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Introduction

Fiber-optic transmission systems (VPS) are understood as a set of active and passive devices designed to

transmit messages over distances over optical fibers(s) using optical waves and signals. In other words, VSP is a set of optical devices and optical transmission lines that provides the formation, processing and transmission of optical signals.The physical medium of optical signal propagation is fiber-optic cables.Currently, wavelengths are used to construct the VSP from 0.8 microns to 1.65 microns. In the future, it is planned to develop longer waves – 2.4 and 2.6 microns, called infrared radiation or optical radiation. Fiber-optic data transmission systems have become widespread due to the following advantages:

- high noise immunity, insensitivity to the influence of external electromagnetic fields and almost complete absence of mutual influences between individual fibers;

- high bandwidth and consequently a significant increase in the number of channels;

- smaller by an order of magnitude the weight and dimensions of the equipment, which reduces

cost;

- complete electrical isolation between the input and output of transmission systems, reliable safety due to the absence of a short circuit when the cable breaks;

- long lengths of regeneration sites;

- low copper consumption and low cable cost in the future;

- high security against unauthorized access.

The disadvantages include the low mechanical strength of optical fibers and the dependence of the transmission characteristics of the optical cable on mechanical deformations during laying and installation.The development of VSP takes place in two main directions.The first is the development and implementation of new fiber–optic technologies that increase the efficiency of VSP. On long-distance communication lines, the main attention will be paid to increasing the speed of information transmission,

by increasing the length of regeneration sections, increasing reliability and using technologies with spectral compaction.The second is the creation of lines that use nonlineanproperties of S, providing a soliton propagation mode.The soliton is the pulse most suitable for transmission over the S, since it propagates over long distances without changing the shape and duration. This will increase the length of the regeneration sites to 1000 km.

Lecture 1. Classification and principles of construction of opticaltransmission systems

The purpose of the lecture: to consider the principle of creating fiber-optic transmission systems and its components.Recently, optical communication systems (OSS) have become widespread in communication and cable television systems, data transmission and control systems, in on-board equipment, etc. According to the length of the OSS can be divided into three groups: local (intra-object), medium-length and trunk. Local OSS are used in data transmission networks, inside enterprises, on mobile objects of civil and military purposes, in computing complexes. Medium-length OSS is used for digital integrated service networks and for tactical military communications. Backbone OSS are used for long-distance multi-channel communication, on trunk and intra-zone systems and networks. To transmit information in modern OSS, time and frequency channel separation methods are used. An electrical signal generated by one method or another modulates the optical carrier source of optical radiation. Since the electric current at the output of the photodetector (photodiode, avalanche photodiode) is proportional to the power (intensity) of the received light flux, then modulation of the intensity of the optical carrier is applied, in which the amplitude of the modulating electrical signal determines the radiation power of the optical source. Basically, all modern OSS are digital, pulse-code intensity modulation (ICMI) is most often used, since at the same time, the requirements for the linearity of the amplitude characteristics of optical radiation sources and receivers are significantly reduced. The block diagram of the digital OSS is shown in Figure 1.The main elements of the system are the optical linear path and terminal devices — transmitting and receiving stations.]gtAt the transmitting station, N primary digital electrical signals (the main digital channels of the BCC) with an information transfer rate of 64 kbit/ s enter the terminal equipment of a typical multichannel transmission system (MSP). From the output of the ICP, a group N-channel electrical signal is fed to the interface device (encoder), where it is converted into the form most convenient for transmission along the linear path. Further, in the optical transmitter, the electrical signal is converted into an optical signal by modulation of the optical carrier and transmitted over the S in a linear path.

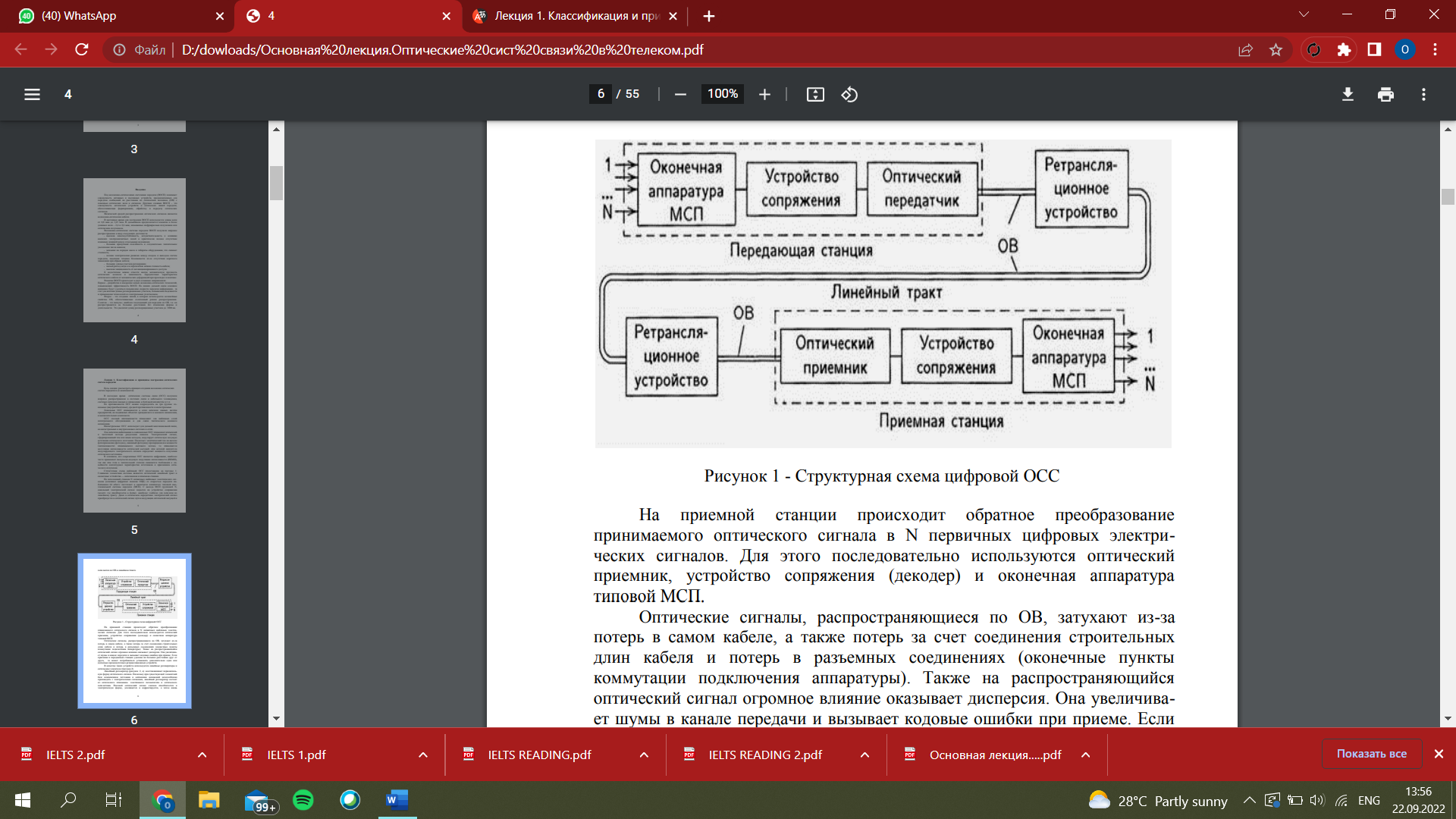
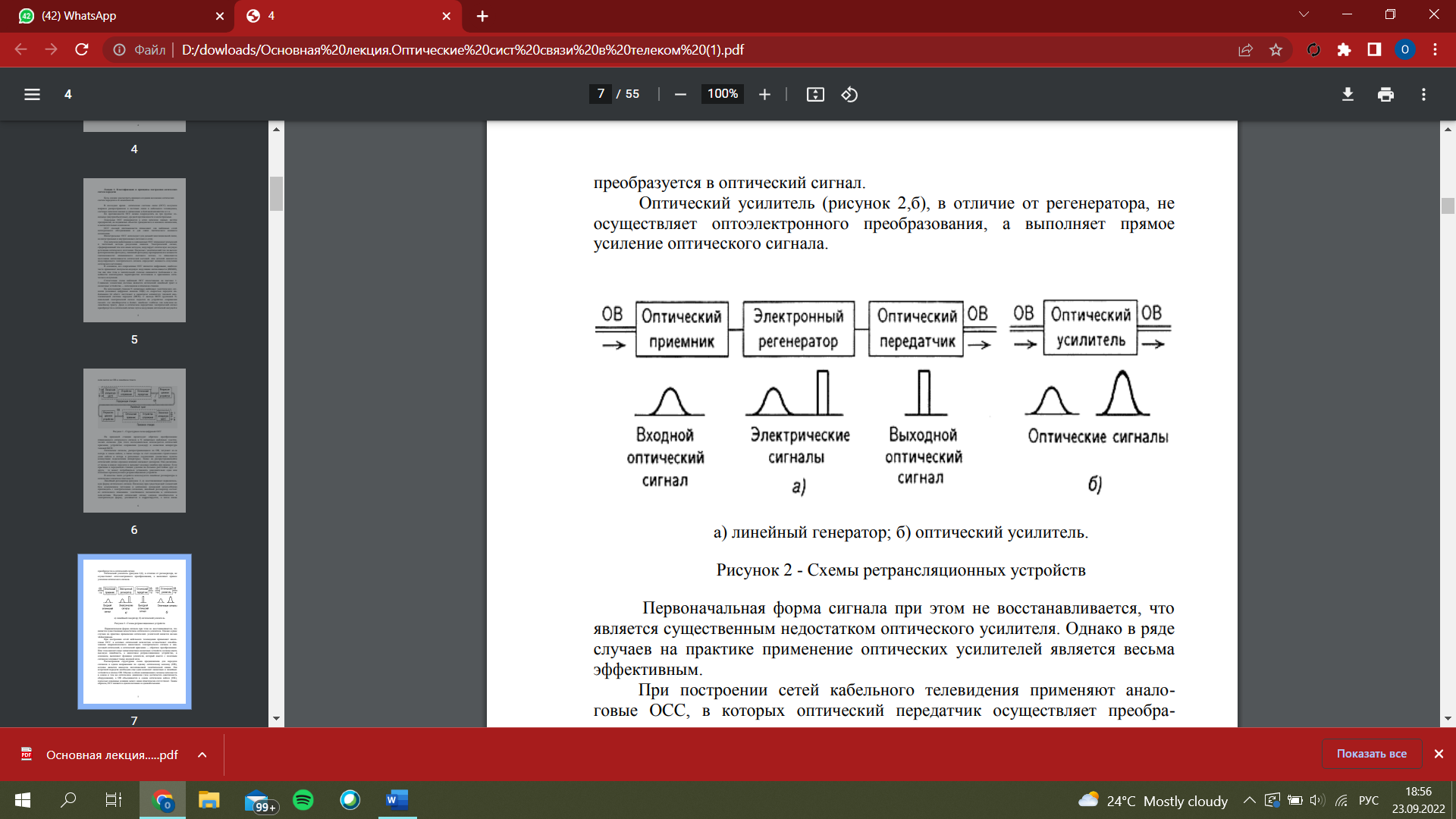


