Most often, transmitters amplify signals in the band of one trunk, but sometimes they are also used to simultaneously amplify the signals of several trunks. The main element of the transmitter is a powerful output amplifier (in direct transfer a trunk, a powerful amplifier is understood as a transmitter), since it is on it that a significant part of the energy consumed by the entire OBR, mass and volume falls. Various microwave devices, traveling wave lamps (TWL), klystrons, solid-state devices (transistors, tunnel, avalanche-span diodes, etc.) are used as the actual amplifying element, depending on the purpose, required power, frequency range, mass, overall dimensions, EF, service life, etc.). TWL constitute the most numerous and rapidly developing class of UHF vacuum devices for on-board equipment, the wide application of which in this field is explained by the fact that they have a number of advantages compared to other UHF devices in the range: high gain, broadband, the ability to operate in pulsed and continuous modes in a wide range of output powers.

The TWLS used in OBR are also distinguished by high EF, compactness, low weight, high durability (up to 100.150 thousand hours) and reliability. These devices operate at voltages less than 6500 V, their design has sufficient rigidity and is able to withstand strong vibrations and shock loads. In fact, all TWL used in OBR have the same design, with the exception of small modifications related to the performance of specific specific OBR functions.

Figure 4.2 shows curves showing the highest values of output power and EF achieved on TWL of various types.For OBR, medium-power TWLS are of the greatest interest, and special economical and small-sized TWLS are created for these purposes. Based on the conditions of application of TWL in on-board maintenance-free equipment, they are subject to very high requirements for EF, durability, overall dimensions and weight.

These methods include:

- changing the phase velocity of the delayed wave along the length of the lamp or correcting the synchronization of the speed;

- formation of a discrete characteristic;

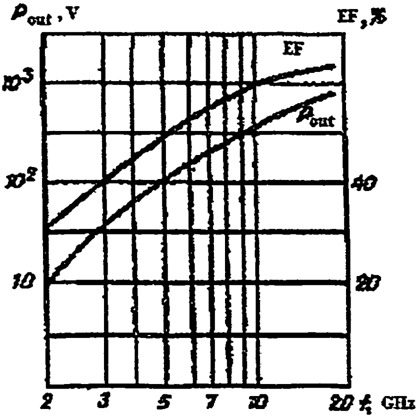


Fig.4.2. Dependences of maximum output power values and EF from the frequency for TWL

- multi-stage recovery in the collector (lowering the potential of the collector or the sequence of collectors to a value lower than the potential of the decelerating structure, which makes it possible to recover some of the unused energy from the working electron beam).

Usually the TWL gain is 40...50 dB, and EF – 64...50%.

The required mode according to the output power level is set by selecting the input power level. On the amplitude characteristic of TWL, two characteristic regions are distinguished, corresponding to two modes of operation.

In linear mode (small signal mode), the gain has a constant value, and the output power varies proportionally to the input. The maximum output power of TWL in linear mode is less than the nominal power by 3...6 dB.

In the saturation mode (large signal mode), the linear dependence of the output power on the input is violated, an increase in the input signal does not lead to a further increase in the output power due to the limited power of the electron beam. In saturation mode, the steepness of the phase amplitude characteristic of TWL increases sharply, which is the dependence of the phase shift introduced by TWL on the amplitude of the input signal, which leads to the transformation of amplitude modulation into phase (amplitude-phase conversion). Thus, a parasitic AM, for example, of a frequency-modulated signal at the TWL input leads to the appearance of a parasitic FM and, consequently, to nonlinear signal distortions.

In the output power amplifiers on TWL, for reasons of economy, it is desirable to use a lamp operating mode close to saturation (nominal). When transmitting broadband signals in saturation mode or near saturation mode, it is necessary to take into account the resulting distortions. Acceptable distortion levels depend on the type of modulation – single–signal FM or FM with multiple carriers – and on the type of multi-station access - MATD or MAFD.

Two phenomena that occur in TWL – the nonlinearity of the amplitude characteristic and the AM-FM transformation – are the causes of mutual interference when amplifying several signals.

Klystrons are also used in OBRC terminal amplifiers. So, in the STV "Screen" system developed in Russia, operating in the range of 702... 726 MHz, a straight-span klystron with an output power of 200...300 Watts with a bandwidth of about 24 MHz at the level of 2 dB is used. The use of klystrons in on-board devices is limited due to their narrow band. The advantages of klystrons include simplicity of design, a smaller number of supply voltage ratings compared to TWL, and high EF. Otherwise, klystron amplifiers are similar to the TWL amplifier with all their advantages and disadvantages (non-linearity of the transfer characteristic, amplitude-phase conversion, etc.).

Solid-state devices as OBR power output amplifiers have been used only recently in connection with the success of semiconductor electronics, which significantly increase the power of transmitters. The development of UHF semiconductor transmitters for OBR goes in two main directions: the creation of new powerful UHF transistors and the addition of the power of semiconductor generators using multi-pole circuits or the addition of power in space using phased array antennas (PAA).

The advantages of solid-state OBR transmitters in comparison with electro-vacuum transmitters are as follows:

- as a rule, significantly greater durability;
- low values of supply voltages (the first ones require no more than units or tens of volts and only one or two nominal values for power supply, the second ones require a whole set of voltages of various nominal values for power supply, the maximum values of which are several kilovolts even with a relatively small output power of the UHF signal);
- the use of semiconductor devices makes it possible to use microelectronics methods in the manufacture of various devices and blocks included in OBR transmitters, which, in turn, causes a significant reduction in the mass and overall dimensions of the latter;
- powerful semiconductor devices have almost instant readiness for operation compared to electro-vacuum devices, in which the incandescent circuit requires preheating. This makes the communication system more flexible and operational.

According to some sources, a significant improvement in the parameters of the OBR trunk was achieved in the satellites of the American RSA Satcom system due to the use of a semiconductor power amplifier (SPA). The replacement of TWL in them with SPA (GaAs field-effect transistors) made it possible to significantly improve the characteristics and reliability of the OBR transmission path. In addition, according to the same work, SPA has a higher linearity of the characteristic, especially in the operating mode near the saturation point. So, for SPA, the level of intermodulation distortion of the third order (when transmitting two carriers) has been achieved, 3 ...8 dB less than for TWL.

The consequence of these advantages is a significant reduction in weight and overall dimensions, increased efficiency, durability and reliability of solid-state OBR transmitters compared to electro-vacuum, all other things being equal.

Along with the advantages, it should be noted the disadvantages of such transmitters:

• semiconductor devices are sensitive to deviations, even short-term, from the permissible operating mode, which can lead to a breakdown of the p-p junction and complete failure of the device; therefore, special measures have to be taken in the transmitter to protect against accidental adverse factors;

• the power of semiconductor devices is limited, and for most of them with increasing frequency / it decreases by law.

There are three main ways of addition: using multi-pole circuits; using multi-element headlights; in a common resonator. In the first method, a large number of the same type of amplifiers are connected to the summing device, the power of which is supplied to the total output load; in the second method, the addition of signal powers is performed in space using headlights, including a large number of correspondingly oriented irradiators, each of which is excited from an independent amplifier.

The third method is used only to add up the power of the microwave generator diodes located in a common resonator. In practice, the first method allows you to increase the power of the transmitter relative to the power of one transistor by 15...20 dB, the second method is 30 dB...40 dB, the third one is 10...13 dB.

The main requirements that the listed summation methods must meet:

1. The signal power at the output of the addition device is equal to or close to the sum of the nominal capacities P_{nom} of individual n amplifiers: $P_{gen}=nP_{nom}$.

2. All amplifiers must be mutually independent, i.e. decoupled from each other. Failure of any amplifier should not affect the operating mode and output power of all other amplifiers.

3. When m amplifiers fail out of the total number, the power in the load should fall by as little as possible, at best — no more than m P_{nom}.

Most often, the addition of UHF power amplifiers is carried out using so-called bridge devices that provide pairwise addition of signals. Bridge devices belonging to the class of directional couplers (DC) are mainly used, i.e. these are eight-pole devices designed for directional energy branching, the distinctive feature of which is as follows: when one of the four DC channels is excited, energy enters only two channels. The same DC can also be used for the reverse procedure — dividing the power by half (i.e. reducing the power by 3 dB).

There are various options for constructing circuits of transistor transmitters with the addition of power amplifiers based on bridge devices. At the same time, the number of folded power amplifiers should be equal to 2n, which is provided by the use of (2n – 1) bridge devices. Using various variants of multi-pole adders-dividers, devices for adding the capacities of a large number of UHF amplifiers are implemented. Such devices consist of three main parts: a signal power divider, two identical UHF amplifiers and a power adder.

For example, Figure 4.3 shows a scheme for adding the capacities of four amplifiers, built on the basis of quadrature bridge devices with ballast loads carried out. This scheme, which allows you to add signals of sufficiently high power, is not difficult to extend to a larger number of identical amplifiers or amplifier blocks stacked in pairs.

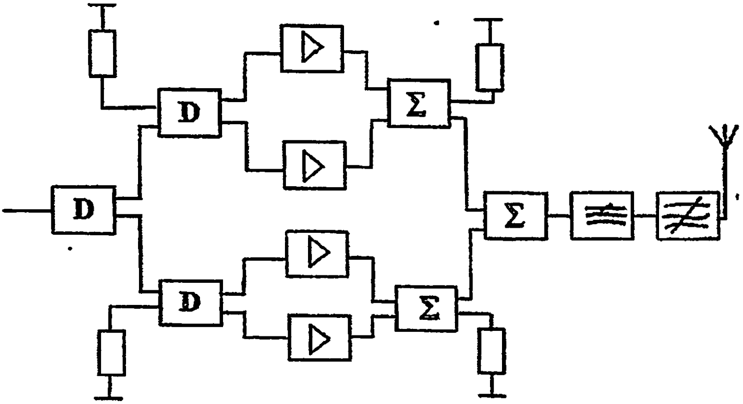


Fig. 4.3. Power addition scheme of even amplifiers:
D - divider; Σ - adder

An important circumstance in the preparation of power addition schemes for individual amplifiers is the fulfillment of the requirement for phasing the folded signals. To do this, use identical dividers in structure (D) and adders (Σ), including their conjugate. In this case, no additional phase shifters are required. The above scheme is typical for transistor modules built using hybrid-integrated technology. Practically, with the help of multi-pole adders, the addition of 50 capacities is carried out...100 semiconductor devices, and usually four transistors are first combined into a module, and then the capacities of 8...16 such modules are added, depending on the required output power of the amplifier.

OBR Input Receivers

General information. The input receivers provide the necessary signal-to-noise ratio of the OBR trunks. The minimum level of the received signals is determined by the intrinsic fluctuation (thermal) noise of the receiving device. In practice, when choosing an effective noise temperature, on the one hand, they proceed from the condition that the contribution of the noise of the Earth-satellite section is 5-10 times less than the noise of the satellite-Earth section, and on the other hand, the minimum effective noise temperature of the AES receiving system cannot be less than the equivalent Earth temperature ET, since the receiving the AES antennas are oriented in her direction.

Noise temperature, OBR input receiver (reduced to the input of the receiving antenna irradiator).

$$T_s = T_e + T_{atm} + bT_{space} + T_{rec},$$

where T_{atm} is the equivalent temperature of atmospheric noise, for stationary AES antennas in the range of 1...20 GHz varies within 2...25 °; T_{space}-is the equivalent temperature of cosmic noise – depends on the area of the sky to which the antenna is directed, and can be determined by special sky maps; maximum values at a frequency of 1 GHz do not exceed 30 ° and drop sharply with increasing frequency; b is a coefficient significantly less than one, which determines the fact that cosmic noise is received only by the side lobes; Trec is the noise temperature of the OBR receiver.

Practical conclusion regarding the choice of T_s

$$T_s=(5\ldots10)T_{resES},,$$

where T_{resEs} is the noise temperature of the receiver of the CS working with this ISS. The input receivers of modern ES when using low-noise amplifiers of various types in the satellite communication ranges have a total noise temperature of 40 ... 300 °. In these cases, respectively, the total noise temperature of Tb can be in the range of 400...3000 K.

Table 4.1 shows the LNA parameters used for OBR.

Table 4.1.

Parameters of low-noise amplifiers

Reception frequency range, GHz	Noise factor, dB	Gain, dB
5,9...6,5	1,2...1,4	24,0...30,0
14,0...14,5	1,4...2,3	24,0...30,0
17,3...18,1	2,0...2,5	24,0...30,0

5. Calculation of the communication session and the flight path of the satellite

Task:

- Learn how to make calculations of satellite communication lines, as well as their main systems according to these parameters.
- Calculate the equivalent isotropic radiated power (EIRP) of the transmitting station.

Methodological guidelines for the calculation:

1. According to the specified values from Table 3.2, write out the initial data for the calculation option.

2. Calculate the gain of the D_{nep} transmitter:

$$D_{tr}=10^{0,05tp}, \text{dB} \tag{5.1}$$

3. Determine the attenuation of energy in free space, determined by a decrease in the density of the power flow when moving away from the emitter:
4.

$$L_0=4\pi d^2/\lambda^2, \text{dB} \tag{5.2}$$

where λ – wavelength ($\lambda = c/f$, $c = 3\cdot10^8$ m/s and $f = 14$ GHz);

d-is the inclined range (the distance between the transmitting and receiving antennas).

5. Determine the power of the transmitter by the formula:

$$P_{tr} = 4\pi d^2\, L_0\cdot P_{rec}\,/\,D_{tr}\cdot S_{rec}\cdot\eta_{tr}\cdot\eta_{rec}, \text{W} \tag{5.3}$$

6. Calculate the equivalent isotropic radiated power (EIRP) of the transmitting station:

$$P_{eirp}=P_{tr}\cdot\eta_{tr}\cdot D_{tr}, \text{W} \tag{5.4}$$

Calculation example:

1. Initial data:

d = 36000 km,	S_{rec}= 4 m²;
G_{tr} = 25 dB,	η_{tr}= 90%
P_{rec} = -120 dBW;	η_{rec}= 90%

2. Calculation of the gain of the R_t transmitter.

$D_{tr}=10^{0,05trp}$, dB,
$D_{tr} = 10^{0,05\cdot 25} = 17,78\ dB.$

3. Determination of the attenuation of energy in free space, determined by a decrease in the density of the power flux at a distance from the emitter.

4.
$L_0 = 4\pi\cdot d^2 / \lambda^2 = (4\pi\cdot d\cdot f)^2 / c^2$, dB,

where d is the oblique range (the distance between the transmitting and receiving antennas), c is the speed of light($c = 3\cdot 10^8$ m/s) and f- is the frequency of the transmitted signal (f = 14 GHz)

$$L_0 = 4 \cdot 3,14 \cdot (36 \cdot 10^6 \cdot 14 \cdot 10^9)^2 / (3 \cdot 10^8)^2 = 3,2 \cdot 10^6 \cdot 10^{30} / 9 \cdot 10^{16} = = 36 \cdot 10^{18}\ dB.$$

5. Determination of the transmitter power:

$P_{tr} = 4\pi d^2\, L_{add}\cdot P_{rec} / D_{tr}\cdot S_{rec}\cdot \eta_{tr}\cdot \eta_{rec}$, W
where L_{add} – additional losses (assumed to be equal to 1 dB) and

P_{rec} - receiver power level dBW what needs to be converted to W according to the formula: P (W) = 1 Вт · 10 (P $^{(\mathrm{dBW})/10}$);

$P_{rec} = 10^{-12}$ Вт
$P_{tr} = 4 \cdot 3,14 \cdot 1296 \cdot 10^{12} \cdot 1 \cdot 10^{-12} / 17,78 \cdot 4 \cdot 0,9 \cdot 0,9 = 282 \cdot 10^{-6}$ W = = 282 W

6. Calculation of the equivalent isotropic radiated power (EIRP) of the transmitting station:

$$P_{eirp}=P_{rec}\cdot \eta_{rec}\cdot D_{tr}, \text{ W}$$
$$P_{eirp}=282 \cdot 0,9 \cdot 17,78 = 4512\ \text{Вт} = 4,5\ \text{kW}$$

Table 3.2.

Initial data on options

The last digit of the magazine number	d, km	G_{tr}, dB	P_{rec}, dBW	$S_{пр}$,m^2	H_{tr} ,%	H_{rec} ,%
1	36000	20	-120	3	85	87
2	37000	21	-120	3,5	86	88
3	38000	22	-120	4	87	89
4	39000	23	-120	4,5	88	90
5	40000	24	-120	3	89	91
6	36000	25	-120	3,5	90	85
7	37000	20	-120	4	91	86
8	38000	21	-120	4,5	85	87
9	39000	22	-120	3	86	88
0	40000	23	-120	3,5	87	89

Questions:

1. Explain the block diagram of OBR.

2. What element base is used to build powerful OBR output amplifiers?

3. How are output power and EF TWL related to frequency?

4. What are the advantages of solid-state OBR transmitters compared to electric vacuum transmitters?

2. What determines the efficiency of the transmitter built using the power summation method?

2. Explain the purpose of the OBR input receivers?

3. Describe the main parameters of low-noise amplifiers (LNA).

PRACTICAL WORK №. 4

STUDYING THE ORGANIZATION OF MULTI-BARREL SATELLITE COMMUNICATIONS

1. The purpose of the work

Study of the structure and principles of construction of multi-barrel satellite communications of Earth and space stations.

2. Task

1. Get acquainted with the principle of using artificial Earth satellites as repeaters for communication systems.
2. Familiarize yourself with the basic principles of building multi-barrel repeaters.
2. Calculate the bandwidth and make a plan for the frequencies of the trunk of one carrier, taking into account the protective frequency intervals necessary for MAFD.

3. Report content

3. Content of the report
1. Purpose and purpose of the work.
2. Principles of construction and features of the SCS as part of Earth and space stations.
2. Simplified block diagrams of the orbital single-barrel and multi-barrel repeater.
3. Simplified block diagram of a multi-barrel repeater of the Earth station with examples.
4. Bandwidth calculation
5. Trunk frequency plan

4. Brief theory

4.1. Artificial Earth satellites as repeaters for communication systems

The tasks of increasing the range and bandwidth of communication systems have always been the fundamental problems of this field of technology. Unfortunately, the corresponding characteristics, as a rule, turn out to be alternative: measures to increase throughput lead to a reduction in range; and vice versa. In particular, increasing bandwidth requires switching to increasingly high-frequency wave ranges, the signals of which can be directly transmitted almost only at line-of-sight distances. As a means of resolving this contradiction, repeaters can be used, raised high enough above the surface of the Earth. The successes of the development of cosmonautics made it possible to use AES as such repeaters. Since they can be located almost arbitrarily high above the Ground, their service area can cover not only individual countries or seas, but also entire continents and oceans. In general, satellites move in elliptical orbits, in one of the foci of which the center of the Earth is located. The satellite moves relative to the ground observer, and with it the service area moves along the dark surface. As a result, it is necessary either to increase the number of satellites in the system, or to agree that round-the-clock communication will not be provided.

An improvement in the situation can be achieved if the satellite's orbit is chosen so that the period of the satellite's orbit around the Earth is in a simple ratio with the period of its rotation around its axis (synchronous orbits). The use of such orbits leads to a constant schedule of possible communication sessions, since for any ground observer, a repeater satellite (RS) appears at a given point in the celestial sphere periodically, constantly at the same time.

Further simplifications of satellite communication systems occur if:

- the satellite's orbit is circular and lies in the plane of the equator;
- the period of the satellite's orbit is exactly one day.

Such a satellite generally remains stationary relative to any ground observer. The corresponding orbit is called geostationary (GEO), and the satellite moving along it is stationary. GSO has a radius of approximately 42.3 thousand km. It is unique and unique, therefore, the placement of satellites on it is strictly controlled by international organizations headed by the International Telecommunication Union (ITU) operating under the auspices of the United Nations. The same organization is entrusted with the international coordination of other satellite communication systems in order to rationally limit the mutual influence between them.