Figure 1 - Block diagram of the digital OSS

At the receiving station, the reverse conversion of the received optical signal into N primary digital electrical signals takes place. To do this, an optical receiver, an interface device (decoder) and terminal equipment of a typical SME are used sequentially. Optical signals propagating through the S are attenuated dueto losses in the cable itself, as well as losses due to the connection of the construction cable lengths and losses in the detachable connections (terminal switching points for connecting equipment). Also on the spreading the optical signal is greatly influenced by dispersion. It increases the noise in the transmission channel and causes code errors during reception. If the receiving and transmitting stations are separated by a large distance from each other, it may be necessary to install one or more intermediate relay devices additionally. Linear regenerators and optical amplifiers are used as such devices (Figure 2).The linear regenerator (Figure 2, a) restores the original shape of the optical signal. Since, with the existing element base, it is advisable to compensate for attenuation and correction of distortion with electrical signals, a linear regenerator consists of an optical receiver, an electronic regenerator and an optical transmitter. The input optical signal is first converted into electrical form, amplified and corrected, and then again it is converted into an optical signal.The optical amplifier (Figure 2, b), unlike the regenerator, does not performs optoelectronic conversion, and performs direct amplification of the optical signal.



a) linear oscillator; b) optical amplifier.

Figure 2 - Diagrams of relay devices

The original waveform is not restored, which is a significant disadvantage of the optical amplifier. However, in some cases, in practice, the use of optical amplifiers is very effective.When building cable television networks, analog OSS are used, in which an optical transmitter converts a broadband analog electrical signal into an analog optical signal, and an optical receiver converts the reverse.In this case, the amplitude characteristics of the terminal devices should have the analog relay device mainly performs the function of an amplifier, which, together with a useful signal, also amplifies the input noise.The considered block diagram is designed to transmit signals in one direction over one optical fiber(S),which is an analog of a two-wire electrical line. For counter transmission, another set of terminal and linear devices and a second S are required. Usually, signals are transmitted in both directions in the same optical range (which achieves uniformity equipment), and the S are combined in one optical cable (OK),since there are practically no mutual influences between them. Thus, the OSS are single-band and single-cable.

Lecture 2. Sources of optical radiation

The purpose of the lecture: to show the main elements of the transmitting module.Consider the differences between laser and light-emitting diodes. Their main characteristics.Light-emitting diodes (LEDs) and laser diodes (LDS) are used as transmitting optical modules (POMS). The basis of their work is injection electroluminescence, which is radiative recombination of carriers (electrons and holes) injected into the active region of the semiconductor. Radiation sources must meet the following requirements:

1) The wavelength of the radiation must coincide with one of the transparency windows.

2) The design of the source must provide a sufficiently high output radiation power and its effective input into the S.

3) The source must have high reliability and long service life.

4) Overall dimensions, weight and power consumption should be minimal.

5) The simplicity of the technology should ensure low cost and high reproducibility of characteristics.

Let's give a comparative characteristic of the light-emitting and laser diode. Light emitting diode (LED). The principle of operation of LEDs is based on the phenomenon of recombination of charge carriers in the active layer.Recombination is a phenomenon opposite to ionization, that is, the disappearance of free charge carriers of opposite signs when they collide.

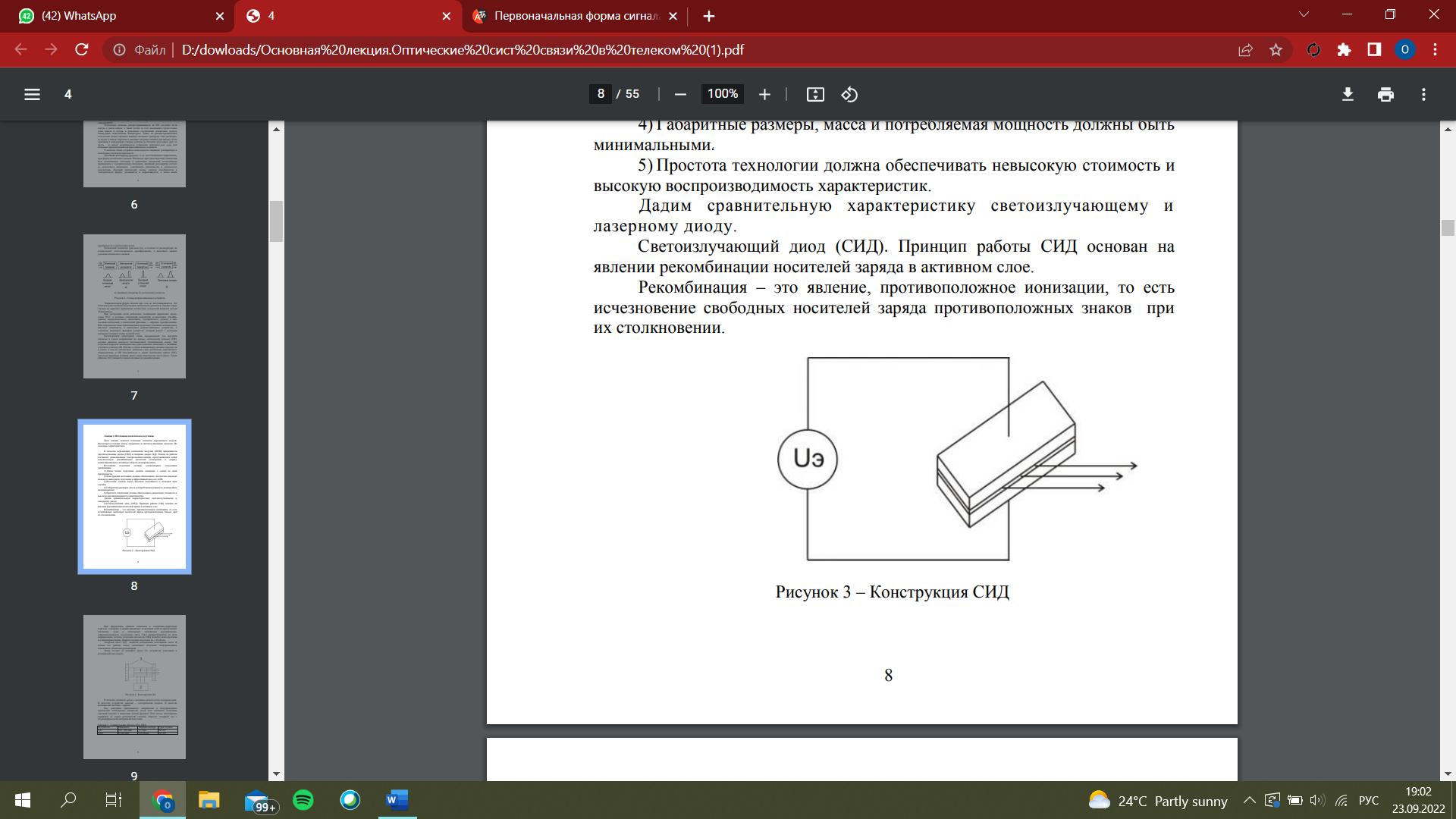


Figure 3 – LED construction

When a forward bias is applied to the electron-hole transition, electrons and holes penetrate into the active layer from adjacent passive layers and experience spontaneous recombination,accompanied by light emission. The light propagates in all directions, so the radiation at the LED output is incoherent and weakly directed. The width of the radiation spectrum Δλ = 20-40 nm. A laser diode (LD) is a coherent light source.His work is based on the spontaneous emission of a semiconductor covered by a volumetric resonator.The laser consists of an active medium (1), a pumping device (2) and resonance system(3).

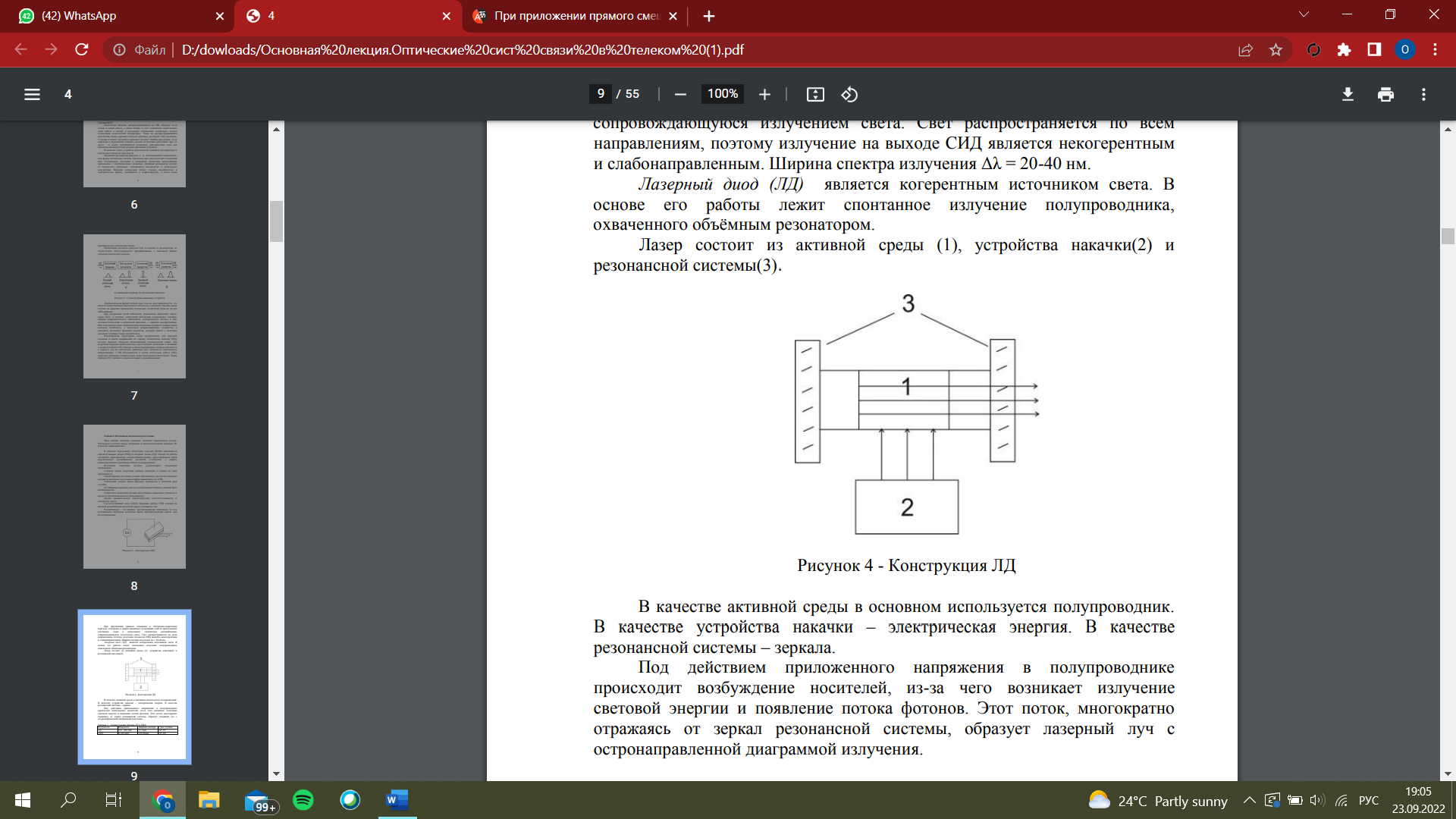
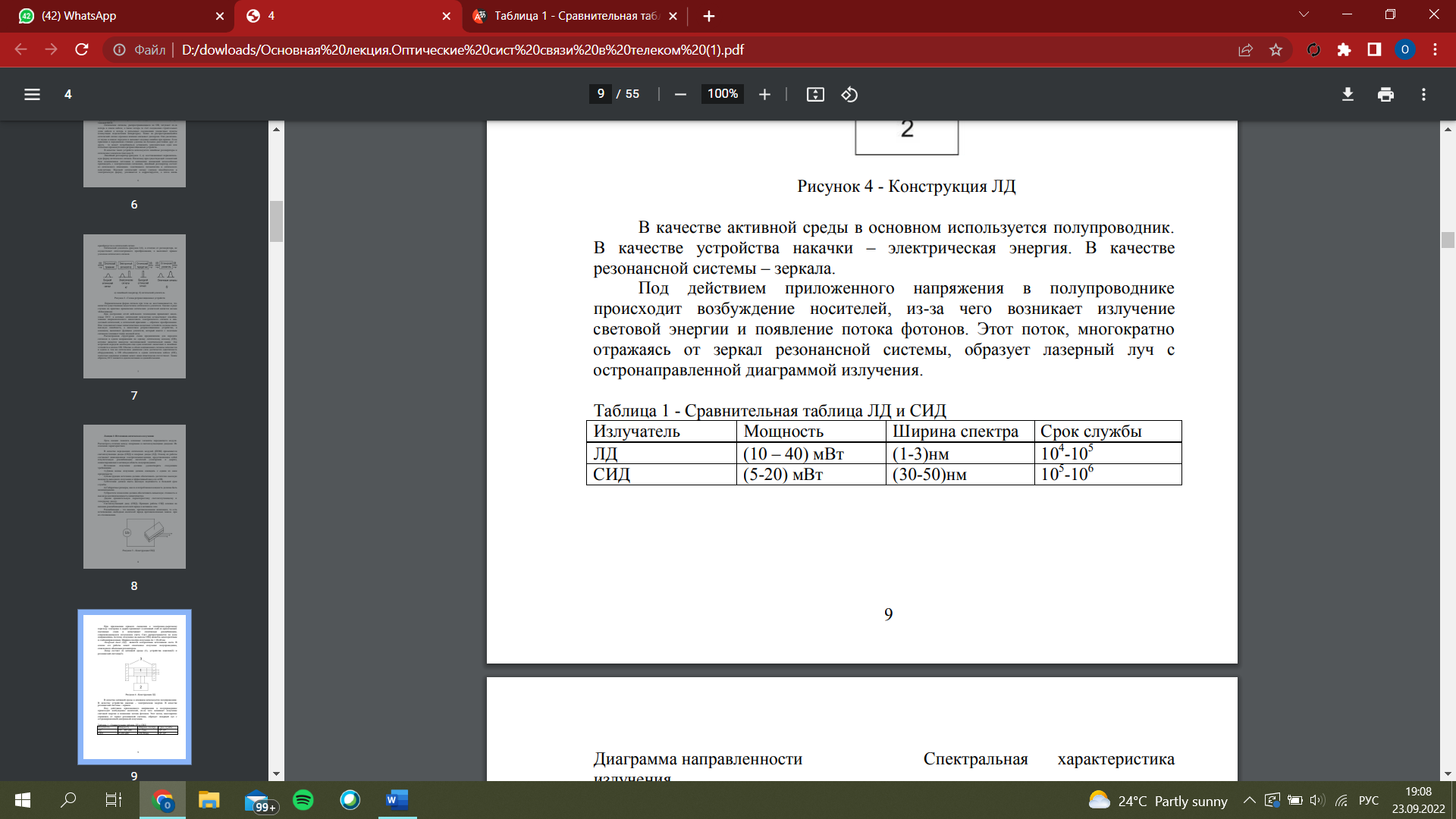


Figure 4 - LD construction

A semiconductor is mainly used as an active medium.Electric energy is used as a pumping device. As a

resonant system – mirrors.Under the influence of the applied voltage, carriers are excited in the semiconductor, which causes the emission of light energy and the appearance of a photon flux. This flux, repeatedly reflected from the mirrors of the resonant system, forms a laser beam with an acutely directional radiation diagram.

Table 1 - Comparative table of LD and LED



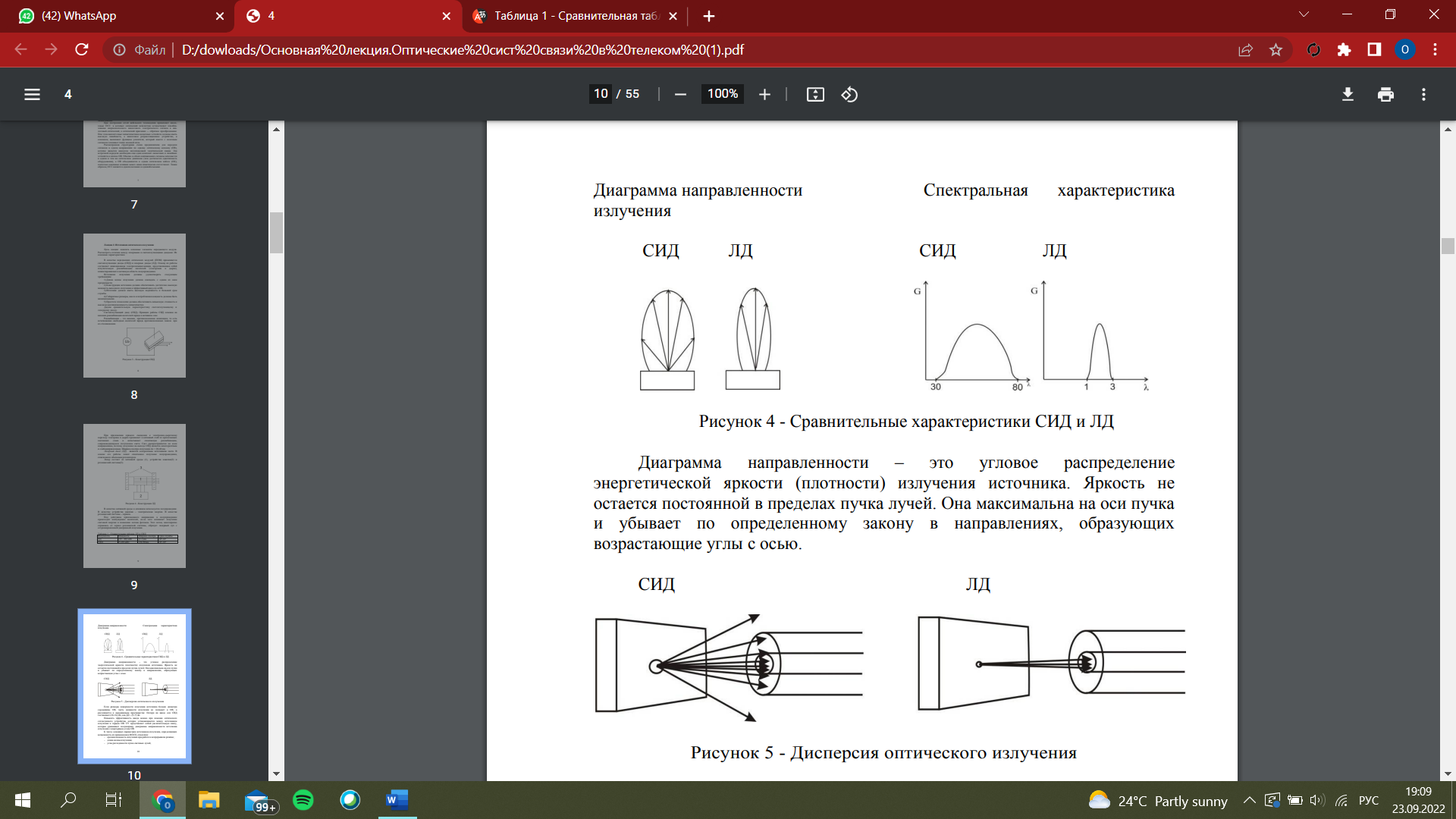


Figure 4 - Comparative characteristics of LED and LD

The radiation pattern is the angular distribution of the energy brightness (density) of the radiation source. The brightness does not remain constant within the beam of rays. It is maximal on the beam axis and decreases according to a certain law in the directions forming increasing angles with the axis.