Although currently the vast majority of the devices used are stationary, they are not without significant drawbacks. It is such satellites that are best suited to serve tropical and subtropical regions. As the observer moves on the Earth's surface from the subsatellite point along the meridian to the poles of the Earth, the angle of the direction to the stationary spacecraft (SC) decreases, reaching zero for latitude 82nd (north or south). For points closer to the poles of the subsatellite meridian, there is no satellite visibility at all. It is easy to understand that the boundary of the geometric visibility of a stationary spacecraft, when the observer deviates from the subsatellite meridian, falls in the direction of the equator. In addition, the operation of radio lines in directions with small angles of location is generally sharply hampered both by receiving signals reflected from the Ground, and by the shielding action of various elevations, forests, buildings or other obstacles. Therefore, stationary spacecraft are practically unable to serve the territories lying north of the northern and south of the southern polar circles. Meanwhile, these territories are often of considerable interest. Even the territory of the North Pole is of considerable interest, primarily due to the fact that the most profitable routes of a number of important airlines run through it. RS orbits can be chosen in such a way as to provide preferential service to certain regions on the Earth's surface. So, Russia was offered an elliptical orbit, specially adapted to serve the northern regions of our planet. The apogee of this orbit is located above the northern hemisphere at a distance of approximately 40 thousand km from the Earth's surface, and the perigee lies at an altitude of several hundred kilometers above the southern hemisphere.

The plane of the orbit is inclined to the equator by about 65 °. The period of the satellite's orbit in this orbit is half a day, so it is a synchronous satellite. During the day, it makes two turns, the first of them, called the main one, reaches its apogee over Siberia (at a point with geographical coordinates 63"5 ° s.w. and 81 ° v.d.), and the second — conjugate — at a point with the same latitude, but shifted in longitude by 180 °, i.e. 99° s.d. (over Canada).

The parameters of this orbit are chosen so that in the part of the orbit adjacent to the apogee, the angular velocity of the satellite in the east-west direction coincides with that of the Earth. This condition is approximately fulfilled throughout the entire working section of the orbit (from three to four hours before reaching the apogee to three to four hours after its passage) and ensures that the satellite does not move in relation to any observer on Earth in the east-west direction.

The repeater satellite (RS) must receive signals from the Earth stations (ES) of the communication system, amplify them and retransmit them to the ES to which the eyes are intended. Thus, RS contains receiving and transmitting equipment for signal retransmission.

Since the end-to-end gain of the RS receiving and transmitting path must be large enough, it is necessary to receive and transmit at different frequencies (otherwise it will not be possible to avoid self-excitation of the path). Thus, frequency converters are also an obligatory element of the relay path.

The peculiarity of the repeaters of the broadcasting service is that for them the main one is the transmitting path, through which the hanging is actually carried out. The receiving equipment used for receiving broadcast programs delivered on board is also installed on broadcast RS. The radio line for feeding programs on board is called the feeder line.

A repeater satellite, like any active spacecraft, in addition to the relay path itself, referred to in relation to this device as a payload (PN), also contains a number of auxiliary systems, such as a power supply system, an orientation and stabilization system, a temperature control and control system. The latter includes systems for generating and transmitting telemetric information. The spacecraft, minus the payload, is called the space platform (KP). Such a platform can be used in combination with various GY to create a number of different spacecraft.

Currently, fixed RS are most often used in the interests of fixed and broadcast services. Typical parameters of the platforms of such satellites:

- power capacity up to 5-7 kW, and 1.5-2 kW is allocated to power the payload;
- weight of about 2-3 tons, including a payload of 0.5-0.8 g;
- accuracy of orientation and stabilization of the order of 0.1 ;
- the period of active existence is 12-15 years.

Along with standard spacecraft, it is currently considered promising to use small spacecraft with a mass of 500-800 kg (including 100-200 kg PN) and an energy capacity of 1.8-2.5 kW in the interests of a fixed service. The advantage of the MC is the possibility of a group or associated launch (together with a typical spacecraft), which significantly reduces the cost of removal. MCAS can be launched at those points where other SRS are already located and provide the necessary addition of trunks working on them or replacement of trunks that have failed. They can also be used to build national satellite communication systems of relatively small or poor countries.

Depending on the composition of users, RS are divided into international and national. The most famous international RS fixed services are Intelsat and Eutelsat. The international company Intersputnik also owns significant resources. RS Eutelsat also contain trunks, most often used by European countries for television broadcasting. The Astra satellite system is used specifically for these purposes.

The national satellite fixed service system of Russia currently uses RS of the Express type, as well as Yamal of various modifications.

4.3. Space stations

The space station contains a repeater and support systems: power supply sources, antenna orientation systems (to Earth) and solar panels (to the Sun), AES position correction systems in orbit, etc.

ST equipment should have a minimum weight and dimensions, high reliability and consume low power. SS repeaters are usually multi-barrel. They consist of transceiver equipment and antennas. The block diagrams of the repeater trunks are similar to those used on the IRS RRL. Depending on the trunk circuit, there are heterodyne type repeaters, repeaters with a single frequency conversion and repeaters with signal processing on board. In addition to demodulation and modulation, SS uses other diverse methods of signal processing. For example, with MTD, after demodulation on SS, it may be possible to separate channels and then combine them on a new basis. At the same time, messages addressed to station I by all other ZS are combined and transmitted down the line in one bundle. In MATD-SP systems, signals are switched on board.

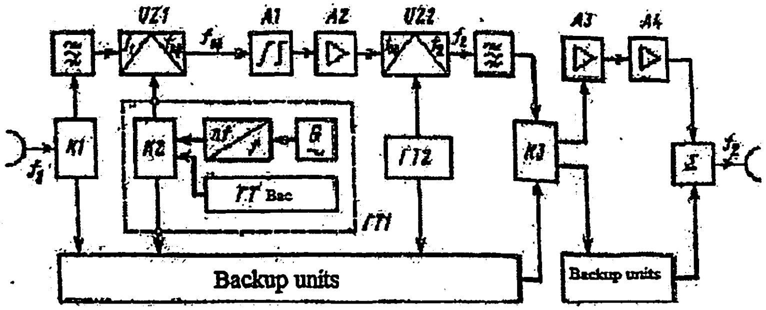
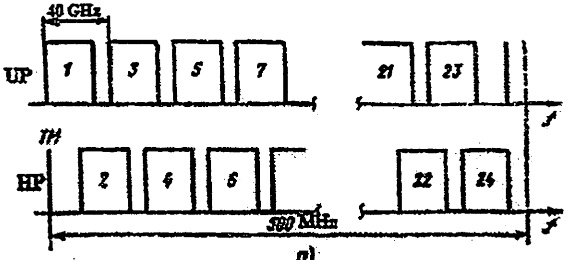


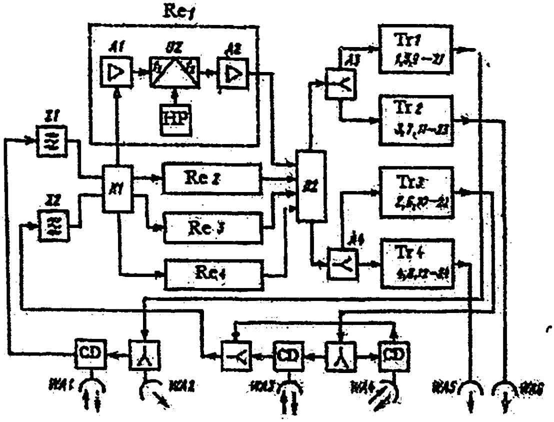
Fig. 4.1. Block diagram of a powerful single-barrel repeater.

In a high-power repeater of the heterodyne type (Fig. 4.1), the frequency of the input signal decreases in the mixer C1, and then, after amplification in the UPF A2, it rises again in the mixer UZ2. The heterodyne tracts HT1 and HT2 are made according to similar schemes. To amplify the microwave signal, the preliminary A3 and output A4 power amplifiers are used. The output power reaches 200... 300 watts. A similar scheme has a repeater on the satellite "Screen". In it, A4 is made on a span klystron. In the scheme, "cold" redundancy of all blocks is accepted. Switches K1–KZ on command from the Ground select the working set. At the same time, the supply voltage begins to flow to it.

Modern multi-barrel repeaters perform in such a way as to obtain maximum throughput. In the 500 MHz band allocated to one satellite, it is possible to place the signal spectra of 12 trunks. Usually the trunk band is 36 MHz, and the RFI between the trunks is 4 MHz. In order to double the capacity of repeaters, the spacing between carriers of neighboring trunks is halved, and the necessary isolation between signals overlapping in the spectrum is obtained due to polarization.



a)



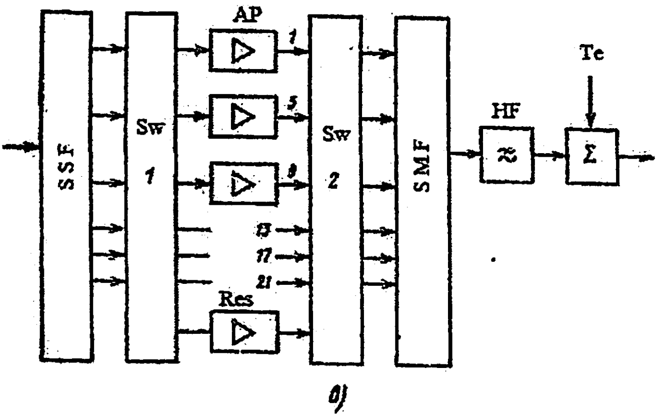


Fig. 4.2. For the construction of multi–barrel repeaters:
a – frequency plan; b – block diagram of the repeater for 24 barrels;
c - block diagram of the transmitting device

For all odd trunks (Figure 4.2, a), for example, vertical polarization (VP) is taken, and for even ones – horizontal (GP). Recall that the use of linear polarization is possible in a satellite with rigid stabilization in orbit. Telemetry (TM) signals are transmitted in the same frequency band. The repeater (Fig. 4.2, b) has six antennas, and WA1, WA2 and WA6 work with vertical polarization waves, WA3, WA4 and WA5 – horizontal, where the antennas WA1, WA3, WA5, WA6 are global; WA2, WA4 are narrowly directional. Combination devices (US) are used to separate the reception and transmission waves. So, signals of odd trunks come to PF Z1.

Switches K1 and K2 allow you to select any two receivers as working ones. Such a reservation is more reliable than a block-by-block one. The transmitting set (Fig. 4.2, b) contains a FRS trunk separation filter, input Km 1 and output Km 2 switches, working power amplifiers (one for each trunk) and backup, filters for combining FFC trunks and a harmonic filter HF. In addition, Figure 2, b shows a device 2 designed for the introduction of telemetry signals.

The first AES with fully semiconductor electronic equipment appeared in the early 80s. The use of transistors can significantly improve the electrical characteristics and reliability of the transmission path of the trunk, reduce weight and energy consumption. Recall that in many existing repeaters with an output power of up to several tens of watts, PA is made on TWL, and the number of trunks in such repeaters is 6-12.

Figure 2, b shows six antennas. Practically, they can be implemented in the form of two MA, each of which has three (or more) different directional patterns. Separate antennas are used for VP and GP waves. In Fig. 2,b, the antennas are attached to the transmitters and receivers. In the improved version of the SS, antenna switches are installed between the antennas and the transceiver equipment, which allow, on command from the Ground, to select any antenna (in MA – any DN) for reception and transmission, of course, taking into account polarization.

4. Earth stations

Earth stations are divided into transmitting, receiving satellite broadcasting systems, as well as transceivers designed to organize duplex telephone communication and to work in the TV program exchange network. Receiving and transmitting ZS are usually multi-barrel.

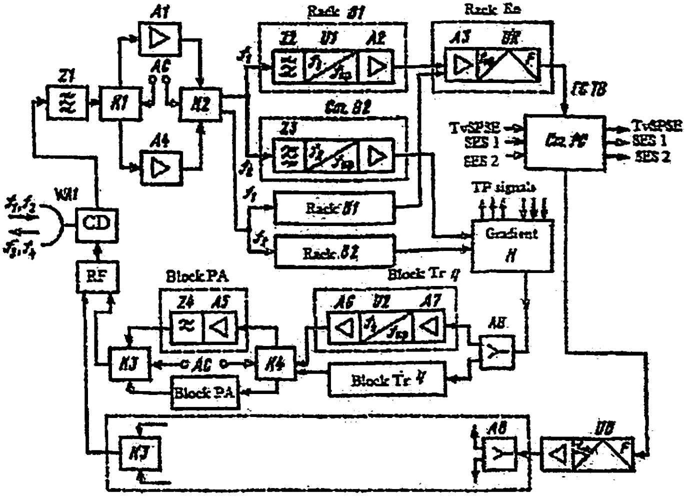


Fig. 4.3. Simplified block diagram of a double-barreled receiving and transmitting ES

A typical transceiver ES operating in the national SCS or in the SCS "Intersputnik" (Fig. 4.3) contains a WA1, BD antenna, receiver and transmitting devices of trunks, Gradient-N equipment, etc. Receiving devices of the "Orbit-2" type are installed in the scheme. They are equipped with broadband PF Z1, waveguide switches K1 and K2, LN A1 and A4, racks of type B (With B1 and B2), racks of type P (D P) and racks of type PC (D PC). The Z1 filter passes the signals of all working trunks and serves to protect broadband LND+ from possible out-of-band interference.

The separation of trunk signals is performed by BF Z2 and Z3, installed at the input of type B racks and tuned to the central frequency of the microwave signal of their trunk. Here the racks in 1 are designed to convert UHF signals of a TV trunk with a central frequency f1 into an IF signal. Racks B2 – for such conversion of microwave signals of the TF trunk with a central frequency f2. Each trunk has a working and backup rack type B. In addition to BF, the frequency converter U1 and IFPA A2 are shown as part of the rack B.

Each trunk has a working and backup rack type B. In addition to BF, the frequency converter U1 and IFPA A2 are shown as part of the rack B. The rack P contains the main UHF A3 and a demodulator of the UR signal, at the output of which the CS TV of the trunk is received. The PC rack performs the separation of this signal. HS

The selection of the working set of LND is performed by K1, and the working rack B is performed by K2. Switching from one set to another occurs automatically when the speaker is received from the receiver control rack (not shown in the diagram).

The signals in the NA trunk are transmitted by the OChC-FM-MFD method. The central frequency of this signal at the output of the rack In fin = 70 MHz. In the receiving part of the Gradient-N equipment, the IF signal is amplified, the separation of 200 FM signals, each of which is transmitted on its own carrier, and their demodulation. TF signals are received at the output of the Gradient-N receiver.

Telephone signals are received at the input of the transmitting part of the "Gradient-N" equipment, in which the signal of the HC-FM-MAFD is formed in the frequency band 70 ± 17 MHz. This signal is sent to the SS trunk transmitter. The transmitter consists of a power divider IF A 8, waveguide switches KZ and K4, two frequency converter units and two PA units. The second blocks are redundant.

The frequency converter unit contains PIFA A 7, a frequency converter U2 and a preliminary UM A6. The PA unit contains an output PA A5 and a harmonic filter Z4. The operation of the KZ and K4 switches is controlled by the speakers coming from the transmitter control unit (Fig. not shown). Thus, a CF channel is organized between the input of the transmitting part of the Gradient-N equipment on the transmitting ES and the output of the receiving part of the Gradient-N equipment of the receiving ES.

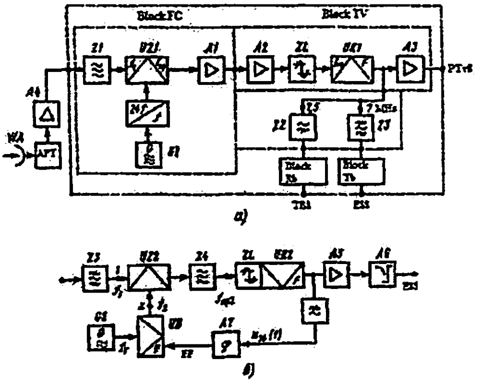


Fig. 4.4. The block diagram of the ZS "Moscow":
a – enlarged; b – the sound block diagram

The group signal of the TV trunk is formed by the transmitting equipment of the PC rack. The TV trunk transmitter contains a UB modulator. Otherwise, the schemes of TV transmitters and TF trunks are similar. The RF block serves to supply the transmitted microwave signals of several trunks to the common AFT. Transmitting devices such as "Gradient", "Helicon", "Ground" television work on the ES.

A3 The notch filters for signal suppression are included, the Receiving ZS "Moscow" (Fig. 4.4) contains the antenna WA, AFT, LNA A4 and the receiving rack Pr. St. As part of the receiving rack, the IF block and the TV block are shown, filters for separating FM signals transmitted at subcarrier frequencies of 7 and 7.5 MHz, the block Sv for SES allocation and Rv block for STB allocation. The IF unit is designed to convert the frequency of the input signal in the mixer C1, which is structurally combined with PLNA A1. The TV unit contains the main AIF A2, a frequency demodulator consisting of AO ZL and H 1, and an output amplifier A3. In the scheme transmitted on subcarrier frequencies of 7 and 7.5 MHz. At the output, TVSP is allocated. In the Sv block (Fig. 4.4, b) and Rv, threshold-lowering demodulators are used. They contain a frequency demodulator SZS 2, an auxiliary frequency converter consisting of a mixer 2, a generator G2, a FBP Z4, and a frequency feedback circuit. The OSF circuit consists of a frequency modulator UB and a phase corrector A7. In addition, the unit includes an output amplifier A5 and VK A6. Frequency of the FM signal at the input of the sound unit.

$$f_1=f_{TV}+\Delta f_{mTV}u_{TV}(t)$$

where $f_{TV}=7$ MHz Δf_{mTV} *- maximum deviation developed SES;* $u_{TV}(t)$*- the voltage of the SPS. and* $|u_{TV}(t)|\leq 1$.

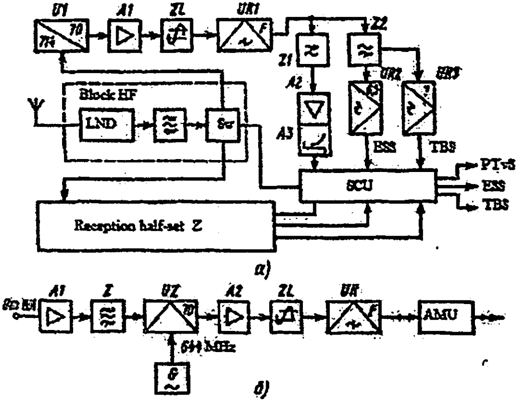


Fig. 4.5. Block diagram of the receiver "Screen" of class 1 (a) "Screen" of class 2 (b)

The voltage iv{t) allocated at the output U2 is supplied to UB. Frequency of oscillations at the output UB:

$$f_2 = f_g + A\ \Delta f_{mTV} u_{TV}(t),$$

where f_g is the oscillation frequency G2; A is the transmission coefficient of the FFB circuit. Frequency of oscillations at the output Z4.

$$F_{rec2} = f_1 - f_2 = f^*_{rec2} + (1-A)\ \Delta f_{mTV} u_{TV}\ (t),$$

where $f_{rec}^* = f_{TV} - f_g$. Using the corrector A7, the SES phase at the input UB is selected so that with an increase in the frequency of the signal at the input / mixer, the frequency of oscillations at the input 2 would increase. In this case, A>0 и (1–A) $\Delta f_{mTV} < \Delta f_{mTV}$, i.e. the frequency deviation at the mixer output is less than at its input. Therefore, the Z4 PF may have a narrower bandwidth than the Z3 PF. In this case, Z4 will determine the noise bandwidth of the audio receiver and the threshold power of the input signal.

In this case, Z4 will determine the noise bandwidth of the audio receiver and the threshold power of the input signal. We see that the application FF lowers the FM threshold of the receiver. Therefore, the latter can receive weaker signals. This makes it possible to reduce the level of fluctuations of subcarrier frequencies in transmission, i.e., to reduce the load on the common path.

The professional receiver of the Screen system (1st class) (Fig. 4.5, a) consists of an RF unit, two identical receiving half-sets (working and backup) and a control and switching unit (c). The RF block includes a transistor LNA, a PF and a diode switch K. Turning on the PF, which is a passive element of the circuit, after the LNA, makes it possible to reduce the T3 of the receiver. Receiving half-sets are made according to the standard scheme of the FM signal receiver. At the output of the FD UR1, filters Z1 and Z2 are installed to separate the

TvSP and FM signals (SES and STH). FD SES UR2 and FM STH UR3. Selected by the filter Z1, the TvSP oes to the output amplifier A2 and VK-AZ. The latter is necessary, since the HTvSP is subjected to predictions at the transmitting ES. With the help of CSU and switch K, the working half-set is automatically selected. The subscriber receiver of the "Screen" system (class 2) is made according to the standard FM signal receiver circuit, which is supplemented by an amplitude modulator unit (SAM) (Fig. 4.5, b).