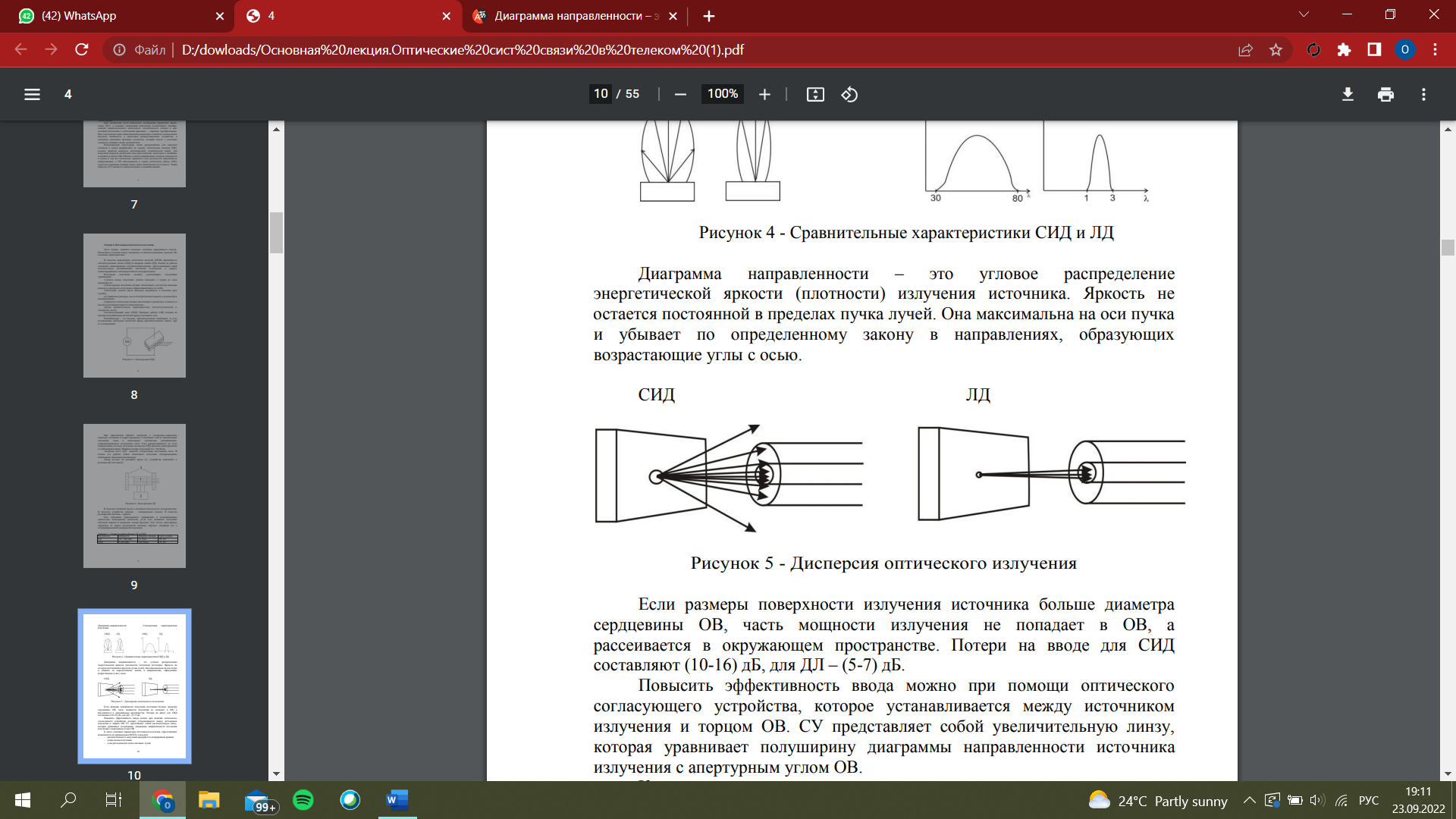


Figure 5 - Dispersion of optical radiation

If the dimensions of the radiation surface of the source are larger than the diameter of the core of the S, part of the radiation power does not fall into the S, but is scattered in the surrounding space. Input losses for LEDs are (10-16) dB, for DL – (5-7) dB. It is possible to increase the efficiency of the input by using an optical matching device, which is installed between the radiation source and the end of the S. The SU is a magnifying lens that equalizes the half-width of the radiation source radiation pattern with the aperture angle of the s.Among the main parameters of radiation sources that determine the possibility of their use in VSP are:

- average radiation power when operating in continuous mode;

- the wavelength of the radiation;

- divergence angles of a beam of light rays;

- the width of the radiation spectrum;

- service life (time to failure).

Therefore, the optimal radiation sources for VSP are LDS. High radiation power and small beam divergence angles make it possible to transmit signals over a distance of tens of km without amplification.In high-speed VPS, to reduce chromatic dispersion (increase the length of regeneration sites), it is necessary to use single-mode LDS. However, their disadvantage is the complexity of manufacturing and, accordingly, the price. Multimode LDS have more than modest technical indicators, but from the point of view of "price-efficiency" they are out of competition on trunk and zone networks, where very high transmission speeds are not required. LEDs have the following advantages: simpler, cheaper, have high durability, sufficiently high temperature stability of parameters. However, the large divergence of the beam (incoherence of radiation), a wide spectrum of radiation, and limited speed significantly narrow the scope of LED applications. They are used in small and medium-length lines.The elements of the optical transmitter are structurally combined into a compact device – the transmitting optical module POM

Lecture 3. Modulation of radiation sources

The purpose of the lecture: to study the types of modulation of the optical signal.To transmit information over an optical fiber, it is necessary to change the parameters of the optical carrier depending on the changes in the original signal. This process is called modulation. Radiation modulation is a change in the parameters of an optical carrier according to the law of information oscillation.VSP uses direct (direct) and external modulation of electromagnetic radiation of the optical range.The simplest type of modulation from the point of view of implementation is direct modulation of the optical carrier by intensity based on a semiconductor radiation source. The radiation intensity is the average power carried by a wave in one second through a wave surface with an area of one square meter. The output radiation of a semiconductor LED or laser can be directly modulated by changing the characteristics of the active layer (pump/injection current, laser resonator volume) as follows,to get the modulation of the radiation power. Most often, with direct modulation , the output power changes due to a change in the magnitude the pump-injection current strength, depending on changes in the information signal.

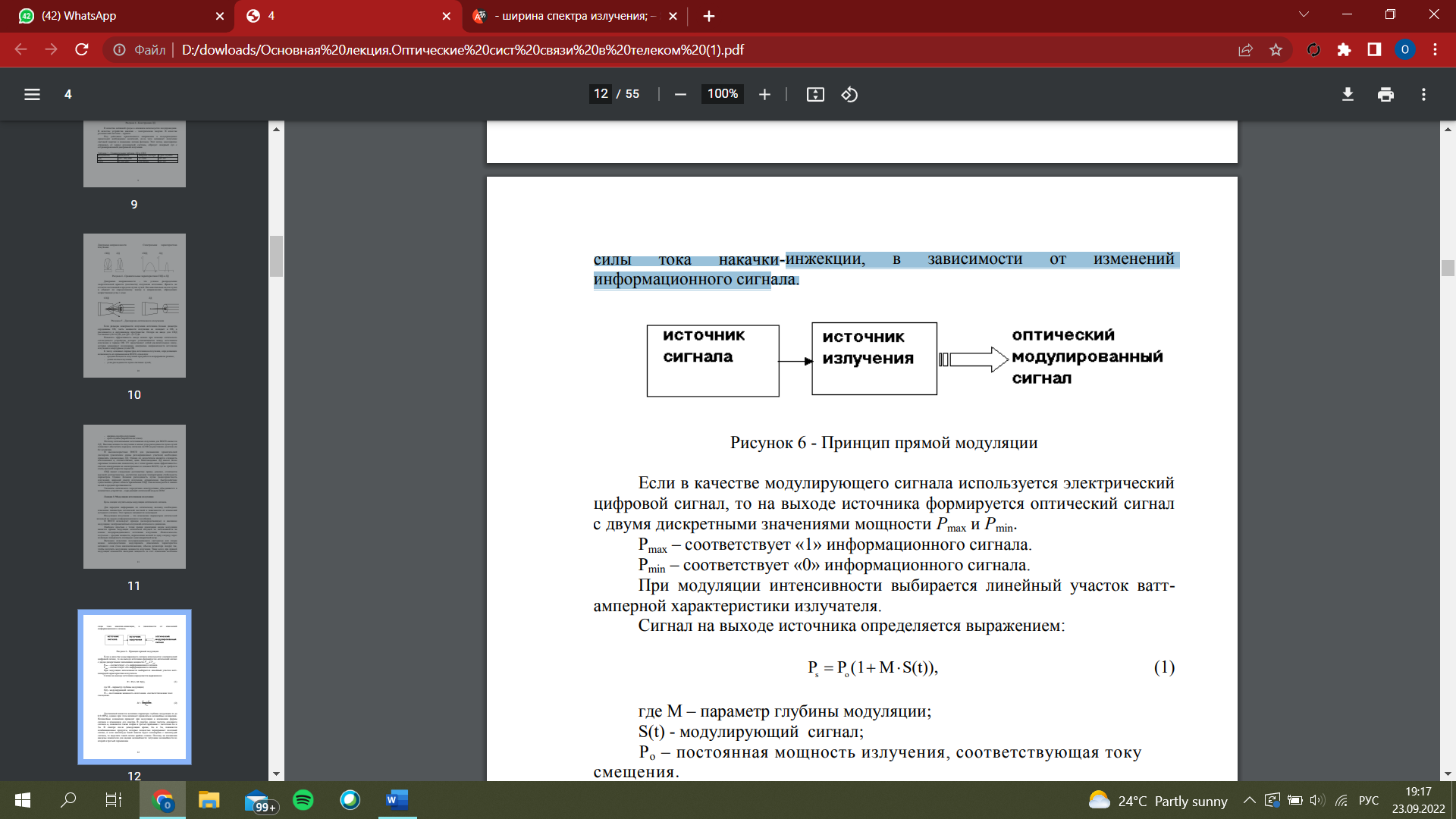


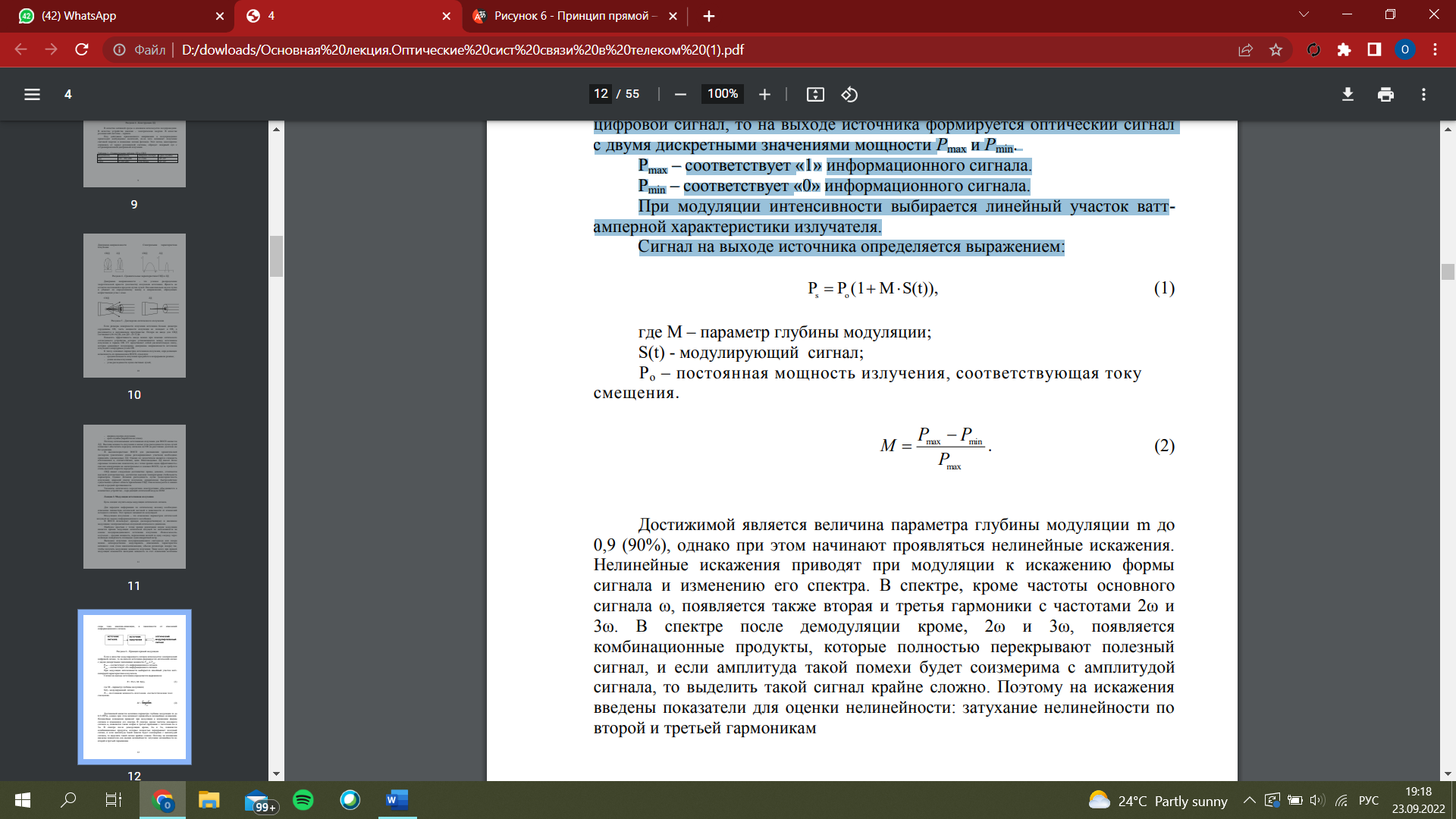
Figure 6 - The principle of direct modulation

If an electric digital signal is used as a modulating signal, an optical signal with two discrete power values Pmax and Pmin is generated at the output of the source.

Pmax – corresponds to "1" of the information signal.

Pmin – corresponds to "0" of the information signal.

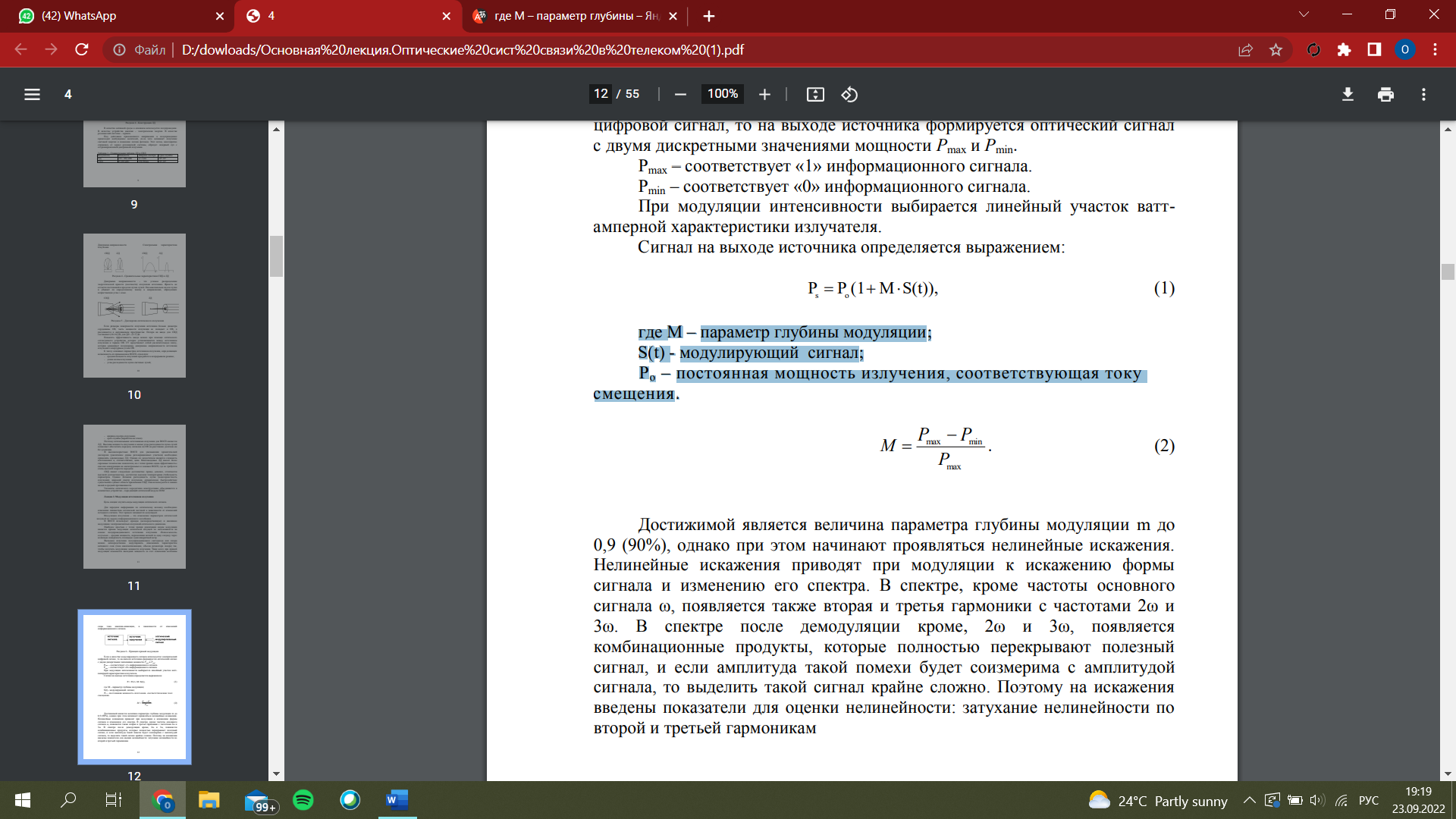
When the intensity is modulated, a linear section of the current-voltage characteristic of the emitter is selected.The signal at the source output is defined by the expression:



where M is the modulation depth parameter;

S(t) - modulating signal;

Po is the constant radiation power corresponding to the bias current.



The value of the modulation depth parameter m up to 0.9 (90%) is achievable, however, nonlinear distortions begin to manifest themselves.Nonlinear distortions lead to distortion of the waveform and a change in its spectrum during modulation. In the spectrum, in addition to the frequency of the main signal ω, there are also second and third harmonics with frequencies 2ω and 3ω.In the spectrum after demodulation, in addition to 2ω and 3ω, combinational products appear that completely overlap the useful signal, and if the amplitude of such interference is commensurate with the amplitude If there is no signal, then it is extremely difficult to isolate such a signal. Therefore, indicators have been introduced for the distortion to assess the nonlinearity: the attenuation of nonlinearity by the second and third harmonics

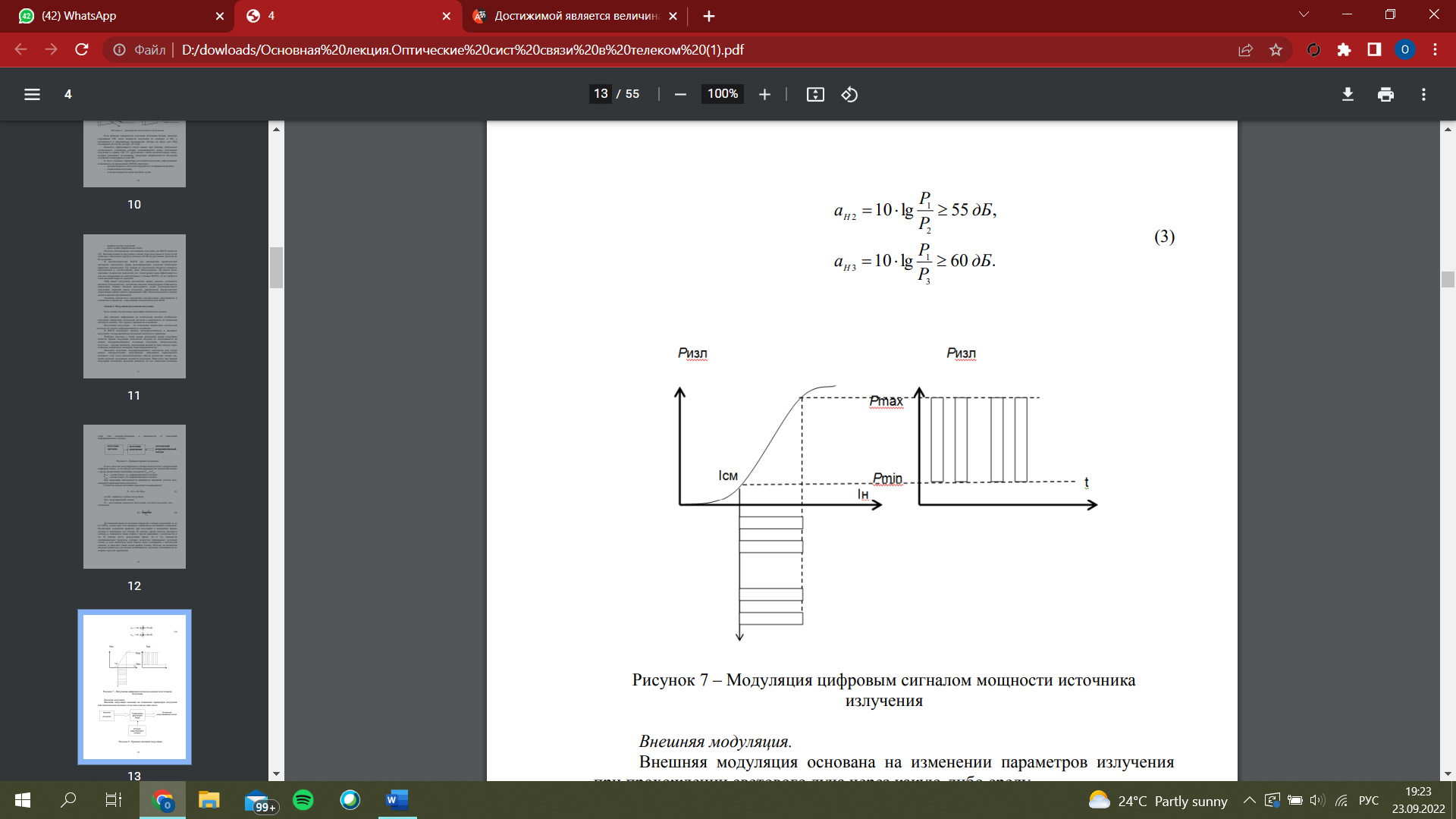


Figure 7 – Digital signal modulation of the power of the radiation source

External modulation.External modulation is based on changing the radiation parameters when a light beam passes through a medium.