The AM block converts the output BH signal UR (Fig. 4.6, a) into a broadcast television radio signal with a carrier fi (Fig. 4.6, b), consisting of an AM image radio signal f and an FM audio signal 2.

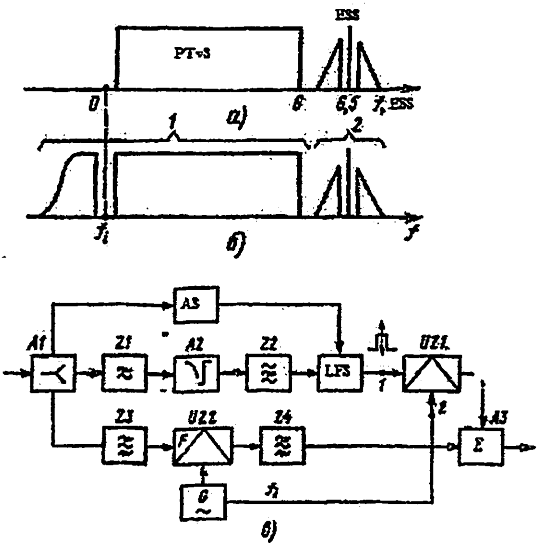


Fig. 4.6. To explain the operation of the AM block:
spectra of signals at the input of the AM block (a) and at its output (b);
block diagram (c)

At the AMB input (Fig. 4.6, c), a cascade with a divided load A1 is installed. Filter Z1 selects TvSP, which, after additional processing, is fed to input 1 of the amplitude modulator UZ1. The circuit includes VK A2 and a notch filter Z2, tuned to a frequency of 6.5 MHz and designed to more effectively suppress the SES transmitted at the subcarrier frequency. To reduce the non-linear distortion of the signal at the output of the AMB, UZ1 serves TVSP with a restored constant component. Recovery is performed by a typical controlled level fixing (CPI) scheme. The amplitude selector (AS) generates control pulses for it from the clock pulses of the input PTVS. The second input UZ1 receives a carrier from the oscillator G, which creates frequency oscillations f, AM is made according to a balanced circuit, so that at its output an AM signal with a suppressed carrier and a partially suppressed lower sideband is received (signal / in Fig. 4.6, b). Filter Z3, tuned to a frequency of 6.5 MHz, selects the FM sound signal. This signal is fed to the SES frequency converter, consisting of a UZ2 mixer, FBP and self-oscillator G. Filter Z4 selects the FM SES with an average frequency f = fi + 6.5 MHz (signal 2 in Fig. 4.6, c). In output stage A3, both signals are combined.

5. Bandwidth calculation and trunk frequency planning

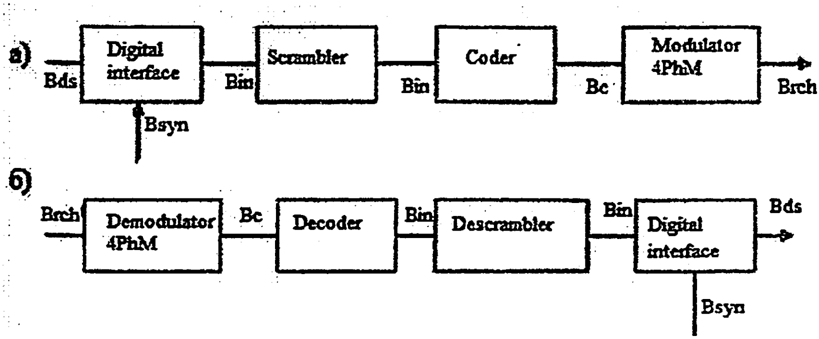
Exercise:

- Determine the transmission rate in the radio channel at various stages of the flow.

- Determine the bandwidth required to transmit a single carrier, taking into account the required guard intervals for FDMA.
- Make an energy calculation of the total attenuation of radio wave energy in each section.

Methodological instructions for the calculation:

1. According to the given values from table 4.1, write out the initial data for the calculation.
2. At the transmitting end of the SLS (satellite communication line) (at the transmitting ES) and at the receiving end (at the receiving ES), the digital signal transmission rate is converted in accordance with Fig. 4.7:



Rice. 4.7. Bit rate conversion:
a) transmit b) receive
b)

where B_{ds} – transmission rate of one information stream (given in the original data);

B_{in} – input stream transfer rate;

B_c – bit rate at the output of the error-correcting encoder, taking into account the coding rate R (R is given in the source data);

B_{syn} – intercom signaling rate;

B_{rch} – the resulting transmission rate in the radio channel with 4PhM modulation.

Determine the transmission rate in the radio channel at various stages of the flow by the formulas:

$$B_{in} = B_{ds} + B_{syn}, \text{ kbit/sec} \tag{4.1}$$

In IDR, intercom signals with $B_{syn} = 96$ kbit/sec are added if $B_{ds} > 1544$ kbit/s. At smaller B_{ds}, intercom signals are not added, i.e. $B_{syn} = 0$.

$$B_{\text{к}} = B_{\text{вх}} / R, \text{ kbit/sec} \tag{4.2}$$

where R – code rate (specified in the source data)

$$B_{rch} = B_c / \log_2 M, \text{ kbit/sec} \tag{4.3}$$

where M = 4 in case of using 4PhM modulation;

3. Determine the frequency band required for the transmission of one carrier, taking into account the guard frequency intervals required for FDMA using the formulas:

The spectrum width of the modulated radio signal is numerically equal to the resulting transmission rate, taking into account the spectrum rounding factor:

$$П_r = B_{rch}\,(1+\alpha),\ \text{Hz} \qquad (4.4)$$

where α is the spectrum rounding factor (specified in the initial data);

Bandwidth required to transmit one carrier:

$$П_1 = (1{,}1\ldots1{,}3)\cdot П_r\,,\ \text{Hz} \qquad (4.5)$$

4. Perform an energy calculation of the total attenuation of radio wave energy in each section.

$$L_{rw}=L_0+L_{add},\ \text{dB} \qquad (4.6)$$

here L_0 – is the signal attenuation in free space:

$$L_0=20\log((4\cdot\pi\cdot d)/\lambda)\ ,\ \text{dB} \qquad (4.7)$$

Where d – slant range;

λ – wavelength, $\lambda= c / f = 21{,}4$ mm

$$L_{add} = L_{atm}+L_{pl}+L_l+L_P,\ \text{dB} \qquad (4.8)$$

Where L_{atm} – calm atmosphere loss, ($L_{atm} = 0{,}15$ dB);

L_{pl} – precipitation losses, dB (under "clear sky" conditions, it is assumed $L_{pl} = 0$);

L_l – losses due to inaccurate pointing of antennas, ($L_l = 0{,}3$ dB);

L_p – polarization loss, ($L_p = 0{,}05$ dB)

Calculation example:

1. Initial data:

Transmission rate of one information stream $B_{ds} = 1600$ kbit/s.
Code speed R = 0,75.
Spectrum rounding factor α = 0,5 bit/(c·Hz).
Slant Range d = 30 000 km

2. Determination of the transmission rate in the radio channel at various stages of the flow.

Because $B_{ds} > 1544$ *kbit/sek*, то $B_{syn} = 96$ *kbit/sek.*

$B_{in} = B_{ds} + B_{syn} = 1600 + 96 = 1696$ *kbit/sek.*

$B_c = B_{in} / R = 1696 / 0{,}75 = 2261{,}3$ *kbit/sek.*

$B_{rch} = B_c / \log_2 M = 2261{,}3 / \log_2 4 = 2261{,}3 / 2 = 1130{,}65$ *kbit/sek.*

3. Determination of the frequency band required for the transmission of one carrier, taking into account the guard intervals required for FDMA.

The spectrum width of the modulated radio signal is numerically equal to the resulting transmission rate, taking into account the spectrum rounding factor:

$$\Pi_r = B_{rch}\,(1+\alpha) = 1130{,}65 \cdot (1+0{,}5) = 1696\ Hz = 1{,}7\ kHz$$

Bandwidth required to transmit one carrier:

$$\Pi_1 = (1{,}1 \ldots 1{,}3) \cdot \Pi_r = 1{,}1 \cdot 1696 = 1865{,}6\ Hz = 1{,}87\ kHz$$

4. Energy calculation of the total attenuation of radio wave energy in each section.

$$L_{add} = L_{atm} + L_{pl} + L_l + L_p = 0{,}15 + 0 + 0{,}3 + 0{,}05 = 0{,}5\ dB$$

Signal attenuation in free space:

$$L_0 = 20 \log((4 \cdot \pi \cdot d) / \lambda) = 20 \log((4 \cdot 3{,}14 \cdot 30\,000 \cdot 10^3) / 21{,}44 \cdot 10^{-3}) =$$
$$= 20 \log(17{,}57 \cdot 10^9) = 20 \cdot 10{,}24 = 204{,}9\ dB$$

The total attenuation of radio wave energy in each section:

$$L_{rw} = L_0 + L_{add} = 204{,}9 + 0{,}5 = 205{,}4\ dB$$

Table 4.1

Initial data by options

Last digit Journal numbers	B_{ds} Kbit/s	R	α bit/(s·Hz)	d km
1	1444	0,5	0	30 000
2	1496	0,75	0,1	30 500
3	1564	0,875	0,2	31 000
4	1586	0,5	0,3	31 500
5	1600	0,75	0,4	32 000
6	1444	0,875	0,5	32 500
7	1496	0,5	0,6	33 000
8	1564	0,75	0,7	33 500
9	1586	0,875	0,8	34 000
0	1600	0,5	0,9	34 500

Questions

1. Give and explain the operation of the block diagram of a powerful single-barrel repeater

2. Give and explain the operation of the block diagram of the repeater for 24 trunks.

4. Give and explain the operation of the block diagram of the transmitter of multi-bárrel repeaters.

5. Give and explain the operation of the block diagram of the AP "Moscow".

6. Give and explain the operation of the block diagram of the receiver AP "Screen".

PRACTICAL WORK №5

STUDY OF SATELLITE COMMUNICATION SYSTEMS ODYSSEY AND ICO

1. The purpose of the work

.Studying types of satellite systems and their orbits

2. Task

1. To study the space and ground segment and service areas of the ODYSSEY system.
2. Study the international ICO system.
3. Compare Odyssey and ICO systems.
4. Calculate the dependence of satellite characteristics on the parameters of longitude and the angle of opening of the antenna.
5. Preparation of the reESrt

3. Report content

1. PurESse and purESse of the work.
2. Main indicators of satellite communication systems ODYSSEY and ICO.
3. Space and ground segments, service areas, services of the Odyssey system.
4. Space and ground segments, organization of communications, services of the ICO system.
5. Calculation of the dependencies of satellite characteristics on the parameters of longitude and antenna aperture angle

4. Satellite communication system

4.1. Satellite trunk organization

Satellite is a communication device that receives signals from the Earth station (ES), amplifies and broadcasts in broadcast mode simultaneously to all ES located in the satellite's visibility zone. The satellite does not initiate or terminate any user information, except for monitoring and correction signals of emerging technical problems and its ESsitioning signals. Satellite transmission begins in some ES, passes through the satellite, and ends in one or more ES.

The satellite communication system consists of three basic parts: the space segment, the signal part and the ground segment, using the example of the Iridium system (Fig. 4.1).

The space segment covers the issues of satellite design, orbit calculation and satellite launch. The signal part includes the issues of the frequency spectrum used, the influence of distance on the organization and maintenance of communication, sources of signal interference, modulation schemes and transmission protocols. The ground segment includes the placement and design of the satellite, types of antennas used for various applications, multiplexing schemes that provide effective access to satellite channels. The space segment, the signal part and the ground segment are explained in the following sections.

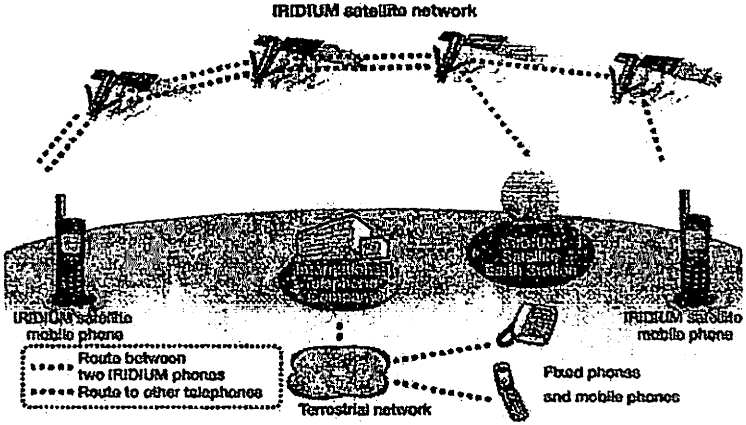


Fig. 4.1 The "Iridium" system

4.2. The space segment

Modern communication satellites used in commercial SSS occupy geosynchronous orbits in which the orbital period is equal to the period of the mark on the Earth's surface. This becomes ESssible when the satellite is placed over a given place of the Earth at a distance of 35,800 km in the plane of the equator.

The high altitude required to maintain the satellite's geosynchronous orbit explains the insensitivity of satellite networks to distance. The length of the path from a given ESint on Earth through a satellite in such an orbit to another ESint on Earth is four times the distance on the Earth's surface between its two most distant ESints. Currently, the most densely occupied orbital arc is 76° (approximately; 67°

by 143° west longitude). Satellites of this sector provide communications to the countries of North, Central and South America.

The main comESnents of the satellite are its structural elements; ESsition control systems, ESwer supply; telemetry, tracking, commands; transceivers and antenna (Fig. 4.2).

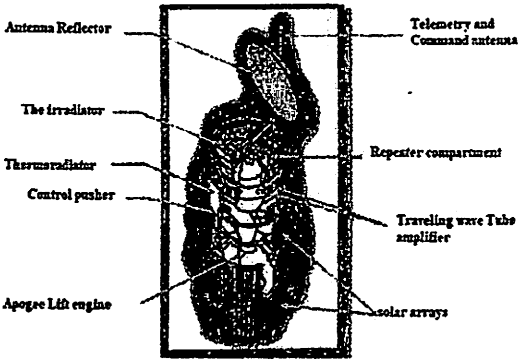


Fig. 4.2 Satellite with rotation stabilization

The structure of the satellite ensures the functioning of all its comESnents. Left to itself, the satellite would eventually switch to random rotation, turning into a device useless for communication. The stability and the desired orientation of the antenna is supESrted by the stabilization system (Fig. 4.3). The size and weight of the satellite are limited mainly by the capabilities of vehicles, the requirements for solar panels and the amount of fuel for the life supESrt of the satellite (usually for ten years).

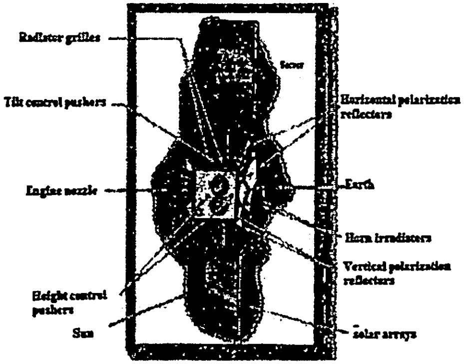


Figure 4.3 Satellite with three-axis stabilization

The satellite's telemetry equipment is used to transmit information about its ESsition to Earth. If the ESsition correction is necessary, the appropriate commands are transmitted to the satellite, uESn receipt of which the ESwer equipment is switched on, and the correction is carried out.

4.3. Signal part

Band width

The bandwidth of a satellite channel characterizes the amount of information t can transmit per unit of time. A typical satellite transceiver has a bandwidth of 36 /IHz.

Usually the bandwidth of the satellite channel is large. For example, one color television channel occupies the 6 MHz band. Each transceiver on modern communications satellites supESrts a 36 MHz band, while the satellite carries 12 or 24 transceivers, which results in 432 MHz or 864 MHz, respectively.

Frequency spectrum

Satellites must convert the frequency of signals received from the ES before relaying them to the ES, therefore, the frequency spectrum of the communication satellite is expressed in pairs. Of the two frequencies in each pair, the lower one is used for transmission from the satellite to the SC (downflows), the upper one is used for transmission from the SC to the satellite (upflows). Each pair of frequencies is called a band.

Modern satellite channels most often use one of two bands: the C-band (from the satellite to the satellite in the 6 GHz region and back in the 4 GHz region), or the Ku band (14 GHz and 12 GHz, respectively). Each frequency band has its own characteristics focused on different communication tasks example in Table 4.1.

Table 4.1

Characteristics of frequency bands

Satellite transmission band ranges, L (GHz)	**Stripe, With (MHz)**	**Frequency range, Ku (GHz)**	**Available width, Ka (Hz)**
1.6/1.5	15	6/4	500
14/12	500	30/120	2500

Most active satellites use the C-band. Transmission in the C-band can cover a significant area of the earth's surface, which makes satellites especially suitable for broadcasting signals. On the other hand, the C-band signals are relatively weak and require developed and rather expensive antennas on the ES. An imESrtant feature of C-band signals is their resistance to atmospheric noise. The Earth's atmosphere is almost transparent to signals in the 4/6 GHz band. Unfortunately, the same factor is due to the fact that C-band signals are most suitable for ground-based ESint-to-ESint microwave transmissions that sESil weaker satellite signals. This circumstance makes it necessary to place ES using the C-band when transmitting, many kilometers away from urban centers and places of dense ESpulation.

Transmission in the Ku band has opESsite properties. The beam in such a transmission is strong, narrow, which makes the transmission ideal for ESint-to-ESint connections or connections from a ESint to several ESints. Ground-based microwave signals do not affect the Ku-band signals in any way, and Ku-band ESSS can be placed in city centers. The natural high ESwer of the Ku-band signals makes it ESssible to do with smaller, cheaper ES antennas. Unfortunately, the Ku-band signals are extremely sensitive to atmospheric phenomena, especially fog and heavy rain. Although such weather events are known to affect a small area for a short time, the results can be quite serious if such conditions coincide with the CNN (the hour of the greatest load, for example, 4 p.m., noon Friday).

Speech and data transmission

Frequency Division Multiplexing (FDM) is widely used to multiplex multiple speech channels or data channels onto a single satellite transceiver.

In FDM, the waveform of each individual telephone signal is filtered to limit the bandwidth to a range of audio frequencies between 300 and 3400 Hz, then converted. Further, the signals of the twelve channels are multiplexed into a comESsite baseband signal. Each group is made up of telephone signals placed in intervals with a bandwidth equal to 4 kHz. Then several groups are repeatedly multiplexed and form a large group, which can contain from 12 to 3600 separate speech channels.

Time Division Multiplexing (TDM) is another method for transmitting speech and/or data over a single channel. If in FDM separate frequency segments within the entire band are assigned to transmit a speech signal (or data), in the TDM method, transmission is carried out over the entire allocated frequency band. In the outgoing channel, repeatable base time periods, sometimes called frames, are divided into a fixed number of clock cycles, which are allocated sequentially to transmit signals from incoming speech channels and data channels. To protect against ESssible loss of information, storage devices (buffers) are used.

4.4. Ground segment

Technological development has led to a significant reduction in the size of the ES. At the initial stage, the satellite did not exceed several hundred kilograms, and the ES were gigantic structures with antennas more than 30 m in diameter. Modern satellites weigh several tons, and antennas, often no more than 1 m in diameter, can be installed in a wide variety of places. The tendency to reduce the size of the ES together with the simplification of the installation of equipment leads to a decrease in its cost. To date, the cost of ES is, perhaps, the main characteristic that determines the widespread use of SCS. The advantage of satellite communications is based on servicing geographically remote users without additional costs for intermediate storage and switching. Any factors that reduce the cost of installing a new ES definitely contribute to the development of applications focused on the use of SCS. The relatively high costs of deploying a ES allow terrestrial fiber-optic networks to successfully compete with the SCS in some cases.

Consequently, the main advantage of satellite systems is the ability to create communication networks that provide new communication services or expand the old ones, while from an economic ESint of view, the advantage of the SCS is inversely proESrtional to the cost of the ES.

Depending on the type, the ES has transmission and/or reception capabilities. As already noted, virtually all intelligent functions in satellite networks are carried out in the ES. Among them are the organization of access to satellite and terrestrial networks, multiplexing, modulation, signal processing and frequency conversion. Finally, let us note that most of the problems in satellite transmission are solved by the ES equipment.

Currently, there are four types of ES. The most complex and expensive are those focused on high intensity of user loading with very high bandwidth. Stations of this type are designed to serve user populations that require fiber-optic communication lines to ensure normal access to the ES. Such ES cost millions of dollars (Fig. 4.4).

Medium-capacity stations are effective for servicing private networks of corporations. The sizes of such ES networks can be very diverse depending on the implemented applications (speech, video, data transmission). There are two types of corporate SCS.

A well-developed corporate system with large investments usually supports services such as video conferencing, email, video, speech and data transmission. All

ES networks have equally large bandwidth, and the cost of the station reaches $ 1 million.

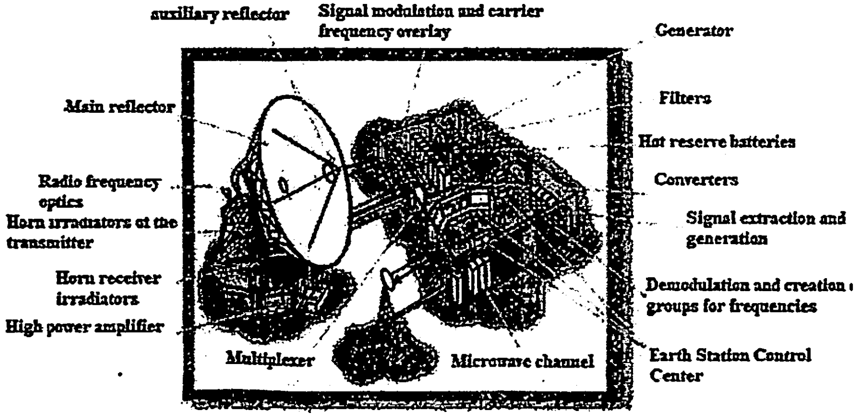


Fig. 4.4. High-throughput ES.

A less expensive type of corporate network is the SCS of a large number (up to several thousand) microterminals (VSAT – Very Small Aperture Terminal) connected to one main ES (MES – Master Earth Station). These networks are usually limited to receiving/transmitting data and receiving audio-video services in digital form. Microterminals communicate with each other through transit with processing through the main PO. The topology of such networks is star-shaped.

The fourth type of ES is limited by reception capabilities. This is the cheapest option of the station, since its equipment is optimized for the provision of one or more specific services. This PS can be focused on receiving data, audio signal, video or their combinations. The topology is also star-shaped.

4.5. Aloha System

The impact of the Aloha Multiple Access protocol (also known as the Aloha system) developed at the University of Hawaii in the early 1970s on the development of satellite and local area networks is difficult to overestimate.

In this ES system, packet transmission over a common satellite channel is used. At any given time, each ES can transmit only one packet. Since the satellite is assigned the role of a repeater in relation to packets, whenever a packet of one ES reaches the satellite during its broadcast of another packet of some other ES, both transmissions overlap (interfere) and "destroy" each other. A conflict situation arises that requires resolution.

In accordance with the early version of Aloha, known as the "pure Aloha system", ES can start transmitting at any time. If, after the time of distribution, they listen to their successful transmission, they conclude that they have avoided a conflict situation (i.e., thereby receive a positive receipt).

Otherwise, they know that an overlap has occurred (or perhaps some other noise source has acted) and they must repeat the transmission (i.e. receive a negative receipt). If the CS repeat their broadcasts immediately after listening, they will probably get into a conflict situation again. Some conflict resolution procedure is required in order to introduce random delays during retransmission, and to spread the conflicting packets in time.

Another option of the Aloha system is to divide the time into segments – windows, the length of which is equal to the length of one packet during transmission (it is assumed that all packets have the same length). If we now require that packet transmission begins only at the beginning of the window (the time is tied to the satellite), then we will get a double gain in the efficiency of using the satellite channel, since overlays are limited to the length of one window (instead of two, as in the pure Aloha system).

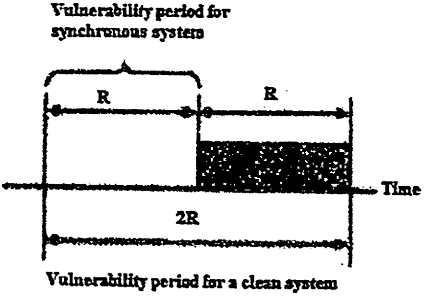


Figure 4.5. Vulnerability period for Alpha system

The third approach is based on reserving time windows at the request of the ES.

Another improvement of the Aloha system can be the assignment of priorities for a high-intensity load system.

4.6. Advantages and limitations of SCS

The USSR has unique features that distinguish them from other communication systems. Some features provide advantages that make satellite communications attractive for a number of applications. Others create restrictions that are unacceptable when implementing some application tasks.

The USSR has a number of advantages:

- Sustainable costs. The cost of transmission via satellite over a single connection does not depend on the distance between the transmitting and receiving ES. Moreover, all satellite signals are broadcast. The cost of satellite transmission, therefore, remains unchanged regardless of the number of receiving ES.
- Wide bandwidth. Low probability of error. Due to the fact that bitwise errors are very random in digital satellite transmission, effective and reliable statistical schemes for their detection and correction are used.
- A number of limitations in the use of SCS:
- Significant delay. The large distance from the spacecraft to the satellite in geosynchronous orbit leads to a propagation delay of almost a quarter of a second. This delay is quite noticeable with a telephone connection and makes it extremely inefficient to use satellite channels with data transmission that is not adapted for SCS.
- Dimensions of the PO. An extremely weak satellite signal at some frequencies reaching the ES (especially for older generation satellites) makes it necessary to increase the diameter of the ES antenna, thereby complicating the station placement procedure.
- Protection against unauthorized access to information. Broadcasting allows any PS tuned to the appropriate frequency to receive the information transmitted by the satellite. Only signal encryption, which is often quite complex, protects information from unauthorized access.
- Interference. Satellite signals operating in the Ku or Ka frequency bands are extremely sensitive to bad weather. Satellite networks operating in the C-band are susceptible to microwave signals. Interference due to bad weather worsens the transmission efficiency in the Ku and Ka bands for a period of several minutes to several hours. Interference in the C-band limits the deployment of ES in areas with a high concentration of residents.
- The influence of the mentioned advantages and limitations on the choice of satellite systems for private networks is quite significant. The decision to use SCS, rather than distributed terrestrial networks, must be economically justified every time. Fiber-optic communication networks are increasingly competing with SCS.

5. ODYSSEY System

The Odyssey system is designed to provide global radiotelephone communication and other types of personal communication services. The cost of the Odyssey project is approximately $ 2.5 billion.

The main contractor is the international company Odyssey Telecommunication International (OTI), and the project is financed by a group of companies, including its founders (OTI), the main investors (TRW Space companies & Technology Group, USA and Teleglobe, Canada), as well as a number of other companies, such as Spar Aerospace (Canada), Thomson CSF (France), etc. These companies have extensive experience in the development and operation of communication systems with geostationary spacecraft. TRW company is the developer of more than 185 satellite, military and scientific space complexes (Milstar, TDRS, etc.), Teleglobe is the largest telecommunications operator in the world.

TRW should develop space and ground complexes and deliver the Odyssey system "turnkey" to OTI. It is planned to deploy a wide network of national operator firms to provide services. Having licenses for operator activity, these providers will operate the system in various regions of the world.

The functioning of the Odyssey system is regulated by the following documents:

- license to create the system — issued by the US FCC in January 1995.;
- permission to work in the L- and S-bands. Frequencies for subscriber lines were allocated in 1992 at the World Administrative Conference on Radio Communications WARC-92;
- permission to work in the Ka-band. Frequencies for feeder lines were allocated in 1995 at the WRC-95 World Radiocommunication Conference.

5.1. Space segment and service areas.

The space segment of the Odyssey system uses medium-altitude circular orbits for global coverage of the Earth and consists of 12 spacecraft. The satellites were placed at an altitude of 10,354 km in three orbital planes with an inclination of 50 ° (in each plane — 4 spacecraft). The mass of the spacecraft is 2500 kg, the service life of the spacecraft is 15 years. The capacity of the satellite's solar panels at the end of its estimated lifetime will be 4.6 kW.

The Atlas IIA launch vehicle put the satellites into orbit (in pairs). The satellite's orbital period is approximately 6 hours, the angular velocity is about 1 deg/min. There are 2 spacecraft above most land areas in the service area at the same time, and at least one of them is not lower than 30 ° above the horizon. The system as a whole provides service to subscribers in the territory from 70 ° s. to 70 ° s. and covers a zone extending over 7 thousand km (with a total width of the satellite's directional pattern of 40 °).

A distinctive feature of the Odyssey system is the quasi—static coverage of the Earth's surface. All satellites are equipped with multipath antennas that create a continuous cellular coverage structure on the Earth's surface, covering (selectively) only land and the most navigable waters of the world ocean. As the spacecraft moves in orbit, the beam positioning system will track the formation of a geographically stationary cellular structure in the serviced area.

Switching service areas is carried out only when the visibility angles for communication with Earth stations become small. The radio visibility of the two satellites is provided at relatively high viewing angles from almost any latitude. Even if only one satellite is available for communication (and the second one is not used), the visibility angle of the spacecraft will be no less than 30°, and will be guaranteed for 95% of the daily time. This will reduce the energy reserve of the radio line necessary to compensate for the loss of propagation through trees, buildings and other obstacles.

To organize communication in the Odyssey system (Fig. 4.6), a simple "transparent" repeater with frequency conversion is used; information processing on board the satellite is not provided. The delay of the signals in the repeater does not exceed 5 ms. Routing and message processing are carried out at ground stations.

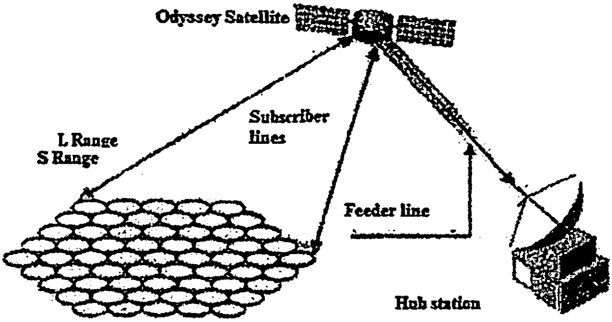


Fig. 4.6 The scheme of the organization of communication in the Odyssey system

Broadband signals and multi-station access with code division of channels (CDMA) are used to transmit information. Reception of information from subscriber terminals is carried out in the L-band (1610.0— 1626.5 MHz), transmission to the subscriber terminal — in the S-band of frequencies (2483.5-2500 MHz). The equivalent isotropic radiation power for the satellite-Earth channel is 24.2 dB/W. Circular polarization is used in the radio lines of the L- and S-bands.

The antenna system of each spacecraft creates a zone on the Earth's surface formed by 61 narrow beams, and the same zones can be used for reception and transmission.

For each of the beams, one pair of carrier frequencies is selected; the frequency reuse coefficient is not lower than 6. The frequency plan for the operation of subscriber lines (Fig. 4.7) provides that the bandwidth in the receiving beam will be 11.35 MHz, and in the transmitting beam — 16.5 MHz.

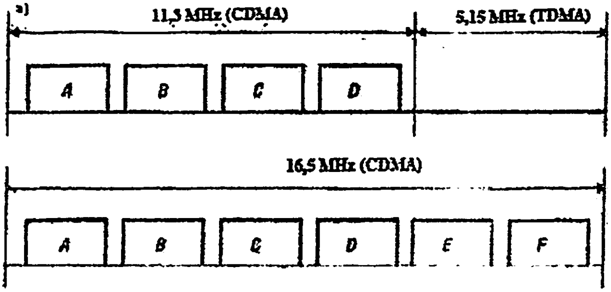


Figure 4.7 Frequency distribution in the Odyssey system:
a - line "subscriber - satellite", b - line "satellite - subscriber"

Two satellites simultaneously serving any of the regions will provide radiotelephone digital communication of 6 thousand radiotelephone channels. For stationary users, the bandwidth of one KA is more than 10 thousand equivalent channels of 4.8 kbit/ s (data transmission mode with a speed of 64 kbit / s). Feeder lines providing communication between the spacecraft and the node stations operate in the Ka-band, as shown in Table 4.1.

Table 4.1

The main characteristics of the onboard equipment of the Ka-band

Indicator	**Communication direction**	
	Reception	**Broadcast**
Frequency range, GHz	29,1-29;4	19,3-19,6
Total bandwidth, MHz	300	300
Channel bandwidth, MHz	2,5	2,5
Type of polarization	LHCP	RHCP
Antenna gain, dBi	38,5	35,7
Beam width at the level of 3 dB,	2,20	30
Receiver noise temperature, K	780	-
Equivalent isotropic radiation power, dBW	-	46,4

5.2. Ground segment and communication organization

The Odyssey satellite communication system is designed to organize radiotelephone communication, data transmission and short messages about the location of mobile objects. The Odyssey ground segment includes nodal (base) stations and terminals. Dual-mode radiotelephone terminal provides operation in GSM, TDMA, CDMA, PHS networks. It allows you to work not only in the Odyssey system, but also in terrestrial cellular networks, and access to the terrestrial cellular network is a priority.

Communication is regulated in such a way that after determining the free frequencies, the call is always sent to the address of the base station of the cellular network. If it is impossible to connect to the base station (the call is blocked or all frequencies are busy), the terminal automatically transmits the request to the Odyssey satellite.

Speech transmission is carried out at a speed of 4.2 kbit / s; the probability of an error in the speech channel is no more than 10-3. In addition to voice communication, the Odyssey terminal provides the ability to receive personal radio call messages (paging) with alphanumeric indication, provides e-mail mode, as well as determining the subscriber's location. The data transfer rate is 2.4—64 kbit/s; the probability of error per bit is no more than 105. Convolutional coding is used to correct errors (R = 1/2, K = 7).

The coordinates are determined by the Odyssey system's own signals. Due to the relatively large (for a medium-altitude orbital grouping) number of satellites, a "constellation" of two or three satellites located at high viewing angles can be observed at any point of the serviced territory. This makes it possible to determine the location of the object only by the signals of the Odyssey spacecraft, the location error is no more than 15 km.

The system does not provide inter-satellite communications. The entire schedule of this region is transmitted through the node stations shown in Table 4.2, which are interconnected by multi-channel communication lines. The tasks of node communication include not only receiving/transmitting a regional schedule, but also providing interface with a public telephone network, managing inter-beam switching, receiving and processing telemetry from a satellite.

Also, in the Odyssey system, when connecting mobile users to the public telephone network, the signal delay, which consists of the delay of the satellite channel (84 ms) and the delay of the ground path (20 ms), ensures high-quality transmission of voice messages.

Table 4.2

Main characteristics of nodal stations

Indicator	**Communication direction**	
	Reception	**Broadcast**
Frequency range, GHz	29,1-29,4	19,3-19,6
Total bandwidth, MHz	300	300
Channel bandwidth, MHz	2,5	2,5
Type of polarization	RHCP	LHCP
Antenna gain, dBi	64,8	60,8
Beam width at the level of 3 dB,	2,2	0,17
Receiver noise temperature, K	666,5	-
Equivalent isotropic radiation power, dBW	-	85,9

It is planned to build one Earth node station in each of the serviced regions; 7 stations are sufficient for global coverage of the Earth's territory. It is planned to install four tracking parabolic antennas with a diameter of about 7 m on each of them, three of which will be used for simultaneous work with satellites, and the fourth for transmitting traffic from satellite to satellite through the station, taking into account radio visibility. In addition, this antenna is necessary to increase the reliability of communication in case of adverse climatic conditions.

The satellite's onboard antennas have a narrow directional pattern, and the satellite receivers have high sensitivity, so transmitters with low output power can be used in subscriber stations. It is planned to release two modifications of subscriber terminals, differing in the output power of the transmitter (0.5 and 5 watts). The terminal design is supposed to use a "four-way spiral" antenna with a gain of 2.5 dB. The energy reserve on the communication line will be 6-10 dB.

5.3. Odyssey System Services

The deployment of the orbital grouping of the Odyssey network was carried out in 2 stages. At the first stage, services are provided by only 6 KA. They provide continuous service in the main regions for 14 hours a day. At the next stage, a full-scale orbital grouping of 12 satellites was deployed. Priority service areas were identified: the territory of the continental United States with coastal areas, Europe, Asia and the Pacific Ocean.

The users of the system will be individuals and government agencies in need of continuous mobile communication in large areas, as well as the population of regions with a low level of terrestrial communication infrastructure. In regions where there are no alternative types of communication, the use of satellite communication channels allows you to expand the coverage areas of cellular networks. Subscribers of such networks are provided with the possibility of global roaming. The short message service offers services similar to paging. Additionally, the following services are provided: customer location detection, voice mail, emergency messages, translation from one language to another.

In 2005, after the end of the ODYSSEY system deployment, the number of its subscribers .exceeded 2 million. At the moment, the number of users is about 9 million people. The price of one subscriber terminal is 350-1000 dollars, the monthly subscription fee is 25 dollars, and the cost of a minute of telephone communication in a satellite channel is 0.75 dollars.

6. International ISO System

6.1.Frequency assurance

The ICO system uses L- and C-frequency bands for communication, supporting digital signal processing on board the satellite. The method of multi-station access with time division of channels (TDMA) is defined as the basic technology.

When determining the optimal frequency bands for subscriber communication lines, several options were considered. The following considerations were taken into account. The 1.5/1.6GHz band, widely used for mobile satellite services (PSS), will obviously be overloaded, which will greatly limit the potential of ICO services. The 1.6/2.4GHz band allocated to the PSS service at the World Administrative Radiocommunication Conference (WARC-92) is fraught with serious coordination problems with other services that use this range, for example, for fixed terrestrial communications; in addition, the US intends to use it for national systems.

Finally, the following ranges were selected: "terminal-satellite" — the range of 1980— 2010 MHz, "satellite-terminal" — 2170-2200 MHz.

Feeder lines are designed to organize communication between spacecraft and node stations. For their work, the WRC-95 World Radiocommunication Conference recommended the 5/7 GHz band ("node—satellite station" range 5150-5250 MHz, "satellite—node station" - 6975-7075 MHz).

6.2. Space segment

The ICO system consists of space, ground and user segments. The space segment includes 12 spacecraft (10 operational and 2 backup) launched into a circular orbit with a height of 10,355 km above the Earth's surface. The launch mass of the satellite is 2750 kg, the estimated period of operation is 12 years. The satellites are placed in two orthogonal planes, 6 spacecraft in each. The angle of inclination of the orbit to the plane of the equator will be 45 °.

Such an orbital grouping provides global coverage of the Earth's surface, including the polar regions. Due to the overlap of coverage areas, two to four spacecraft are simultaneously located within the visibility of each point of the service area. One satellite serves approximately 25% of the Earth's surface (Fig. 4.8)..

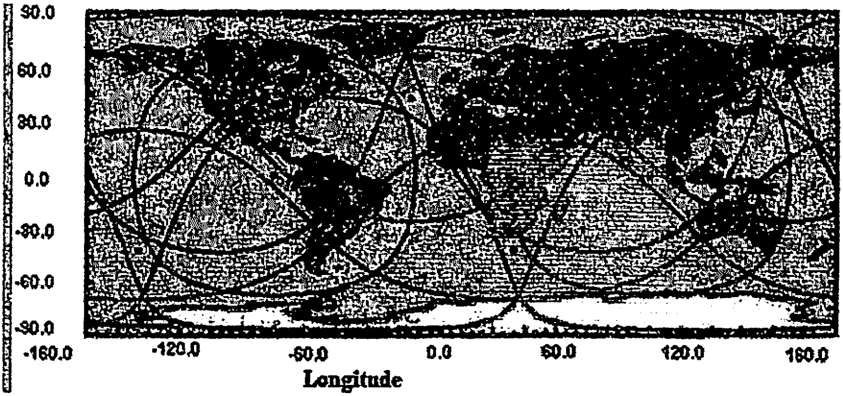


Figure 4.8 Diagram of the instantaneous coverage area of the Earth's surface by the ICO system when using 10 KA

The duration of customer service is determined by the following values:

- the time of flight of one satellite over the service area;
- the average time spent on switching the subscriber from the outgoing horizon to the ascending spacecraft;
- the duration of establishing a connection, determined by the communication organization scheme. The average duration of customer service will be 50 minutes; the maximum time spent by one spacecraft in the radio visibility zone can reach 1.5-2 hours.