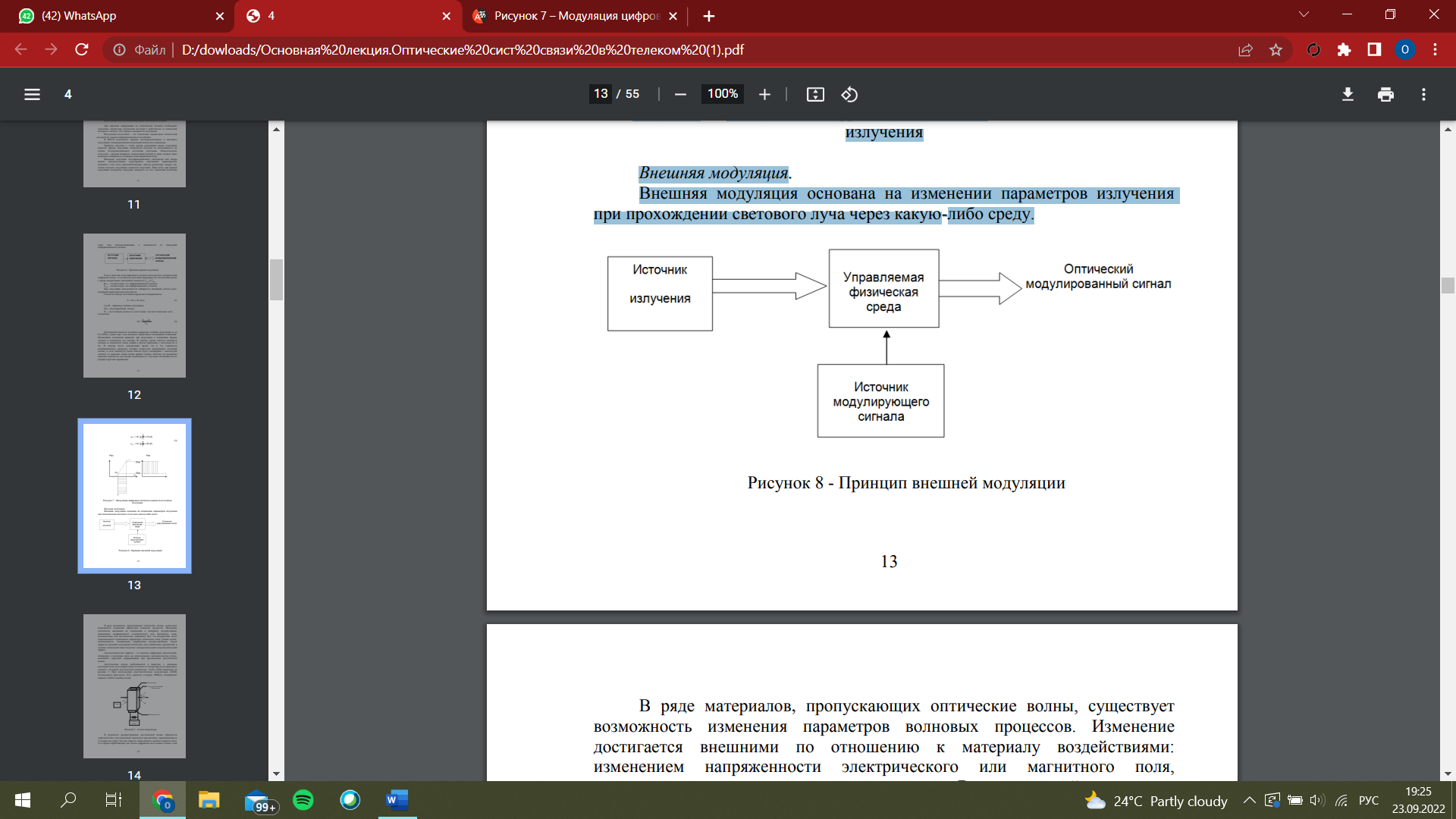


Figure 8 - The principle of external modulation

In a number of materials that transmit optical waves, it is possible to change the parameters of wave processes. The change is achieved by external influences in relation to the material: changes in the intensity of the electric or magnetic field, mechanical or acoustic pressure. All these effects can be accompanied by changes in the parameters of optical waves (wavelength, intensity, polarization, direction of propagation). Among the effects of external modulation of optical waves , the electro-optical and acousto-optical effects have received the greatest application in optical communication technology. The acousto-optic effect is the phenomenon of diffraction, refraction, reflection and scattering of light on periodic inhomogeneities of the medium caused by elastic deformations during the passage of an acoustic wave.Acoustic waves are excited in a substance by means of a piezo crystal, to which a signal is supplied from a modulating signal generator with high acoustic power. The AOM scheme is shown in Figure 9. In the manufacture of acousto-optic modulators (AOM) , crystals of TeO2 (tellurium dioxide), PbMoO4 ( lead molybdenum), LiNbO3 (lithium niobate) are used.

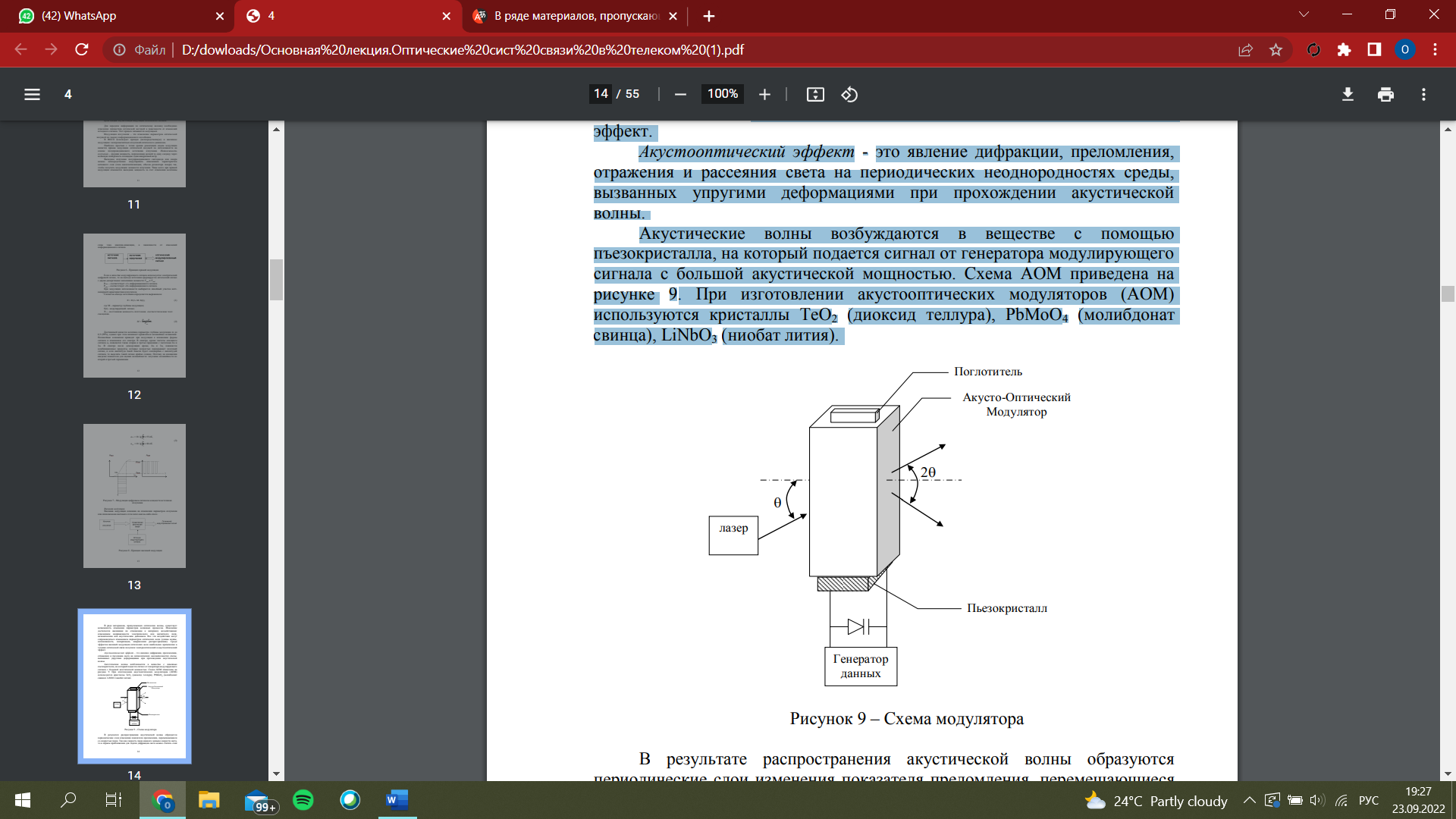
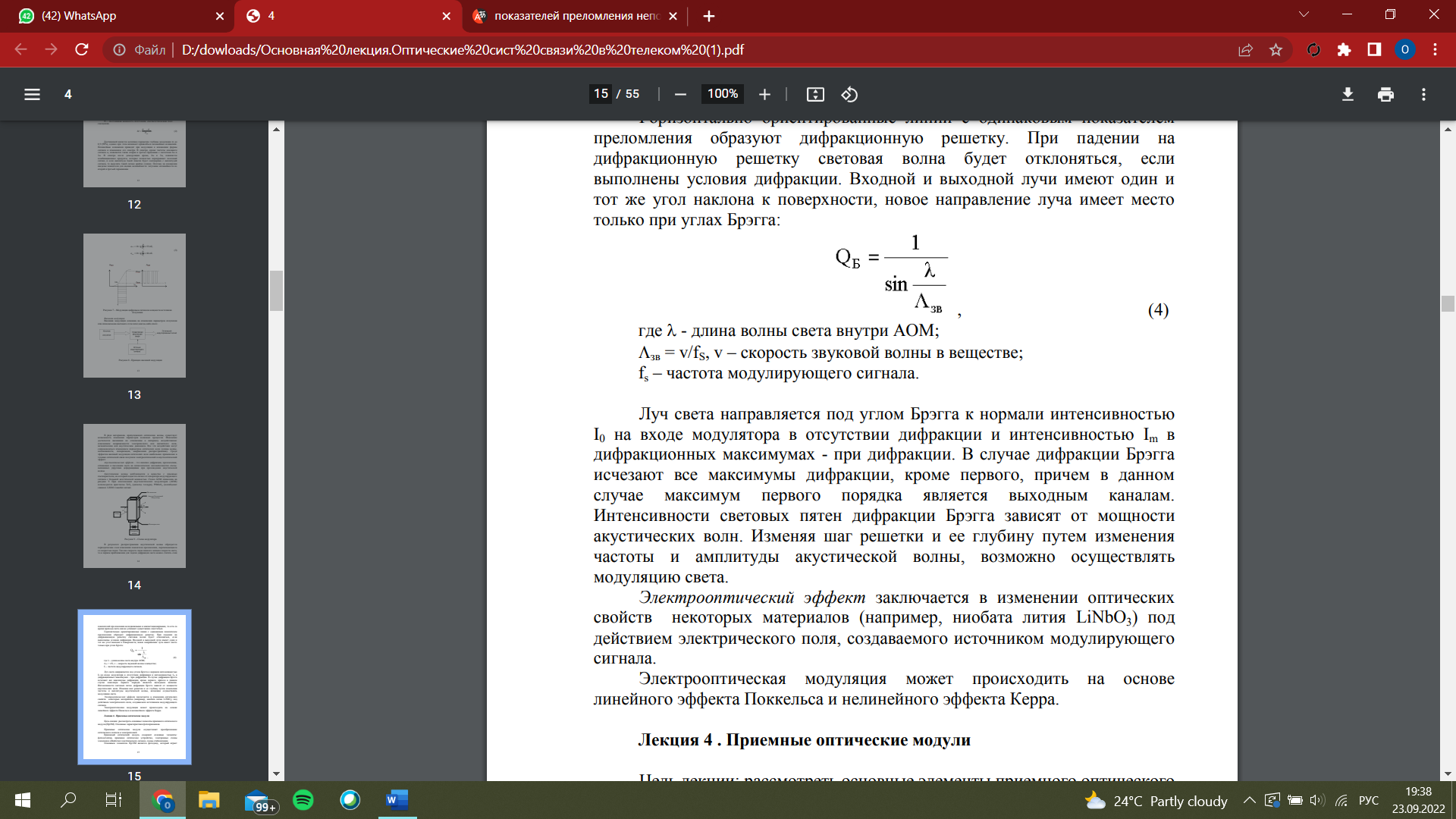