The ICO system mainly uses already known and proven technical solutions. For the manufacture of satellites, the HS-601 satellite platform of Hughes Space and Communications Corporation (USA) is used to create large-sized satellites in geostationary orbit. Changes have been made to the design, in particular, a revised orientation program for onboard antennas and solar panels, and a simplified propulsion system has been installed.

In order to exclude interference by the ICO system when using 10 KA reception and transmission paths, separate antennas for each frequency range are used on the spacecraft. The L-band antenna has a diameter of 2 m. The use of a multipath diagram-forming scheme provides multiple frequency assignment. According to the project, 163 separate beams are used for receiving/transmitting in the ICO system (the energy reserve will be 8-10 dB); the service area of one spacecraft is about 7 thousand km (Fig. 4.9). Satellites with C— and S-band repeaters installed on them simultaneously support 4,500 telephone channels.

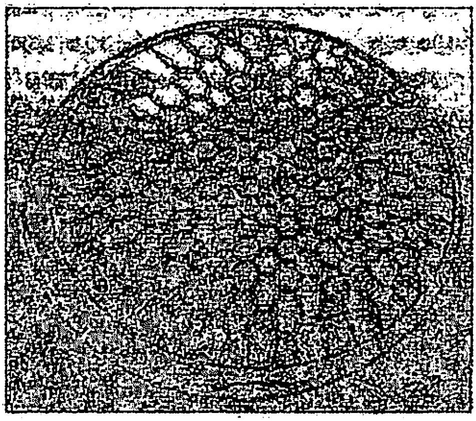


Fig. 4.9 The service area of one spacecraft (163 beams) of the ICO system

The ICO system does not provide on-board signal processing in full. However, frequency assignment control and signal routing are carried out using an on-board processor.

The use of arsenide-galium batteries provides a power consumption of 8700 watts at the end of operation. The preliminary list of launch vehicles that launched ICO satellites includes Atlas IIA, Delta III, Proton and Zenit (for launching from offshore platforms).

6.3. Ground segment and communication organization.

The ground segment includes the SS Satellite Group Control Center (Satellite Control Center), the Ground Network Management Center (Network Management Center) and the ICONET ground network (ICO network),(fig. 6.10).

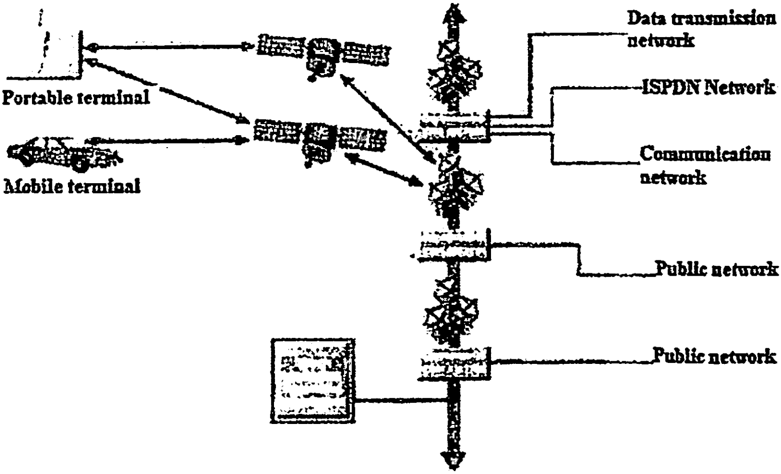


Fig. 6.10 ICO system structure (schematically)

NMS, the ICONET terrestrial network control center, is located in Japan, and the SCC center is located in London. The functions of the latter include maintaining the orbital grouping in a working state, collecting telemetry data on individual spacecraft subsystems, monitoring operating parameters, etc. SC services are responsible for launching the spacecraft, managing and redistributing frequencies between the beams of EACH.

Satellite channels are connected to existing communication networks through its own ICONET network, which at the first stage of implementation consists of 12 ground stations — the so-called satellite access nodes (Satellite Access Node). SAN nodes serve as "gateways" between ICO satellites and subscribers of public terrestrial networks. High-bandwidth trunk channels connect nodes to each other.

Communication between subscribers (as in the existing Inmarsat system) is organized only through SAN nodes; direct communication of subscribers is not supported. The ICO radiotelephone terminal operates in two modes — via ICO satellite systems or cellular ground base stations — and is compatible with its basic standards. Special terminals are used to communicate with mobile objects.

6.4. User terminals

In the ICO satellite network, a portable dual-mode terminal is used as a base, combined with a GSM (or CDMA, D-AMPS, RDS) cellular phone. It is planned to develop a single-mode radiotelephone terminal operating only through the ICO system spacecraft. Main characteristics of the base terminal:

- weight — less than 750 g,
- volume — about 500 cm,
- cost — 750-1500 dollars,
- a separate battery provides one-hour transmission and 24-hour standby reception.

The portable ICO radiotelephone terminal meets all safety requirements related to operation in the HF band. The average power of the transmitter does not exceed 0.25 watts (for comparison: the power of cellular radiotelephones is 0.25—0.6 watts).

Based on the technology used in the base terminal, various modifications of subscriber terminals can be created. These are, for example, a terminal for data transmission only, terminals in automotive, marine and air versions, semi-stationary ("rural payphone") and stationary, as well as unattended (SCADA unit) terminals. ICO has signed an agreement for the development of 3 million portable terminals with three leading companies — Panasonic, NEC and Mitsubishi.

6.5. ISO System Services

The following types of services are provided to users: two-way voice communication, transmission of group 3 facsimile messages, data transmission at a speed of 2.4 kbit/s. The quality of voice communication corresponds to the GSM standard for cellular networks. Paging communication with deep penetration is provided (i.e. with a large margin for the energy of the channel), as well as additional services — voice call, communication with credit card payment, display of the caller's number on the indicator built into the terminal, determination of the subscriber's location. In the absence of a spacecraft within the line of sight, there is a notification of subscribers about a call, about the presence of an e-mail message and the display of the caller's number on the display.

Developers see five key areas of application of the ICO system:

- expanding the range of services for satellite subscribers in areas already covered by cellular networks;
- public mobile communications via portable radiotelephone terminals in areas not covered by cellular communications or using incompatible standards;
- specialized mobile communications for cargo transportation, as well as provision of road, sea and air communications;
- semi-fixed communication for corporate users of the oil and gas industry, small businesses (warehouses, large stores, etc.);

- communication for government agencies.

The system's bandwidth is 1 million subscribers with an average conversation duration of 60 minutes/month. For comparison: according to experts' forecasts, in the Iridium system, under the same conditions, the number of users is 600-800 thousand, and in Globalstar — 1 million.

The development and manufacture of 12 spacecraft is estimated at $ 1.3 billion, and their launch will cost $ 900 million. According to the calculations of IKO specialists, the price of subscriber equipment will be $ 750÷1500, and the cost of a minute of conversation is about $ 2.

7. Comparison of Odyssey and ICO systems

Among the largest projects for the creation of global personal radiotelephone communication systems include (in addition to the Odyssey and ICO systems discussed above) the low-orbit Iridium and Globalstar systems, shown in Table 6.1. Providing users with almost the same set of telecommunications services (speech, data, paging, short messages, location determination), competing systems differ significantly in their characteristics and ground structures. Thus, to ensure global communication in Odyssey/ICO systems, only 7-12 node stations are required, and to serve Globalstar users — 20 times more. The structure of the terrestrial segment of the Iridium network is somewhat simpler than in Globalstar (thanks to the use of inter-satellite communication lines).

The ICO system is the only one of the four competing systems that does not yet have a US license for the commercial use of radio frequencies. However, the organization is making every effort to solve this problem.

Technical and economic parameters are the most important for the user, but this information is often of an advertising nature (i.e. it is not completely objective), which is explained by the fierce competition in the market. Particularly heated disputes are caused by the price of terminals and the proposed tariffs. So, it is difficult to explain why a dual-mode Motorola terminal, which provides almost the same characteristics as terminals from other companies (for example, Mitsubishi terminals for Odyssey and ICO systems), costs several times more than they do. Time will tell what the final prices and tariffs will be.

Table 6.1

Comparative characteristics of global radiotelephone communication systems

Indicator	Odyssey	ICO	Iridium	Globalstar
Type of orbit	MEO	MEO	LEO	LEO
The number of KA	12	12	66	48
Orbit height, km	10 354	10 355	780	1400
Inclination of the orbit, °	50	45	86	52
Weight of the spacecraft, kg	2500	2750	690	450
Power consumption, W	4600	8700	1000	1200
Number of rays	51	163	48	16
The service life of the spacecraft, years	15	12	5	7,5
Multi-station access method	CDMA	TDMA	TDMA	CDMA/FDMA
Number of nodal stations	7	12	25	150-210
The number of KA channels equivalent to 4.8 kbit/s	3000	4500	from 600	1300
The cost of the project is billions of dollars	2,5	2,8	От 3,5	2,0
The cost of a dual-mode terminal, USD.	350	750	3000	750
Tariff, USD/min	0,75	2	3	0,35-3

8. Calculation of the dependences of satellite characteristics on the parameters of longitude and angle of opening of the antenna

Task:

- Determine the gain of the on-board repeater antenna depending on the opening angle.
- Determine the inclined range between the CS and CS.
- Calculate the width of the radiation pattern by the level of half power.

Methodological guidelines for the calculation:

1. According to the specified values from Table 5.4, write out the initial data for the calculation.

2. Determine the gain of the on - board repeater antenna by the formula:

$$G_b = 44.4 - 10 \lg F_0 - 10 \lg F_1,\ \text{dB} \qquad (8.1)$$

where F_0, F_1 are the opening angles of the satellite antenna (for symmetrically opening antennas $F_0 = F_1$ (set according to the variant);

After the calculation, it is necessary to convert the value of G_b (dB) to G_b (times) according to the formula:

$$G_b(\text{once}) = 10^{G_b(\text{dB})/10},\ \text{onec} \qquad (8.2)$$

3. The inclined range between the ES and the CS is determined by the formula:

$$d = 42644 \cdot \sqrt{1 - 0{,}295 \cdot \cos\psi},\ \text{km} \qquad (8.3)$$

Where

$$\cos\psi = \cos\xi \cdot \cos\Delta\lambda \qquad (8.4)$$

ξ – the latitude of the receiving station (set by option);
$\Delta\lambda$ – the difference in longitude between ES and CS (set by option).

4. Calculate the width of the radiation pattern by the half power level.

$$\theta_{0,5} = \sqrt{4{,}9 \cdot 10^3 \cdot g/Gb} \qquad (8.5)$$

where g = 0.5 is the utilization factor of the antenna surface

Calculation example:

1. Initial data:
The opening angles of the antenna artificial Earth satellite $\Phi 0 = \Phi 1 = 5o$.
The latitude of the receiving station $\xi = 42°$.
The difference in longitude between ES and CS $\Delta\lambda = 7°$.

2. Determination of the antenna gain of the on - board repeater by the formula:
$G_b = 44{,}4 - 10 \lg 5 - 10 \lg 5 = 44{,}4 - 6{,}9 - 6{,}9 = 30{,}6\ dB$
Translate the value G_b (dB) in G_b (ones) according to the formula:

$G_b\,(ones) = 10^{Gb\,(dB)/10} = 10^{30,6/10} = 10^{306} = 1148$ *ones*

3. To determine the inclined range between the ES and the CS , we first define:
$cos\psi = cos\xi \cdot cos\Delta\lambda = cos42° \cdot cos7° = 0,743 \cdot 0,993 = 0,738$
Then:
$d = 42644 \cdot \sqrt{1 - 0,295 \cdot cos\psi} = 42644 \cdot \sqrt{1 - 0,295 \cdot 0,738} = 37720$

KM

4. Calculation of the width of the radiation pattern by the level of half power.
$L_{add} = L_{atm} + L_d + L_n + L_n = 0,15 + 0 + 0,3 + 0,05 = 0,5\ dB$
Signal attenuation in free space:
$\theta_{0,5} = \sqrt{4,9 \cdot 10^3 \cdot g/Gb} = \sqrt{4,9 \cdot 10^3 \cdot 0,5/1148} = 1,6°$

Table 8.1

Initial data on options

The last digit of the magazine number	$F_0 = F_1$	ξ	Δλ
1	17°	30°	3°
2	11°	32°	4°
3	5°	34°	5°
4	2,5°	36°	6°
5	17°	38°	7°
6	11°	40°	3°
7	5°	42°	4°
8	2,5°	44°	5°
9	11°	46°	6°
0	5°	48°	7°

Questions

1. What are the basic parts of the satellite communication system?
2. List the main components of the satellite and explain their functional tasks.
3. What types of ES exist? Give them a brief description.
4. What is the Aloha system?
5. Give and explain the scheme of communication organization in the Odyssey system.

PRACTICAL WORK №6

STUDYING THE PRINCIPLES OF BUILDING VSAT EARTH STATIONS

1. Purpose of the work

Study of the principles of constructing functional circuits of Earth stations for telephony and data transmission.

2. Task

1. Get acquainted with the definition of the VSAT Earth station class.
2. Study the types of VSAT networks.
3. Familiarize yourself with the structure of the VSAT network for data transmission.
4. Calculate the parameters of the ZS receiver
5. Make a report.

3. Report content

1. The purpose of the work.
2. Functional diagram (as instructed by the teacher).
3. The main options for organizing communication in VSAT networks.
4. Calculation of the parameters of the ZS receiver

4. A brief theory

4.1. Definition of the VSAT Earth Station class

The class of VSAT (Very Small Aperture Terminal) earth stations includes satellite communication stations whose technical characteristics meet the following requirements of the Rivers. ITU-R S.725 "VSAT Technical Specifications":

- VSAT stations are installed directly at users, and the density of their placement in a limited area can be very high;
- monitoring and management of VSAT stations in the network are carried out centrally, but local station monitoring and control systems can also be used additionally;
- VSAT stations belong to the Fixed Satellite Service (FSS) and must meet the requirements of the Radio Regulations (RF) and ITU-R Recommendations, as well as all FSS Earth stations;

- VSAT stations are usually used in so-called dedicated networks (private, business) for data transmission and telephony in digital form in reception-only (simplex) or reception/transmission (duplex) modes;
- VSAT antennas usually have a diameter of 1.8...3.5 m, but larger antennas (up to 6 m in diameter) can also be used in individual systems;
- VSAT stations use a low-power radio transmitter (usually from 1 to 20 watts) with mandatory limitation of radiated power for safety reasons.

4.2. Types of VSAT networks

VSAT networks are usually classified according to two main characteristics: traffic configuration and the structure of the network management system (centralized and decentralized).

From the point of view of traffic , there are three main options for organizing connections in VSAT networks:

1) a point-to–point network is the simplest case of a duplex communication line between two remote stations;

2) star type network – for multidirectional radial traffic between the network center and peripheral (remote) communication points;

3) a network of the "everyone with everyone" type (MESH type network in English literature) — for direct connections between any points of the communication network.

A point-to-point network (Fig. 4.1) allows for direct duplex communication between two remote communication points. Such a communication scheme is most effective when there are large distances between points or their location in hard-to-reach regions.

In the most common networks of the "star" type for VSAT class stations (Fig. 4.2), multidirectional radial traffic is provided between the CES of the network (TS) and remote peripheral stations (terminals) of VSAT according to an energetically advantageous scheme: a small VSAT – a large TS with a large diameter antenna and a powerful transmitter.

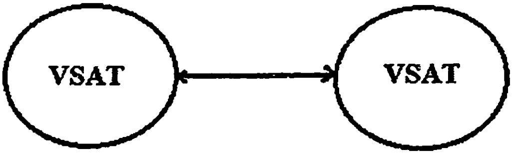


Figure 4.1. Point-to-point network

VSAT networks of this kind are widely used to organize information exchange between a large number of remote terminals that do not have mutual traffic, and the company's central office, transport or financial institutions.

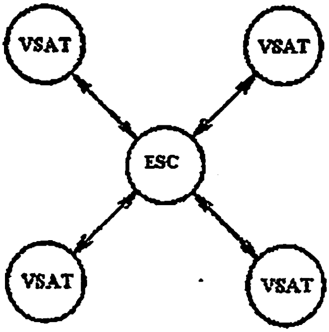


Fig. 4.2. The "star" type network

Similarly, telephone networks have been built to serve so-called remote subscribers, who are provided with access to a public switched telephone network through a central station connected to one of the ground-based channel switching centers (GATEWAY).

Control and management functions in a network of the "star" type are usually centralized and concentrated on the central control station (CCS) of the network. The data center performs the service functions of establishing connections between subscribers of the communication network and maintaining the working state of all peripheral terminals of the VSAT of this network. Such a centralized VSAT network management system using a data center is economically feasible for networks with a sufficiently large number of simplified and therefore cheap VSAT peripheral terminals. However, there are examples of the implementation of VSAT networks without a data center with a decentralized distributed control system, the elements of which are part of each VSAT station.

In some operating VSAT telephone networks of the star type, the functions of the TSS and the TSS are divided between different Earth stations, but more often the functions of the TSS are combined with the functions of the TSS (see Figure 6.2). Such a combined scheme of the TSS/TSS is used mainly in packet-switched data transmission networks, where the TSS/TSS acts as a dispatcher – router network traffic and simultaneously provides a satellite network interface with a terrestrial data transmission network based on the ITU-T X.25 protocol

In centrally managed VSAT networks created by large satellite operators, the software and technical resources of a single data center can be provided to several autonomously operating and newly created VSAT subnets by allocating part of these resources to each of the subnets. Thus, the possibility of gradual expansion of the network and the implementation of additional services to consumers is realized.

In the "everyone with everyone" network (Fig.4.3), direct connections are provided between any VSAT stations located at all points of communication. The connection of any two stations in such a network is established via satellite in one "jump". The scheme is optimal for telephone networks created in hard-to-reach and remote areas, and for data transmission networks with a relatively small number of remote VSAT terminals.

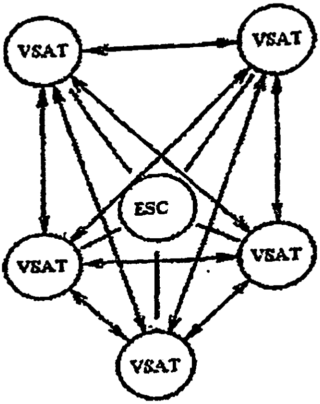


Figure 4.3. The "everyone with everyone" type of network

With a centralized control scheme for such a network, the data center performs only the service control and management functions necessary to establish a connection between the subscribers of the VSAT network, but does not participate in the transmission of traffic.

There is no DCS in the decentralized version of network management, and the elements of the control system are part of each VSAT station. Such networks with a distributed control system are characterized by increased "survivability" and flexibility due to the complexity of the equipment, the expansion of its functionality and the rise in cost of VSAT terminals for these reasons.

4.3. Types of multi-station access in VSAT networks

Multi-station access in VSAT networks is usually organized on the basis of the frequency division method in the mode of fixed channels between stations with heavy traffic or in the mode of the frequency division method with the provision of channels on demand of the frequency division method-the provision of channels on demand for interactive traffic. In the interactive mode of information transmission, VSAT network stations provide access to carriers allocated in the repeater trunk based on the time separation method (TIME SEPARATION METHOD), including the protocol of the TIME SEPARATION METHOD with random access of the ALOHA type or more effective varieties of this protocol: tactile ALOHA (S-ALOHA) and ALOHA with redundancy (R-ALOHA).

As shown in Fig. 4.4, in the networks of the "star" type, there are outgoing (CES-VSAT) and incoming (VSAT-CES) satellite channels, which are formed on the basis of the frequency separation method in the frequency band of the satellite repeater trunk allocated for this VSAT network.

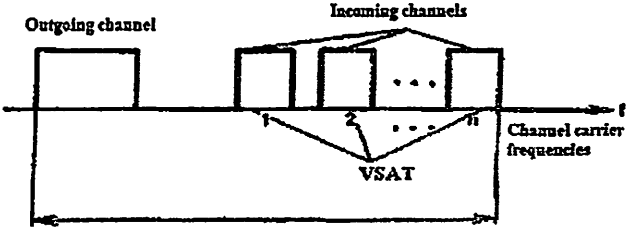


Figure 4.4. Multi-station access in VSAT networks of the "star" type

In VSAT networks with a large number of peripheral terminals, each outgoing channel of the CES usually corresponds to several (1,2,...,n) incoming channels (n<32) used by various groups of VSAT terminals. The structure of incoming and outgoing channels in each case is determined based on the requirements for the communication network, network composition, types and speed of transmitted information.

Several outgoing and corresponding incoming channels can be organized in one network.

The outgoing channel of the CES-VSAT is usually organized as a channel on a separate carrier with time separation (BP) and bundling of the transmitted information. The speed of information transmission in the outgoing channel is determined by the total volume of radial traffic from the CES of the network to the group of serviced peripheral VSAT terminals. Typical data transmission rates in the outgoing channels of existing VSAT networks are 256...2048 kbit/s, the modulation method is double phase manipulation (DFM/QPSK).

The CES transmits information in the outgoing channel in the form of a continuous signal with a regular frame structure consisting of a time sequence of information packets repeating the classical packet structure of systems using the TSV: 1) the packet start flag (preamble), 2) the packet header, 3) data block (useful information), 4) verification sequence (error correction), 5) the flag of the end of the package (postambula). The frame boundaries are indicated by a unique word (UW) and a block of service information, which are used for network frame synchronization of packets transmitted by VSAT terminals in incoming VSAT channels-the CES, and for controlling VSAT terminals via S, R-ALOHA protocols.

The totality of packets transmitted in the outgoing channel of the CES is intended (addressed) to a group of peripheral VSAT terminals. Each VSAT terminal, by the code of the address field in the packet header, accepts only packets addressed to this terminal from the transmitted sequence. Other packets are skipped (ignored).

In each of the incoming VSAT response channels there is a CES transmitted on separate carriers (see Fig. 4), temporary access of a group of VSAT terminals is organized with the transmission of information in packets with the following structure: 1) preamble, 2) title, 3) information block, 4) verification sequence, 5) postambula.

Packets of different VSAT stations are located on time intervals within a common time frame. For access, the most commonly used varieties of one of the protocols of the TSM with random access such as S-ALOHA, R-ALOHA or more efficient protocols that are adaptive to the channel load value (for example, the type of TSM-PCHonD). Typical transmission rates of packaged information in incoming channels are 64/128 kbit/s, modulation is FM-2/FM-4 (BPSK/QPSK).

Sometimes, in telephony transmission networks, incoming VSAT-CES channels are organized as ordinary channels with a frequency division of the "one channel per carrier" type (FDM-O) and economical transmission speeds of 16/24/32 kbit/s, provided on demand to subscribers of the telephone network for the entire connection time.

In a number of cases, multi-station access with code separation of signals (MDCR) is used, which makes it possible to most effectively solve the problem of electromagnetic compatibility (EMC) of VSAT networks with terrestrial and other satellite networks, but inferior to the TSM and the FSM in terms of the efficiency of using the bandwidth of a satellite repeater.

Currently, both VSAT networks are used for transmitting certain types of information (telephone networks, data transmission networks), and integrated business satellite communication networks that provide users with a range of services for transmitting various types of information in digital form from each VSAT terminal (data, voice messages, fax and telex signals). In this case, the most effective of the above methods of VSAT terminal access to the satellite segment can be used to transmit each type of information, which provide optimal delays in transmitting information between network subscribers for interactive modes of operation, transmission of large data files or combined traffic options. Next, we will consider the main characteristics of such networks.

4.4. VSAT network structure for telephony

Configuration of VSAT peripheral stations

A typical VSAT terminal for telephony (TLF) operating in a satellite telephone network (Fig. 4.5) consists of three main elements:

- Antenna system (AS);
- outdoor installation unit (BN) placed directly on the speaker;
- an indoor installation unit (BV) located in the user's room.

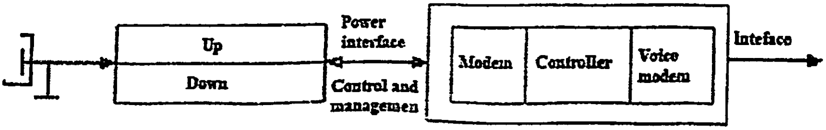


Fig.4.5. Functional diagram of the VSAT-TLF station

Where: by providing channels on demand – equipment by providing channels on demand; LNA- low–noise amplifier;

The antenna system includes an offset-type parabolic reflector with an irradiating system and an antenna-waveguide path (AVT); the BN is placed directly on the antenna. Manufacturers produce a wide range of antenna systems of VSAT stations with different values of the Q-factor of the receiving system (G/T) and equivalent isotropically radiated power (EIM) for use in satellite networks with different energy characteristics of onboard satellite repeaters.

For operation in the frequency range of 14/11-12 GHz (Ci range), small antennas with a diameter of 0.75...1.8 m are most often used, although larger antennas can be used for regions with high precipitation intensity. The offset design provides a minimum level of side lobes corresponding to the envelope G = 29-25 log dB in accordance with Rec. ITU-R S.580-2 (the angle relative to the maximum of the antenna pattern). In the frequency range of 6/4 GHz (band C), the antennas of VSAT stations have slightly larger reflector sizes (1.8 ...4.5 m) for better spatial selectivity.

The main parameters of VSAT antenna systems should correspond to the requirements of the Rivers. ITU-R S.727 and S.728.

When using linear polarization in the Ci range, the VSAT station antenna is usually equipped with a device for adjusting the polarization plane to the received signal. The cross-pclarization isolation in the antenna-waveguide part of the VSAT station in the case of linear polarization should be at least 25 dB within the contour of the main lobe of the antenna pattern with a attenuation of 0.3 dB and at least 20 dB in any other direction (Rec. ITU-R S.727 "Cross-polarization isolation for VSAT").

As a rule, antenna systems of VSAT stations do not use a satellite tracking system due to the insignificant level of guidance losses when working with a satellite with an instability of ± 0.1 ° within the main lobe of the antenna bottom. However, a number of foreign VSAT manufacturers (HUGHES Network Systems, USA, NEC CorESration, Japan) equip VSAT stations with antenna guidance systems in order to supply such stations to the Russian market to work with existing Horizon satellite systems characterized by insufficiently high accuracy of their retention on the GO.

The outdoor BN unit, which implements the functions of a transceiver, consists of two main parts: a low—noise amplifier (MSHU) with a low-noise microwave/ IF receiving converter (in English literature Low Noise Block - LNB) in the receiving path and an IF / microwave converter in the transmission path with a microwave power amplifier (UM), made in a sealed all-weather design.

The BN receiving unit is usually located directly on the antenna irradiator in order to reduce losses in the receiving microwave path to the MSU. The transmitting part of the BN (UM and PrF "up") is mounted on the structures of the AC, connected to the transmitting microwave part of the AVT and connected to the internal unit by a coaxial connector, through which signals of IF reception and transmission, DC power supply to the outdoor device, control and control signals of the BN unit are transmitted.

Most manufacturers of VSAT stations perform BN in an unserved version, which simplifies the design and reduces the cost of the VSAT terminal, but imposes very high requirements for the reliability of this device. Typical values of the output power of foreign BN in the S/Ku ranges when using solid-state transistor UM (SSPA) are 2...30 W/1...16 watts. If it is necessary to increase the EIIM of VSAT stations, UM based on a traveling wave lamp (BV) are used.

The modern MSU in the receiving part of the BN is usually performed on field GaAs HEMT transistors with a minimum noise coefficient (the typical equivalent noise temperature of a modern receiver is 200...220 K in the range of 11/12 GHz and 50...60 K in the 4 GHz band). To increase the reliability and reduce the cost of VSAT equipment, the technology of hybrid monolithic microwave integrated circuits is used.

For the convenience of placing the VSAT station, the maximum length of the connecting coaxial cable between BN and BV can be 100...200 m .

The radiation of VSAT stations in the direction of GO and parasitic studies are strictly normalized, and due to the possibility of placing a sufficiently large number of VSAT stations in a limited area, their radiation parameters should be limited more rigidly than the parameters of large SS FSS.

A typical BV internal installation unit (see Fig. 6.5) consists of a modem and a computerized digital controlthe device (controller WITH ON-DEMAND CHANNEL DELIVERY), as well as the speech codec. BV provides an interface with BN for IF, power supply, remote monitoring and control and an analog interface with the necessary types of user terminal equipment for transmitting speech information, fax or telex signals.

In the variant of the VSAT telephone network, the BV contains a speech codec that converts an analog telephone signal into digital form; the most common conversion option is adaptive differential ICM (ADICM) with a speed of 32 kbit/s in accordance with Rec.. ITU-R G.721, although dedicated networks often use ADICM with lower speeds: 24 and 16 kbit/s to transmit voice information and fax signals over a telephone channel. In addition to speech information, service alarm signals transmitted over the subscriber telephone interface when establishing a connection are also converted into digital form.

The system with the provision of channels on demand, operating under the control of the VSAT network Control Center, ensures efficient use of the satellite repeater bandwidth in the mode of loose channels provided to subscribers of the VSAT network on demand.

The VSAT modem includes an additional frequency converter that allows for frequency separation during the joint transmission of control and control signals, as well as transmitted and received IF signals via a coaxial cable between the outdoor and indoor units of the VSAT station.

The information transfer rate of digital modems of VSAT telephone terminals is 19.2...35.0 kbit/s, taking into account the transmission of additional service information, modulation is FM-2/FM-4. Almost all modern modem stations include a digital codec (encoder-decoder) of a noise-resistant code with "direct" error correction. The most common encoding method is the use of convolutional code (SC) in the encoder transmission path with relative encoding rates R=1/2, 3/4 and 7/8. In the receiving path at the output of a coherent FM signal demodulator, a SC decoder is used, which implements one of the two most effective decoding algorithms: 1) Viterbi algorithm (maximum likelihood decoding) or 2) sequential algorithm in combination with a "soft" (quantized) solution for each received symbol.

The energy gain from the use of the above-mentioned coding algorithms (EVCs) at a relative code rate of R = 1/2 is 5.5 ...6.5 dB with the probability of error at the output of Ros = 1 • 10-6. With an increase in the relative encoding rate to R = 3/4, 7/8, the EVC decreases by 1...2 dB, respectively.

An additional increase in the EVC by 2.5...3.0 dB is achieved when the SC encoder and the Reed-Solomon codec are cascaded on, designed to combat error batching at the output of the SC decoder. When using such signal-code structures in VSAT station modems, very strict requirements must be met for the possibility of phase jumps of clock and carrier frequencies in the synchronization systems of coherent FM demodulators due to the very low Pc/Rs ratio in the operating frequency band.

The generator equipment of the VSAT equipment contains, as part of the BV or BN blocks, a highly stable reference generator of the frequency range 10... 100 MHz with very high requirements for spectral "purity" and long-term stability of the frequency of the output signal, which is used to form heterodyne frequencies in the up and down RF. The typical value of the long-term stability of the frequency of the generators used is not worse than 1 •10-7 per year.

The monitoring and control system, which is part of the VSAT station equipment, must meet the requirements of the Rec. ITU-R S.729 "Control and management of VSAT stations". According to this recommendation, each VSAT peripheral station should operate under the constant control of the Control Center, ensuring that interference to other stations of the network and other systems does not occur in case of emergency situations at unattended VSAT stations. For this purpose, the VSAT networks should provide for remote control by the TSS via the TSS-VSAT radio channel of the frequency and transmission power of VSAT stations in accordance with network traffic, as well as a ban on the emission of VSAT power in emergency situations.

In order to avoid unwanted radiation towards neighboring satellites in case of accidental displacement of the antenna position of an unattended VSAT transceiver station, each VSAT station must have a protection (monitoring and control) system that does not allow power radiation until a signal is received from the satellite from the central control station of this VSAT network.

The considered set of VSAT station equipment provides the organization of a single duplex telephone channel provided in fixed mode or on demand. As a rule, the BV has a modular structure for several telephone channels and allows increasing the number of terminal sets of equipment to increase the volume of traffic. The user interface is implemented in a 2-wire subscriber version or in a 4-wire E&M type, designed for direct connection of a telephone or an institutional PBX (PBX).

4.5 Configuration of the central control station of the telephone network

The central control station (CCS) of the VSAT telephone network (Fig. 4.6) contains a large-diameter antenna with an automatic satellite tracking system, radio frequency. equipment and equipment of the modulating frequency band. The configuration of the data center has a modular structure that allows you to economically increase the volume of network traffic as the network develops and the range of services to consumers expands.

The DCS antenna has a diameter from 4.5 (6.0) to 11.0 m in order to save the power of the transmitters of the VSAT peripheral stations and the energy resource of the satellite repeater.

The primary on-demand channel delivery controller, which is the core of a centralized system (providing channels on demand), performs the functions of monitoring and managing the network and providing channels on demand, interacts via a common signaling channel (ACS) with each secondary channel controller providing channels on demand of VSAT terminals.

The DCS involved in traffic additionally includes blocks of channel-forming equipment: modems, secondary channel controllers with on-demand channel delivery and speech codecs that are modularly increased with increasing network capacity.

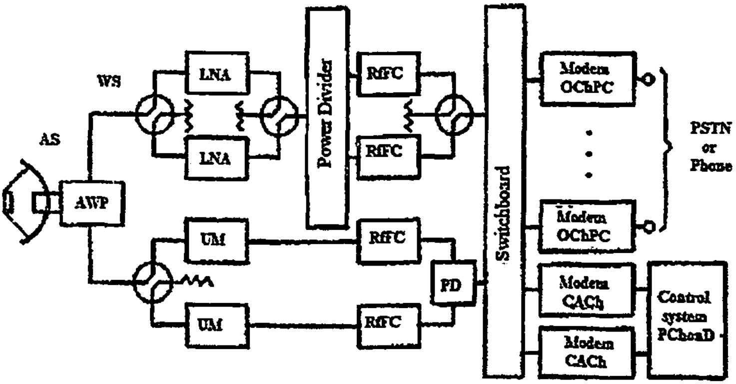


Fig.4.6. Functional diagram of the DSCS/CENTRAL EARTH STATION of the VSAT telephone network

Where: AWT -- antenna-waveguide path; AS — antenna system;

D — IF power divider; LNA — low—noise amplifier; OKN — one channel per carrier: CACh — common alarm channel; WS — waveguide switch; providing channels on demand — providing channels on demand; PrF - frequency converter (up/down); PA - power amplifier

The system of providing channels on demand is designed to service 256 duplex telephone channels and the number of serviced terminal channel blocks is 2000 pcs.

5. Calculation of receiver parameters earth station

Task:

- Determine the noise temperature of the receiving path of the Earth station.
- Determine the noise power at the input of the receiver earth station.
- determine the signal strength at the receiver input of the earth station.
- determine the maximum allowable throughput of the trunk.
- Select a digital broadcast standard.

Methodological guidelines for the calculation:

1. According to the specified values from Table 6.1, write out the initial data for the calculation of the variant.

2. The noise temperature of the receiving path is determined by the formula:

$$T_{pr} = T_0 \cdot (K_{sh} - 1), K \tag{5.1}$$

where K_{sh} is the noise coefficient of the receiver earth station (given by the variant)

T_0 is the noise temperature of the EARTH STATION ($T_0 = 290$ K)

To account for interference from other communication systems, it is necessary to increase the R_{sh} by 20%.

3. Total noise temperature:

$$T_\Sigma = T_A + T_0\,((1-\eta)/\eta) + T_{\pi p}/\eta, K \tag{5.2}$$

where T_A is the noise temperature of the earth station antenna (set according to the variant);

η – The efficiency of the avt earth station (set according to the option);

4. Determination of the noise power at the receiver input earth station:

$$R_{sh} = k \cdot T_{\Sigma} \cdot \Delta f_{in}, \text{ WT} \tag{5.3}$$

where $k = 1.38 \times 10^{-23}$ is the Boltzmann constant;
T_{Σ} – total noise temperature, K;
Δf_{in} – the effective frequency band of the trunk (set by option).

5. Determination of the signal power at the receiver input earth station.

For satellite communication systems: $R_s/R_{sh} = 10...12$ dBW

For correct calculations, it is necessary to convert the noise power determined from Equation 3 from W to dBW. To do this , you can use the equation:

$$R\,(\text{dBW}) = 10 \log_{10}(P\,(\text{WT}) / 1\,(\text{WT})) \tag{5.4}$$

$$R_{s\,pr} = R_{sh} + R_s/R_{sh}, \text{ dBW} \tag{5.5}$$

6. Determination of the maximum permissible throughput of the trunk:

$$C = \Delta f_{\text{ств}} \cdot \log_2(1 + R_s/R_{sh}), \text{ bit/sec} \tag{5.6}$$

7. There are several digital television standards:
4:4:4 – 324 Mbps;
4:2:2 – 216 Mbit/sec;
4:1:1 – 162 Mbit/sec.

We choose the standard of digital television broadcasting according to the size of the trunk bandwidth.

Calculation example:

1. Initial data:
Earth station receiver noise factor $K_{sh} = 8$.
Noise temperature of the earth station antenna $T_A = 40$ K.
effectiveness auto earth station $K_n = 0.8$.
The effective bandwidth of the trunk $\Delta_{fst} = 72$ MHz.

2. Noise temperature of the receiving path:

$T_{pr} = T0 \cdot (K_{sh} - 1) = 290 \cdot (8 - 1) = 2030\ K$

3. Total noise temperature:

$T_{\Sigma} = T_A + T_o\ ((1- \eta)/\eta) + T_{pr}/\ \eta = 40 + 290\ ((1- 0{,}8)/0{,}8) + 2030\ /\ 0{,}8 = 2650\ K$

4. Determination of the noise power at the input of the receiver earth station:

$R_{sh} = k \cdot T_{\Sigma} \cdot \Delta f_{stv} = 1{,}38 \cdot 10^{-23} \cdot 2650 \cdot 72 \cdot 10^{6} = 2{,}63 \cdot 10^{-12}\ WT$

To take into account interference from other communication systems, it is necessary to increase R_{sh} by 20%.

$P_{sh} = 2{,}63 \cdot 10^{-12} \cdot 1{,}2 = 3{,}16 \cdot 10^{-12}$

5. Determining the signal strength at the input of the receiver earth station.

For example, $R_s/R_{sh} = 10$ dBW

For accurate calculations, it is necessary to convert the noise power from W to dBW. For this we use the equation:

$R\ (dBW) = 10\ \log_{10}(P\ WT)\ /\ 1\ (WT)) = 10\ \log_{10}(3{,}16 \cdot 10^{-12}) = -115\ dBW$

$R_{s\,pr} = R_{sh} + R_s/R_{sh} = -115 + 10 = -105\ \ dBW$

6. Determination of the maximum permissible capacity of the well:

$S = \Delta f_{stv} \cdot \log_2(1+ R_s/R_{sh}) = 72 \cdot 10^{6} \cdot \log_2(1+ 10) = 252 \cdot 10^{6}\ bit/s = = 252\ Mbit/s$

7. From the above standards, the 4:2:2 standard is suitable in terms of bandwidth for digital television broadcasting.

5.1-Jadval

Options to perform

Number of variants	Ksh	T_A K	η	Δ_{stv} MGts
1	6	30	0,75	60
2	7	40	0,8	64
3	8	50	0,85	68
4	9	60	0,9	72
5	6	70	0,95	74
6	7	30	0,95	70
7	8	40	0,9	60
8	9	50	0,85	64
9	7	60	0,8	62
0	8	70	0,75	68

Control questions

1. What are the requirements for VSAT earth stations according to ITU-T Rec. ITU-R S.725 "VSAT characteristics"?
2. List the main options for organizing communications in VSAT networks.
3. What types of multiple access are used in VSAT networks?
4. Give the functional scheme of the VSAT-TLF station.
5. Give functional diagram of NCC / CENTRAL EARTH STATION of VSAT telephone network.

PRACTICAL WORK №7

STUDYING THE PRINCIPLES OF CONSTRUCTION OF THE TRANSMITTING PART OF THE TEMPORARY CHANNEL SEALING EQUIPMENT

1. Purpose of the work

Studying the principles of building satellite communication systems, the composition of earth and space stations.

2. Tasks

1. Familiarize yourself with the principle of classification of space and Earth stations.
2. Get acquainted with the main indicators of terrestrial and space communication systems.
3. Calculate the main parameters of the digital transmission system
4. Make a report.