Figure 9 – Modulator diagram

As a result of acoustic wave propagation, periodic layers of refractive index changes are formed, moving

at the speed of sound. Since the speed of sound is much less than the speed of light,then in the first approximation for the problem of light diffraction, layers can be considered the refractive indices are fixed and quasi-stationary, that is, they do not have time to shift significantly during the passage of light. Horizontally oriented lines with the same refractive index form a diffraction grating. When falling on a diffraction grating, the light wave will be deflected if the diffraction conditions are met. The input and output beams have the same angle of inclination to the surface, the new direction of the beam takes place only at Bragg angles:



where  is the wavelength of light inside the AOM;

sv = v/fS, v is the velocity of the sound wave in the substance;

fs is the frequency of the modulating signal.

The light beam is directed at the Bragg angle to the normal intensity I0 at the input of the modulator in the absence of diffraction and the intensity of Im at diffraction maxima - during diffraction. In the case of Bragg diffraction , all the diffraction maxima except the first one disappear, and in this case the maximum of the first order is the output channels. The intensities of Bragg diffraction light spots depend on the power of acoustic waves. By changing the pitch of the grating and its depth by changing the frequency and amplitude of the acoustic wave, it is possible to modulate the light. The electro-optical effect consists in changing the optical properties of some materials (for example, lithium niobate LiNbO3) under the influence of an electric field created by a source of a modulating signal. Electro optical modulation can occur on the basis of the linear Pockels effect and the nonlinear Kerr effect.

Lecture 4 . Receiving optical modules

The purpose of the lecture: to consider the main elements of the receiving optical module (PROM). The main characteristics of the photodetector. Receiving optical modules converts an optical signal into an electrical one. The receiving optical module contains the main elements: a photodetector, an optical receiving device, electronic circuits for amplification and processing of an electrical signal, stabilization circuits. The main element of Pr.The OHM is a photodiode that plays the role of the photodetector.The detector's function is to convert the input optical signal into an electrical one, which is then amplified and processed by electronic circuits. The photodetector must accurately reproduce the shape of the optical signal without introducing additional noise.

Therefore, the following requirements are imposed on photodetectors:

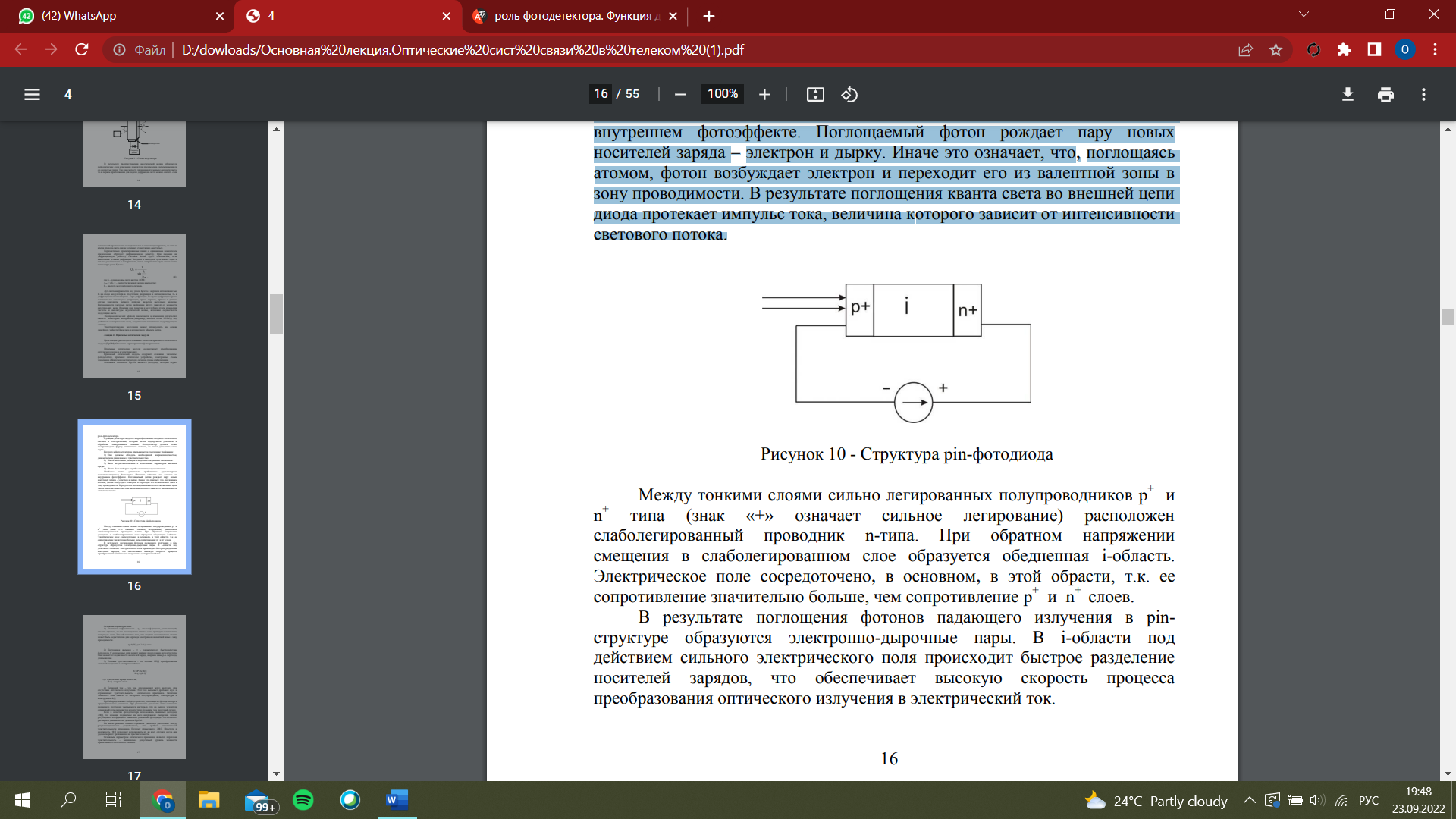
1) They must have the necessary broadband, dynamic range and sensitivity.

2) Have small size and reliable connection with fiber.

3) Be insensitive to changes in environmental parameters.

4) Have a long service life and minimal cost.

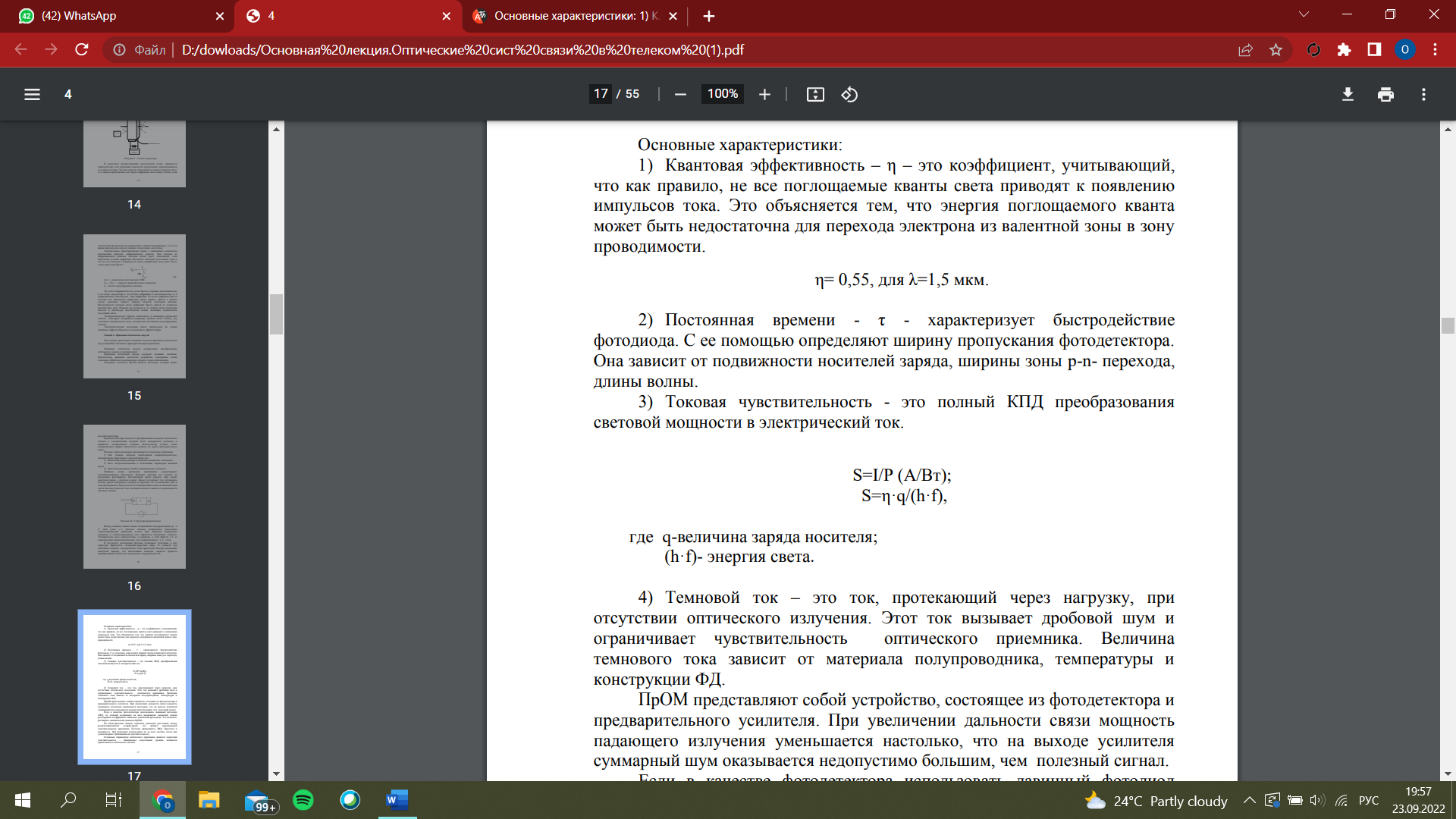
Semiconductor photodiodes meet these requirements most fully. Its principle of operation is based on an internal photo effect. The absorbed photon gives birth to a pair of new charge carriers – an electron and a hole. Otherwise, it means that, being absorbed by an atom, a photon excites an electron and passes it from the valence band to the conduction band. As a result of the absorption of a quantum of light , a current pulse flows in the external circuit of the diode, the magnitude of which depends on the intensity of the luminous flux.