3. Report content

1. Purpose and purpose of the work.
2. The main indicators of Earth and space stations.
3. Simplified block diagram of the receiving path of a single-barreled earth station.
4. Simplified block diagram of the receiving and transmitting paths of a multi-barreled earth station.
2. Calculation of the main parameters of the digital transmission system

4. A brief theory

4. Block diagram of the simulation layout of the sealing equipment

The basis of the device is a modulator that allows you to combine, for the purpose of effective visualization, three types of modulation – AIM, PWM, FIM, and also to receive a group 4-channel signal for these types, taking into account the rules of the VRK. The possibility of observing all characteristic signals using an oscilloscope, taking into account the display of the corresponding control points on the front panel of the layout.

Figure 4.1 shows the block diagram of the layout.

The scheme contains:

- clock pulse generator 1;
- counter-divider 2;
- LIN 3 trigger pulse shaper;
- synchronization marker pulse shaper 4;
- LIN 5 generator;
- comparing device (comparator) 6;
- analog switch 7;
- converter normalizer (PN) 8;
- input signal generator 9;
- summing device 10;
- computer 11;
- power supply unit 12;
- oscilloscope 13;
- - control sockets (G 1..D 8) 14.

The operation of the block diagram of the simulation layout of the sealing equipment Fig. 4.1 is illustrated by the time diagrams shown in Fig. 4.2.

Clock pulses with a TT period of the type U1 from the output of the clock pulse generator (control socket G1, hereinafter Gp), arrive at the inverse counting input of the four-digit binary counter 2. Binary-dependent pulse sequences U2,U3,U4 (G2,G3,G4) appear at the outputs of the digits (20...23) of the counter, as well as the pulse sequence (23), designed to synchronize the beginning of the scan in the oscilloscope (not shown in the diagram). The rear edge of the pulses of the type U2 with a period of 2TT (G2), at the inverse input, the shaper 3 is started and at its inverse output (G5) a negative voltage drop of the type U5 appears, or a negative pulse of duration δ1, which in turn contributes to the start (start of action) of the generator of linearly varying voltage GLIN. This voltage is of the type U6 (socket G6), then it is supplied to the first input (for example, direct) of the comparing device – comparator 6. The second input of the comparator (inverse) is alternately fed, with a period of 2TT = Tc, the input voltage values of each of the four channels (Uvx1 ... Uvx4) from the output of the analog switch 7. The graphs of linearly varying voltage U6 (socket G6) and Uvxi are combined in the diagram, from where their points of intersection at times t1 ... are visible.t4, the appearance of which depends on the value of Uxxi. As a result of comparing these voltages, a PWM signal is generated at the output of the comparator.

The mode of alternately comparing the input voltages of each of the channels is provided by automatically switching the input channel analog signals coming from the input signal generator 9 (1...4) through the inputs 1...4 of the analog switch 7 operating in multiplexer mode to the output of the switch. This mode is caused by the presence of a built-in decoder controlled by counter bits 21 and 20 in the switch.

In this case, the input from the switch is used to disable (suppress) its information inputs for a time interval of δ1.

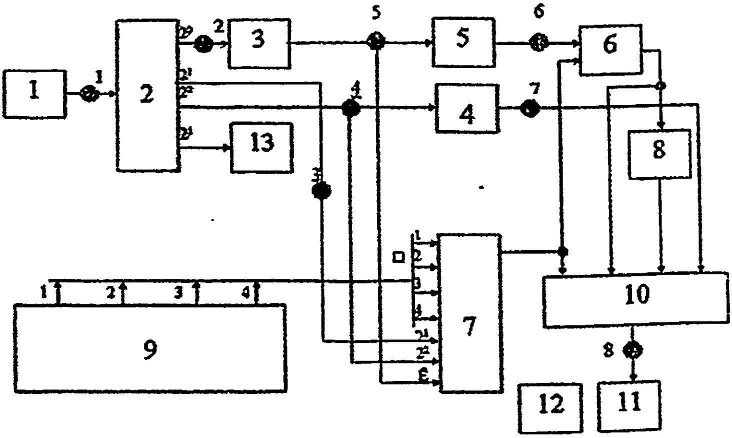


Figure 4.1. Block diagram of the sealing equipment

This contributes, firstly, to the steady resumption of the LIN process, and secondly, to the creation of a so-called protective interchannel time interval □1, during which, for example, the receiving part can be rebuilt to receive the next channel.

Thanks to the multiplexing mode, an AIM signal (1k...4k) appears at the output of the switch 7. It is shown on the graph (Fig.7.2) U7+AIM channel-by-channel and with the possibility of changing the sign, as shown, for example, in the 3k period.

From the output of the comparator 6, a group PWM sequence (without a synchronization attribute) enters the input of the FIM sequence shaper 8, where corresponding phase pulses of duration δ2 are formed along the trailing edge (slice) of each channel pulse.

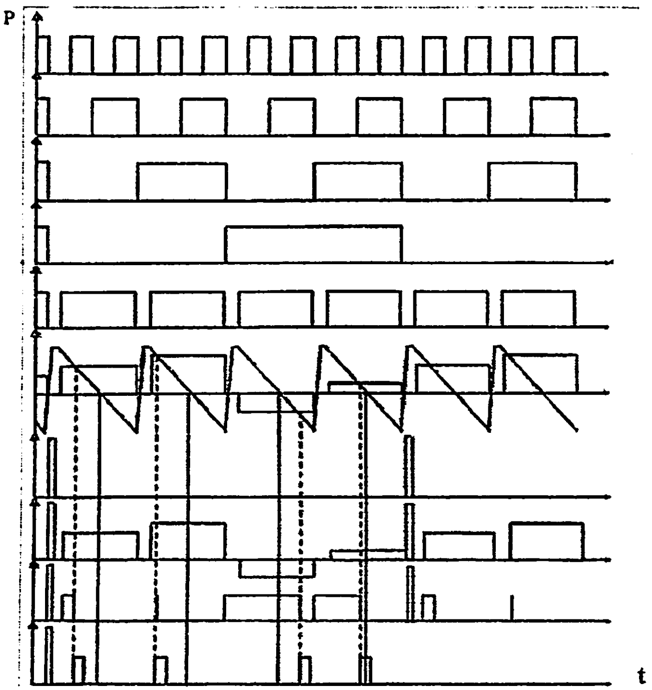


Figure 4.2. Time diagram

The time-pulse sequences of AIM, PWM and FIM formed in this way are fed to separate inputs of the summing device 10, where, depending on the mode selected for study, and separately, they potentially add up to a pulse sequence of the form U7 (G7). These pulses, with a duration of $\delta 3 \approx 0.5\delta 1$, provide synchronous differentiation of group periods Ti and act in time in the first half of the protective interval before each first channel interval Tk. The synchro pulses U7 arrive at a separate input of the summing device 10 from the direct output of the group synchronization pulse generator 4, which, in turn, is triggered by affecting its inverse input of the trailing edge of the pulses of the sequence U4 (G4) of the third digit (2^2) - the divider counter 2. The action of synchro pulses U7 (G7) occurs with a time period of 8TT = Ti, which is a group period. The range of change in the pulse response of the PWM and FIM signal conversion is indicated on the diagram as Δt, and the range of change in the amplitude response of the AIM signal conversion is indicated as ΔU.

The channel pulse sequences of AIM, PWM, and FIM group signals formed in this way together with the synchro signal can be individually fed to the input of the oscilloscope 13 (synch. ots.) or to the information analog input of the computer 11, for their visualization and study, both in static and dynamic modes of the layout.

5. The main provisions of the communication system with the vrk

5.1. The principle of channel allocation

In systems with time division of channels, a common communication path is provided alternately to each subscriber for the time of the Tk, called the channel interval. Each channel is connected to the path, periodically, with a period of Ti, and sends its channel signal (CS) to the group path. If there are N channels in a group, it is true that $Tk \leq Ti/ N$, and the greater the number of channels in the group (N), the shorter the duration of the CS, i.e. the shorter the time allotted for processing each of the signals.

Thus, in VRK systems, transmission is carried out in cycles or periodically, in groups of N different channel signals (CS). The duration of the Ti cycle includes, in addition to N channel intervals, Tk and intervals of auxiliary signals, for example, cyclic synchronization of the Tc.s., as well as the interval of service communication of the Tc.s.

5.2. Types of signal conversion in VRK systems

Signals in systems with VRK undergo transformations in order to prepare them for input into the channel through the appropriate linear (or channel handler). There are the following main types of conversion:

a) sampling – replacement of a continuous signal S(t) with a sequence of discrete samples of its instantaneous values;

b) pulse modulation – the formation of pulse channel signals of the CS carrying information about the counts of the Sc (t). This operation is called the first stage of modulation.

c) compaction in time of all CS carrying information or placement of bodies of a group pulse-analog (time-pulse) signal of the Kgr(e) on a group time interval.

Further, in the channel processor, as a rule, and mainly for broadcasting, this signal is modulated by a high-frequency carrier.

Reverse transformations are performed in the receiver.

d) isolation of Ugr(t) from the received radio signal.

e) separation of the Ugr(t) signal into separate channel signals ;

f) transformation of each CS to restore the corresponding
reference Sk(t).

g) interpolation of the transmitted signals according to the sequence of their samples Sk(t).

In some cases, the last two operations may be combined.

Interpolation (point g), as the most responsible and complex operation of restoring a signal based on its Sk(t) counts, has deeper roots in the prehistory of scientific disputes and doubts that were sufficiently resolved with the appearance in 1933 of the proof of the counts theorem or V.A. Kotelnikov's theorem. This theorem provides a justification for choosing the sampling frequency of a signal with a limited spectrum: a signal S(t) with a limited spectrum is completely determined through instantaneous samples (values) taken after a time interval $T \leq 1/2Fb$. In this case, S(t) for any t is determined by a series that takes into account the interaction of individual harmonics of the sample signal appearing in the spectrum:

$$S(t)=\sum_{k=1}^{\infty}F(kTi)\frac{Sin2\pi Fв(t-kTi)}{2\pi Fв(t-kTi)}$$

In foreign literature, this theorem is called the sampling theorem or the sampling theorem, and the frequency Fi = 2Ab = 1/Ti is the Nyquist frequency.

Guided by the position of this theorem, it is possible to optimize the communication system by sampling frequency and thereby give it the best efficiency with the required efficiency, for example, in the matter of speed. So, based on this theorem in practice, if for a standard telephone channel Fb = 3.4 kHz and Fi ≥ 2Fb = 6.8 kHz. However, in order to facilitate the implementation of the interpolator (LPF) and to increase the accuracy of the interpolation itself, in modern communication systems it is customary

Fi = 8 kHz , Ti=125 microseconds.. These values are recommended by the ICCR for all international communication lines with a temporary seal.

5.3. Compaction and modulation

When transmitting signals of N number of channels over a communication channel, the pulses of all channels are evenly distributed within the clock period. To do this, it is necessary that the clock frequencies of all channels are equal and strictly synchronous, and there must be constant phase shifts between them equal to $360^0/N$, which corresponds to the time interval or group period Ti/N.

When transmitting 6 channels, the time interval between pulses is 125/6 = 20.83 microseconds.

From what has been said, it follows that in a communication line where a temporary seal is used, the frequency of repetition of pulses of a group signal or a group frequency is equal to:

$$F_{grush} = NFi$$

For example, for the transmission of 6 channels, F_{groups} is equal to:

$$F_{groups} = 6*8=48 \text{ kHz}.$$

Figure 3 shows separate sequences of unmodulated pulses of 6 channels, respectively shifted in phase, as well as the group signal of all six channels as it is fed into the communication line after the addition of the signals of all channels.

If the pulses of all channels were the same, it would be impossible to find out on the receiving side which pulse carries the information of which channel and, the switchgear would not be able to correctly distribute the pulse signals to the corresponding correspondents. In this regard, the equipment of temporary compaction should allocate pulses of one of the channels according to some distinctive feature, uniquely determined on the receiving side. Such a pulse is called a marker pulse or synchronization pulse (SI). A synchro pulse can be any of the transmitted pulses, but always agreed in advance; the synchronizing channel (SC) serves as a reference for counting channel numbers in the switchgear of the channel separation equipment at the receiving end of the communication line. Usually, the first channel serves as a marker channel in a group. The marker pulse is transmitted once per clock period. This is an example of the simplest type of marker pulse used in many radio relay stations. In this case, the marker pulse is called "latitudinal" because it differs from other pulses by its duration (Fig. 5.3). In our case, the marker pulse differs from the channel pulse in amplitude.

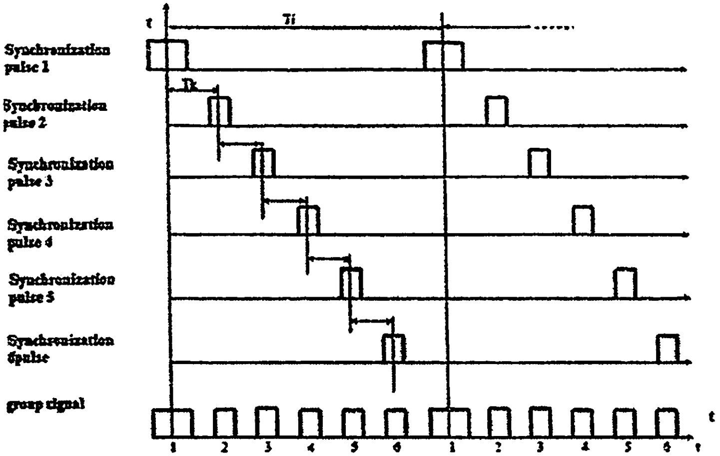


Figure 5.3. Formation of a group signal in IBS

5.4. Phase stability and protection interval between channels

Low-channel communication with phase-pulse modulation is widespread and effectively used, because this is the most stable type of pulse modulation along with pulse modulation and delta modulation.

phase-pulse modulation also allows you to build a very compact and not expensive temporary compaction equipment. but phase-pulse modulation has some drawback. in this type of multi-channel pulse modulation, ,each channel pulse during modulation occupies a significant part of the time interval between the pulses of other channels. the noise immunity of phase pulse modulation depends on this . therefore, if special measures are not taken when constructing the equipment, the pulses of one channel during modulation may enter the area allocated for the pulses of another channel, as a result of which strong mutual interference between the channels may occur. In addition, reliable pulse separation at the receiving end will become impossible.

For each individual channel, it is necessary to allocate a time interval Δt_k, called the channel interval, beyond which the pulses of this channel should not go out at any values of the modulating signal. Between the channel intervals, it is necessary to leave a protective interval Δt_3, necessary to ensure reliable isolation of pulses of various channels on the receiving side. The protective interval is also needed for technical reasons. There are a large number of external factors seeking to shift the pulses from their nominal phases.

5.5. Spectrum of amplitude-modulated pulses

Figure 7.4, a shows a sequence of rectangular pulses of one of the channels modulated by the amplitude of low frequency signals F.

As is known, the sequence of unmodulated pulses (Fig.5.4, b) can be decomposed into a Fourier series of the form:

$$A_1(t) = \frac{A_0}{q}\left[1 + 2\sum_{n=1}^{\infty}\frac{\sin x}{x}\cos n\Omega i t\right],$$

Where $x = \frac{n\Omega i\tau}{2} = \frac{n\tau}{q}$ and $q = \frac{Ti}{\tau}$ - the duty cycle of these pulses.

Based on this equation, it is possible to construct an amplitude spectrum of sinusoidal harmonic components, the sum of which consists of the above sequence. This spectrum is shown in Figure 5a. The envelope of this spectrum has the form of a $\frac{Sinx}{x}$ function, which is zero at points where $f = \frac{k}{\tau}$ (k is any integer). It follows from this that the main part of the spectrum is concentrated in the frequency range $\Delta F = \frac{1}{\tau}$. It also follows from this that the pulse duty cycle q is numerically equal to the number of harmonics of the clock frequency Fi located inside the frequency band ΔF.

Since the duration of normal operating pulses in systems with IBS is approximately equal to or less than one microsecond, then q ≥ 100. Therefore, the amplitudes of the first few components arȩ multiples of the clock frequency of the spectrum (Figure 7.5, a), are practically equal to each other and equal to $2\frac{A_0}{q}$, and the constant component will be 2 times less (Figure 5.5, b).

Since the duration of normal operating pulses in systems with IBS is approximately equal to or less than one microsecond, then q ≥ 100. Therefore, the amplitudes of the first few components are multiples of the clock frequency of the spectrum (Figure 7.5, a), are practically equal to each other and equal to $2\frac{A_0}{q}$, and the constant component will be 2 times less (Figure 7.5, b).

If, in the absence of modulation, the amplitude of all pulses was constant and equal to A_0, then when the pulses are modulated in amplitude by a sinusoidal signal with a frequency F and with a relative modulation depth $m_A = \frac{\Delta A_m}{A_0}$, the law of pulse amplitude variation over time can be described by the equation:

$$A_0(t) = A_0(1 + m_a \cos 2\pi F t) = A_0(1 + m_a \cos \Omega t)$$

Therefore, the spectrum of modulated pulses will be described by the same Fourier series above, if we replace the constant amplitude A_0 with the variable amplitude A_0 with the variable amplitude $A_0(t)$:

$$A_2(t) = \frac{A_0(t)}{q}[1 + 2\sum_{n=1}^{\infty}\frac{\sin x}{x}\cos n\Omega i t] =$$

$$= \frac{A_0}{q}(1 + m_q \cos \Omega t)[1 + 2\sum_{n=1}^{\infty}\frac{\sin x}{x}\cos n\Omega i t] =$$

$$= \frac{A_0}{q}[1 + 2\sum_{n=1}^{\infty}\frac{\sin x}{x}\cos n\Omega i t] + \sum_{n=1}^{\infty}\frac{\sin x}{x}\cos(n\Omega i - \Omega)t =$$

$$= A_1(t) + \frac{A_0 m_a}{q}\cos \Omega t + \frac{A_0 m_a}{q}\sum_{n=1}^{\infty}\frac{\sin x}{x}\cos(n\Omega i \pm \Omega)t$$

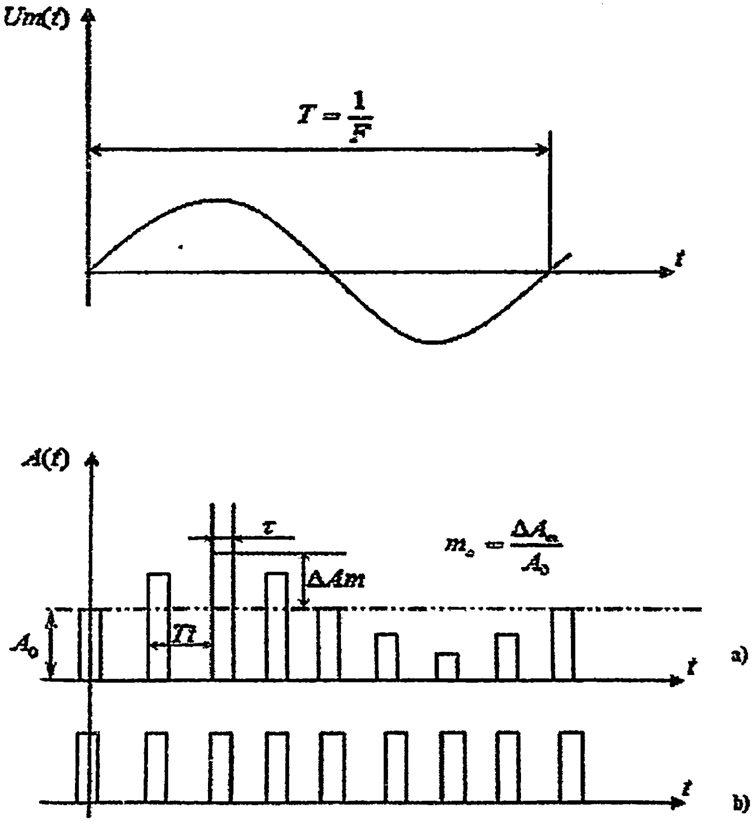


Figure 5.4. Sequence of rectangular pulses of one channel modulated by amplitude

The spectrum of amplitude-modulated pulses differs from the spectra of unmodulated A1(t) pulses only by the appearance of two side frequencies symmetrically located near each component of nFi.

As follows from the second term of the sum, in addition to these components, there is also a component of a useful low-frequency signal F, the amplitude of which is equal to:

$$A_F = A_0 \frac{m_a}{q} = A_= * m_a$$

where A = - a constant component.

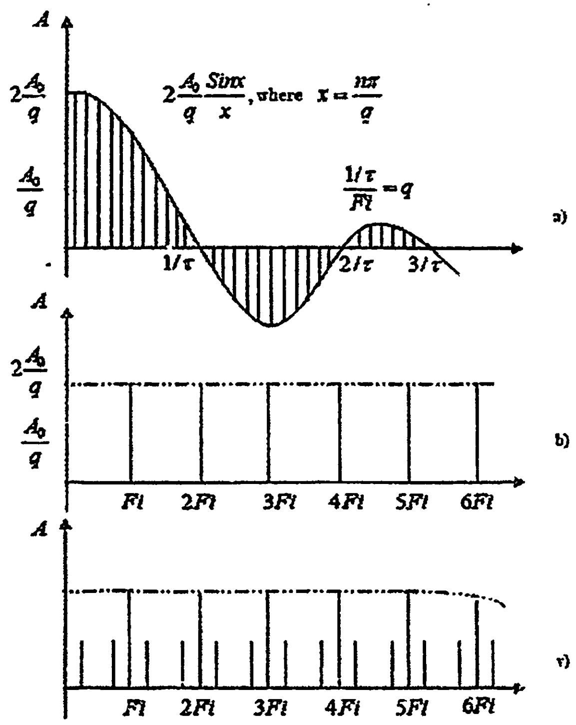


Figure 5.5. Spectrum of amplitude-modulated pulses

The amplitude of the side frequencies of the first harmonic of the clock frequency are also equal:

$$A(F_t \pm F) \cong A_0 \frac{m_a}{q} = A_F$$

Theoretical and experimental research has shown that AIM has the same noise immunity as conventional amplitude modulation. With these types of modulation, the signal/interference ratio at the output of the telephone channel is equal to the same ratio at the receiver input (under optimal reception conditions). This is the main reason why AIM is used for communication extremely rarely, since there are many other types of pulse modulation much whiter than noise-resistant ones.

5.6. Spectrum of pulses modulated by duration

Figure 7.6 shows a sequence of PWM pulses modulated by a low-frequency sinusoidal signal A. Just as with AIM, the $\frac{\Delta Am}{A_0}$ ratio is commonly called the modulation depth ma, with PWM, the $\frac{\Delta\tau_m}{\tau_0}$ ratio is also called the modulation depth mi. Due to the fact that with PWM, the displacement of the pulse front causes a simultaneous displacement of the "center of gravity" of the pulse, the pulses are also modulated in phase, as a result of which the PWM spectrum is much more complex than the AIM spectrum. Indeed, let the pulse duration change as a function of time according to the sinusoidal law:

$$\tau(t) = \tau_0(1 + m_u \cos\Omega t)$$

Let's substitute this equation into the original formula, given $q = \frac{Ti}{\tau(t)}$, then we get:

$$A_3(t) = A_0 \frac{\tau(t)}{Ti}[1 + 2\sum_{n=1}^{\infty} \frac{\sin\frac{n\pi\tau(t)}{Ti}}{\frac{n\pi\tau(t)}{Ti}} \cos n\Omega it] =$$

$$= A_0 \frac{\tau(t)}{Ti} + \frac{2A_0}{\pi} \sum_{n=1}^{\infty} \frac{\sin\frac{n\pi\tau_0(1 + m_u \cos\Omega t)}{Ti}}{n} \cos n\Omega it =$$

$$= \frac{A_0}{q} + \frac{A_0 m_u}{q} \cos\Omega t + \frac{2A_0}{\pi} \sum_{n=1}^{\infty} \frac{\sin[\frac{n\pi}{q}(1 + m_u \cos\Omega t)]}{n} \cos n\Omega it$$

As follows from this result, the PWM spectrum contains (as in the case of AIM) a constant component equal to:

$$A_{=} = \frac{A_0}{q}$$

and a component of the same frequency as the modulating signal with amplitude:

$$A_P = \frac{A_0 m_n}{q}$$

But the main difference between the PWM spectrum and the AIM spectrum is that from the third term of the sum equation, with further decomposition, it turns out that about each component, a multiple of the clock frequency, there are in principle an infinite number of side frequencies that differ from the components of nFi by pF hertz, where p is any integer (see Fig.5.6). The amplitudes of these side frequencies are calculated using the Bessel function as with conventional phase modulation. It follows from this that theoretically, with this type of modulation, it is impossible to isolate a useful signal of frequency F from the general spectrum using a low-pass filter, as was possible with AIM. Nevertheless, the calculation and experiment show that with multichannel communication, the movement of the front pulses $\Delta\tau_m$ is so small compared to the clock period that the amplitudes of the side frequencies $Fi \pm pF$ at $p > 1$ are practically zero, and therefore the spectrum of pulses with PWM is virtually no different from the spectrum of pulses with AIM in the low frequency region.

Therefore, PWM, as well as AIM, can be used to isolate an undistorted useful signal using a simple low-pass filter with a boundary frequency of $F_{gr} = \frac{1}{2} Fi$.

PWM is more noise-resistant than AIM, since pulses can be limited in amplitude without compromising the useful signal, nevertheless, PWM is not efficient enough to use it in communication lines. With PWM, the average power of the transmitter should be large due to the fact that it is proportional to the average pulse duration of τ_0, and τ_0 is always greater than $\Delta\tau_m$, which it is desirable to choose as much as possible to obtain better noise immunity. Therefore, PWM, as well as AIM, is practically used only as an intermediate type of modulation.

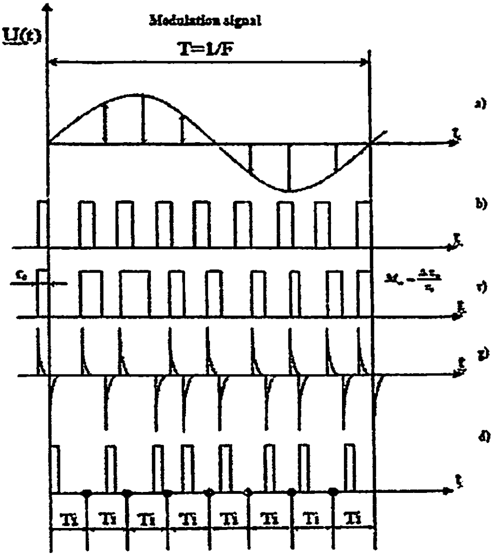


Fig.5.6. Generation of PWM pulses and phase pulse modulation

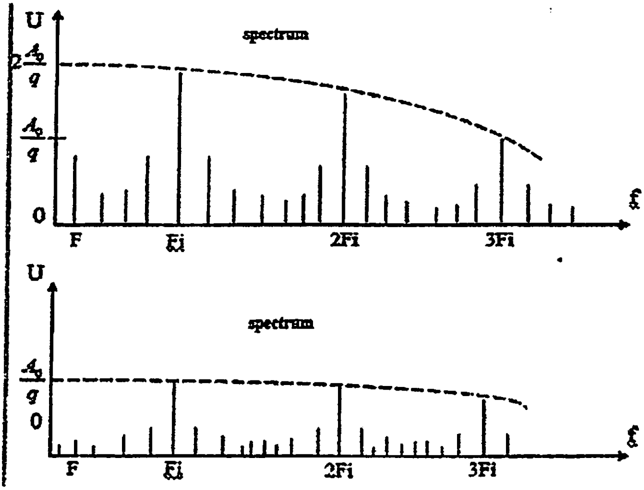


Fig.5.7. Spectrum of pulses modulated in width and phase

5.7. Spectrum of phase-modulated pulses

Due to the fact that in fact, with PWM, it is not required to transmit the entire pulse to the correspondent, but it is enough to report only the "phase" of its modulated front, it is more expedient to convert PWM into phase pulse MODULATION, for example, by differentiating pulses with PWM (see Fig. 1.4g). In this case, the width-modulated pulses turn into a sequence of phase-modulated very narrow pulses of the same duration $\tau_0=\tau_{min}$. Since the duration of all pulses with phase PULSE MODULATION is the same and is equal to τ_{min}, which was with PWM and corresponds to the bandwidth of the communication line, then ΔF is optimal and the noise immunity of this type of modulation is higher than with PWM.

At the same time, with the same average power of the transmitters of both systems, it is possible to increase the peak power of a system with phase-pulse modulation by as many times as τ_{min} is less than τ_0 with PWM.

An increase in the amplitude of the pulses, respectively, increases the steepness of the fronts, and therefore the phase of the fronts. For these reasons, phase pulse modulation has become the most common of all types of pulse modulation used in time-sealed communication lines.

Pulses modulated in phase by a sinusoidal signal of low frequency F can be decomposed into a Fourier series of the form:

$$A_\varphi(t)=\frac{A_0}{q}+\frac{A_0}{q}\Delta t_m\Omega\cos\Omega t+$$

$$+\frac{2A_0}{q}\sum_{n=1}^{+\infty}\sum_{n=1}^{+\infty}Jk(n\Omega\Delta t_m)\sin(\frac{n\pi}{q}+\frac{k\pi}{T/\tau_0})\cos(n\Omega i+k\Omega)$$

It follows from this equation (see Fig.5b) that the phase pulse modulation spectrum consists of a constant component:

$$A_= = \frac{A_0}{q}$$

from a component whose frequency coincides with the frequency of the modulating signal F with an amplitude equal to

$$A_F=\frac{A_0}{q}\Delta t_m\Omega$$

Unlike the AIM and PWM spectra, the amplitude of the modulating frequency component is very small, since $\Delta t_m=\alpha\frac{Ti}{2N}$ where $\frac{Ti}{2N}$ is half of the interval between channel pulses, and α is the utilization factor of this interval (α is always less than one) and $\Omega=2\pi F\frac{Fi}{Ti}=\frac{\pi}{Ti}*\frac{2F}{Fi}=\frac{\pi}{Ti}\mu$ where

μ is a coefficient showing how many times 2F is less than or equal to one. Therefore

$$\Delta t_m*\Omega=\frac{\alpha\mu\pi}{2N}<<1$$

In addition, A_F depends on the frequency of the modulating signal and at $\Omega\to0$; $A_F\to0$ is a measurement process this period.

5.8. Review and analysis of modulation methods

Like other signal conversion processes in communication techniques – obtaining a time-pulse measure of the input analog signal, the process as a whole is characterized, for example, by accuracy, speed, economic feasibility of using methods and devices for converting measuring information. Since the task set in the work involves the use of a time–pulse modulator - a measuring converter, the choice of the device is further made by analyzing and evaluating the properties of known similar measurement methods.

Digital measuring systems with an analog-to–digital converter at the input are known, containing a measuring transducer -sensor (microphone) with an analog output, for example, an inductive parametric bridge converter, an analog matching device and an analog-to-digital converter. The structure of the analog matching device of known systems depends on the required switching circuits, the nature of the resistance of the converter element, sensitivity, spectral composition of the supply voltage, and may contain a number of analog converters. The use of analog converters as part of matching devices complicates and increases the cost of measuring instruments, especially with increased requirements for speed and accuracy of measurement. As a consequence, in known measuring devices, the metrological properties of a parametric bridge converter are limited. Closer to the problems of time-pulse conversion, as a technical solution, is the well-known method of electrical measurements, which consists in determining the time constant of the electrical circuit τ, used in particular to determine the parameters of inductive differential sensors included in the scheme of a parametric bridge converter. At the same time, the values of the time constants of the dividing circuits of the bridge circuit and the difference of these values are measured for each single reading of information received after time $t \geq \tau$. The disadvantage of this method is its low speed due to the need for time spent on measuring the value of the time constant τ in the process of obtaining information.

The increase in the speed of this method was achieved by influencing the input diagonal of the measuring bridge with pulses with periods T, the value of which is selected within $0{,}1\tau \leq T < \tau$ and comparing the difference in the instantaneous values of transient voltages of exponential form with the reference value on the output diagonal of the measuring bridge and measuring the pulse duration [8]. This method allows you to obtain PWM and CHM converter signals directly from the output of the comparing device (comparator without additional analog converters and is the most versatile, accurate and fast-acting today in the technique of bridge parametric measurements. From the point of view of metrology , it can be characterized by a transcendental equation of the form:

$$Ae^{\frac{t}{\tau_1+\Delta\tau_1}} - Ae^{\frac{t}{\tau_2+\Delta\tau_2}} = \delta$$

where A is the initial value of the exponent,

τ_1, τ_2 – the time constants of the dividing circuits of the bridge, usually $\tau_1 = \tau_2$

$\Delta\tau_1$, $\Delta\tau_2$ are increments of time constants $\Delta\tau_1$, $\Delta\tau_2$, in a function of time determined by the current parameters of the converter elements (element), δ is the threshold of operation of the comparing device.

This expression does not allow us to represent in explicit mathematical form, the relationship of the output value – the pulse duration time T from the increment value $|\Delta\tau|$,(T=f ($|\Delta\tau|$)), however, the practice of tabular calculations, as well as the use of this method in solving real problems of PWM (CHIM) transformations shows the effectiveness of and the expediency of its application. Despite its advantages, the method described above requires a holistic implementation for each source of information. This is due to the inability to quickly switch analog sources for conversion in view of the finite duration of the establishment of initial transients. So, in order to obtain all these advantages in the VRK mode, when using this method, as many converters (a bridge comparator) as many channels need to be grouped will be required. This may be economically feasible, for example, when creating precision peripheral systems for collecting measurement information (telemetry systems).

More economical, as well as satisfactory in accuracy and reliability in the application of the task is the well-known method of time-pulse unfolding conversion [10], consisting in comparing the instantaneous values of the analog signal voltage and linearly varying voltage (LIN), which allows switching the required number of channels to one high-quality converter without additional time losses. Therefore, it is advisable to use this method in the future.

Within the scope of the assignment and on the basis of the above, the design of the laboratory layout can be carried out under the following basic conditions:

- the number of channels in the group shown should not exceed 4. This is necessary for a more visual and accurate picture of the image on the screen of an oscilloscope (monitor) in real time.

Thus, we accept for 4 channels: at Fi=8 kHz and Ti=1/Fi=125 microseconds, Tk=Ti/4≈32 microseconds.

Other, lower values of Tk should be set from the calculation of the bandwidth of the computer's audio path, in order to visualize the signal on its monitor, for example, Tk = 320 microseconds.

- the synchronization pulse, or the beginning of the group, must be inserted hardware into the protective interval between the first and last channel interval, in order to synchronize the entire group in the oscilloscope. This pulse is received as a group sync signal (marker pulse) in accordance with the rules in the Republic of Kazakhstan.

6. Calculation of the main parameters of the digital transmission system

Task:

- Determine the number of all channels organized by the pulse modulation system.

- Determine the duration of the transmission cycle (sampling period).
- Determine the duration of the channel interval.
- Determine the duration of the clock interval between code pulses in the channel interval.
- Determine the duration of the code pulse.
- Calculate the clock frequency of the linear signal.
- Determine the duration of the control channel pulse.
- Calculate the required bandwidth of the linear path pulse modulation transmission system.

Methodological guidelines for the calculation:

1. According to the specified values from Table 7.1, write out the initial data for the calculation of the variant.

2. Determine the number of all channels, including communication, synchronization and control channels by the formula:

$$N_O = N + N_c \qquad (6.1)$$

where N is the number of communication channels (set by option)

N_c - number of signaling channels (set by option)

3. Transmission cycle duration (sampling period):

$$T_O = 1/f_O \qquad (6.2)$$

Where f_O is the total frequency of the transmitted signal calculated by the formula:

$$f_O = (2{,}3..2{,}4)\ f_B,\ Hz \qquad (6.3)$$

where f_B is the upper frequency of the spectrum of the transmitted signal (set by option);

4. Determination of the channel interval duration:

$$T_K = T_O / N_O,\ s \qquad (6.4)$$

5. Determination of the duration of the clock interval between code pulses in the channel interval:

$$T_T = T_K/n,\ s \qquad (6.5)$$

where n is the number of digits in the code combination of the quantized report (set by option);

6. Determination of the duration of the code pulse:

$$\tau = 0{,}5 \cdot T_T,\ s \qquad (6.6)$$

7. Calculation of the clock frequency of a linear signal:

$$f_T = n \cdot N_O \cdot f_O\ ,\ Hz \qquad (6.7)$$

8. Determination of the duration of the control channel pulse:

$$t_i = T_O/4N_O,\ s \qquad (6.8)$$

9. The calculation of the required bandwidth of the linear path pulse modulation of the transmission system is performed according to the formula:

$$\Delta f = 1/\tau, \text{Hz} \qquad (6.9)$$

Calculation example:

1. Initial data:

Number of communication channels N=30.

Number of alarm channels N_c=2.

The upper frequency of the transmitted signal spectrum f_v=3800 Гц.

The number of digits in the code combination of the quantized report n=8.

2. The number of all channels, including communication, synchronization and control channels:

$N_O = N + N_c = 30 + 2 = 32$

3. Determination of the transmission cycle duration (sampling period):

$f_O = (2,3..2,4)\, f_B = 2,35 \cdot 3800 = 8930\ Hz$

$T_O = 1/f_O = 1/8930 = 112 \cdot 10^{-6}\ s$

4. Channel interval duration:

$T_K = T_O / N_O = 112 \cdot 10^{-6}/32 = 3,5 \cdot 10^{-6}\ s$

5. The duration of the clock interval between code pulses in the channel interval:

$T_T = T_K/n = 3,5 \cdot 10^{-6}/8 = 0,438 \cdot 10^{-6}\ s$

6. The duration of the code pulse:

$\tau = 0,5 \cdot T_T = 0,5 \cdot 0,438 \cdot 10^{-6} = 0,219 \cdot 10^{-6}\ s$

7. Calculation of the clock frequency of a linear signal:

$f_T = n \cdot N_O \cdot f_O = 8 \cdot 32 \cdot 8930 = 2,29 \cdot 10^{6}\ H_z = 2,29\ MHz$

8. Duration of the control channel pulse:

$t_u = T_O/4N_O = 112 \cdot 10^{-6}/4 \cdot 32 = 0,875 \cdot 10^{-6}\ s$

9. Calculation of the required bandwidth of the linear path pulse modulation of the transmission system:

$\Delta f = 1/\tau = 1/0,219 \cdot 10^{-6} = 4,57 \cdot 10^{6}\ Гц = 4,57\ MHz.$

Table 7.1 Initial data on options

The last digit of the magazine number	N	N_c	fv Hz	n
1	32	4	4000	6
2	30	4	3600	8
3	26	4	3500	6
4	38	4	4200	9
5	28	2	3600	6
6	30	2	4200	8
7	36	4	4800	10
8	42	4	6000	10
9	36	3	4600	8
0	30	4	3800	10

Questions

1. What is the sampling frequency and what should be its minimum value?
2. What is the sampling frequency value selected in the studied layout and why?
3. What is the duration of the sampling period in this layout?
4. What is the pulse period at the output of the group pulse sensors?
2. What is the duration of the triggering pulses selected in the studied layout and why?
3. Give a description of the principle of operation of this layout according to its structural scheme.

Content

List of literature

1. Р.Р. Ибраимов, Д.А. Давронбеков, Ш.У. Пулатов, А.П. Хатамов. Спутниковые системы связи и приложения. Т.: «Alokachi»,2018. 365 с.
2. Ибраимов Р.Р., Давронбеков Д.А., Тошманов Е.Б.,Писецкий Ю.В. Беспроводные системы связи и программы. Учебник, Т.: “Aloqachi”, 2018, 216 с.
3. Радиорелейные и спутниковые системы передачи. Учебник для ВУЗов. Под ред. А.С. Немировского.- М.: Радио и связь, 2000, -392 с.
4. Аболиц А.И. Системы спутниковой связи. Учебное пособие, 2004.
5. Сборник трудов, института космических исследований Российской академии наук, Современные проблемы ориентации и навигации космических аппаратов, под редакцией Г.А. Аванесова. М.: Изд-во ИКИ РАН, 2013. – 205 с.
6. Global Navigation Satellite Systems – Signal, Theory and Applications. Edited by Shuanggen Jin. 2012
7. Сырова А.С., Бортовые системы управления космическими аппаратами. М.: Изд-во МАИ-ПРИНТ, 2010. – 304 с.

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