A weakly alloyed n-type conductor is located between thin layers of highly doped p+ and n+ type semiconductors (the "+" sign means strong doping). At the reverse bias voltage, a depleted i-region is formed in a weakly alloyed layer. The electric field is concentrated mainly in this area, because its resistance is much greater than the resistance of p+ and n+ layers.As a result of absorption of photons of incident radiation, electron-hole pairs are formed in the pin structure. In the i-region, rapid separation occurs under the action of a strong electric field charge carriers, which ensures a high speed of the process of converting optical radiation into electric current.

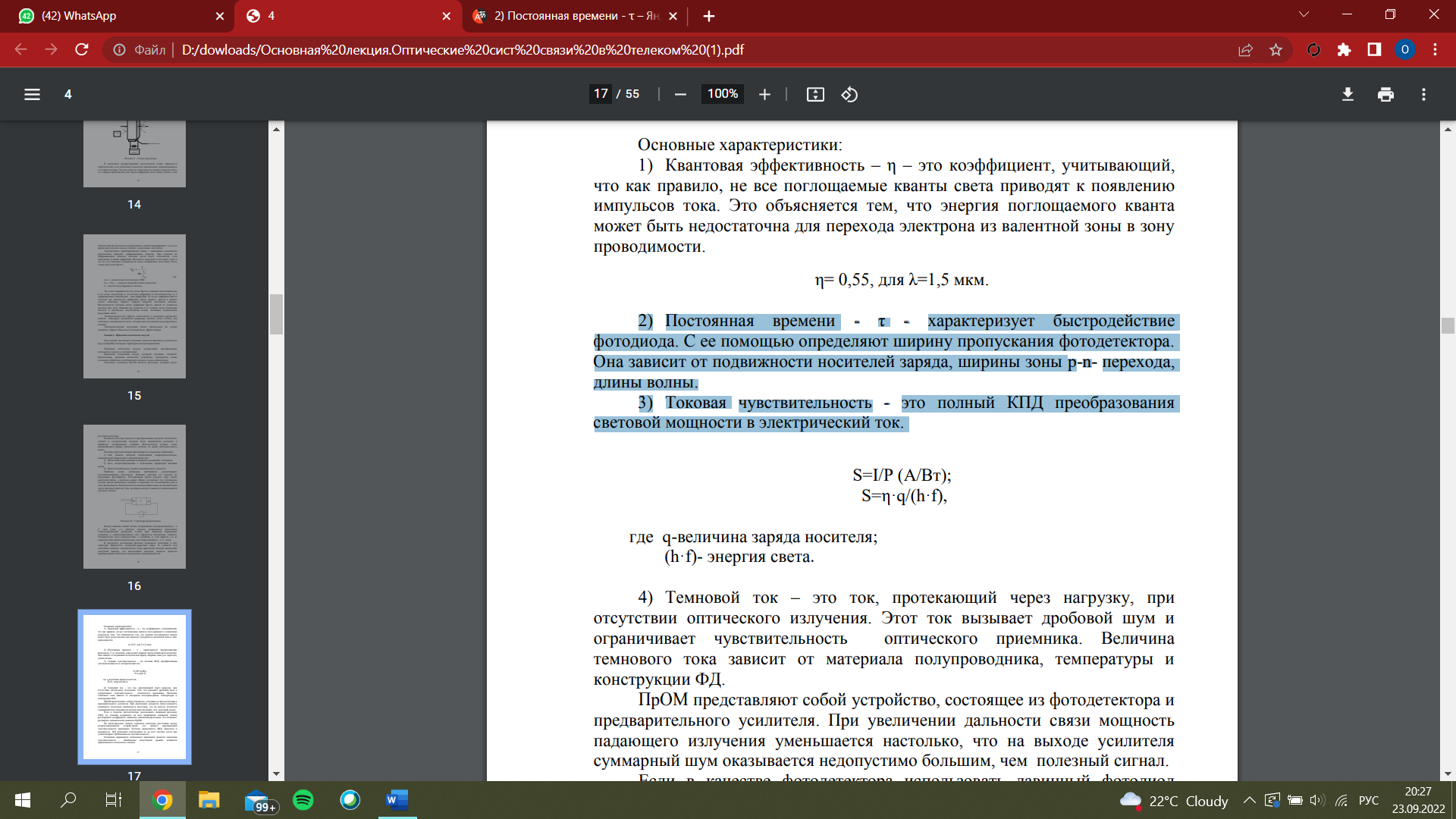
Main Features:

1. Quantum efficiency – n is a coefficient that takes into account that, as a rule, not all absorbed light quanta lead to the appearance of current pulses. This is explained by the fact that the energy of the absorbed quantum may not be sufficient for the transition of an electron from the valence band to the conduction band.



2) The time constant - τ - characterizes the speed of the photodiode. With its help, the transmission width of the photodetector is determined.It depends on the mobility of the charge carriers, the width of the p-n junction zone,and the wavelength.

3) Current sensitivity is the total efficiency of converting light power into electric current.

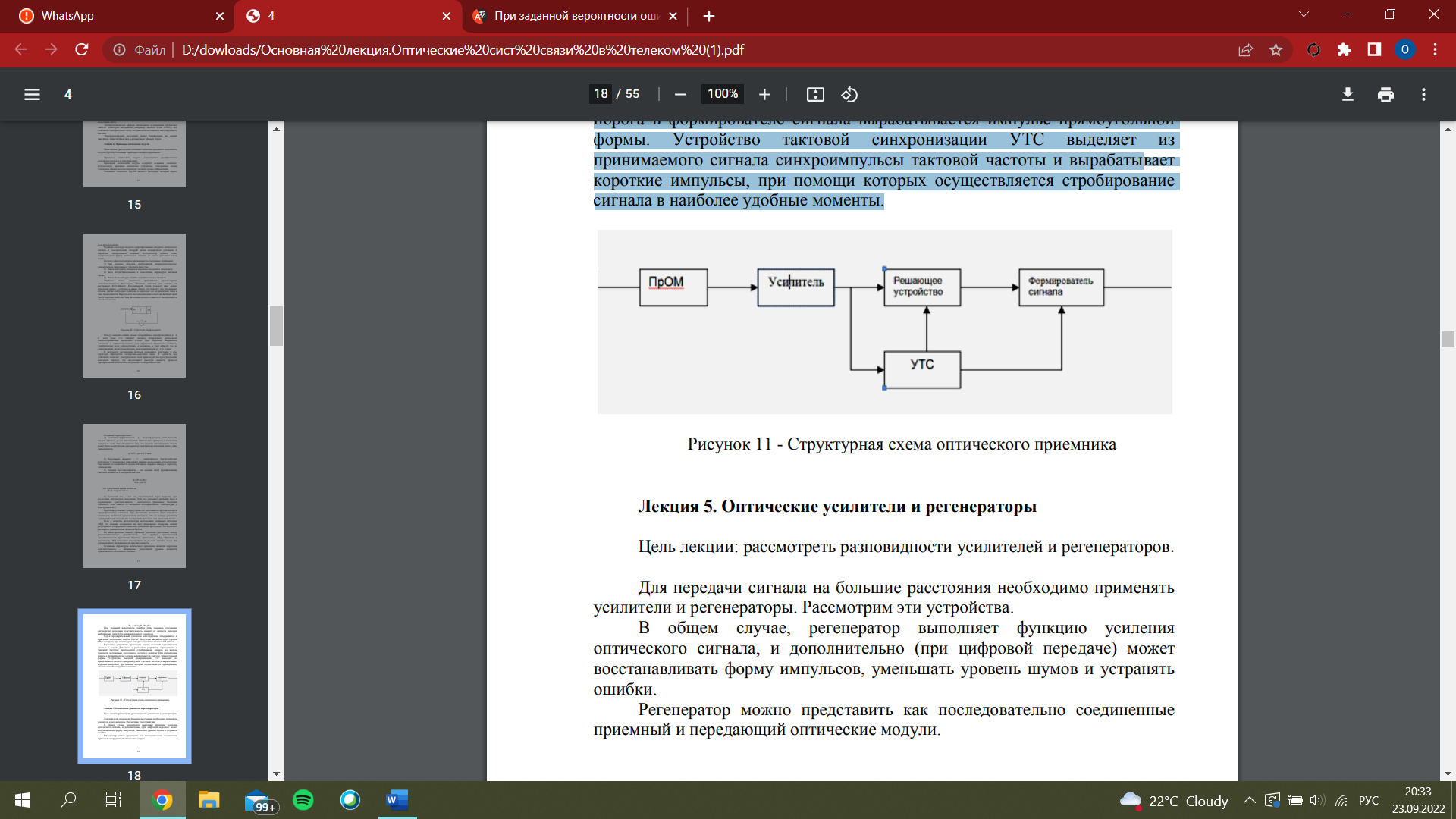


where q is the value of the carrier charge;

(h·f) is the energy of light.

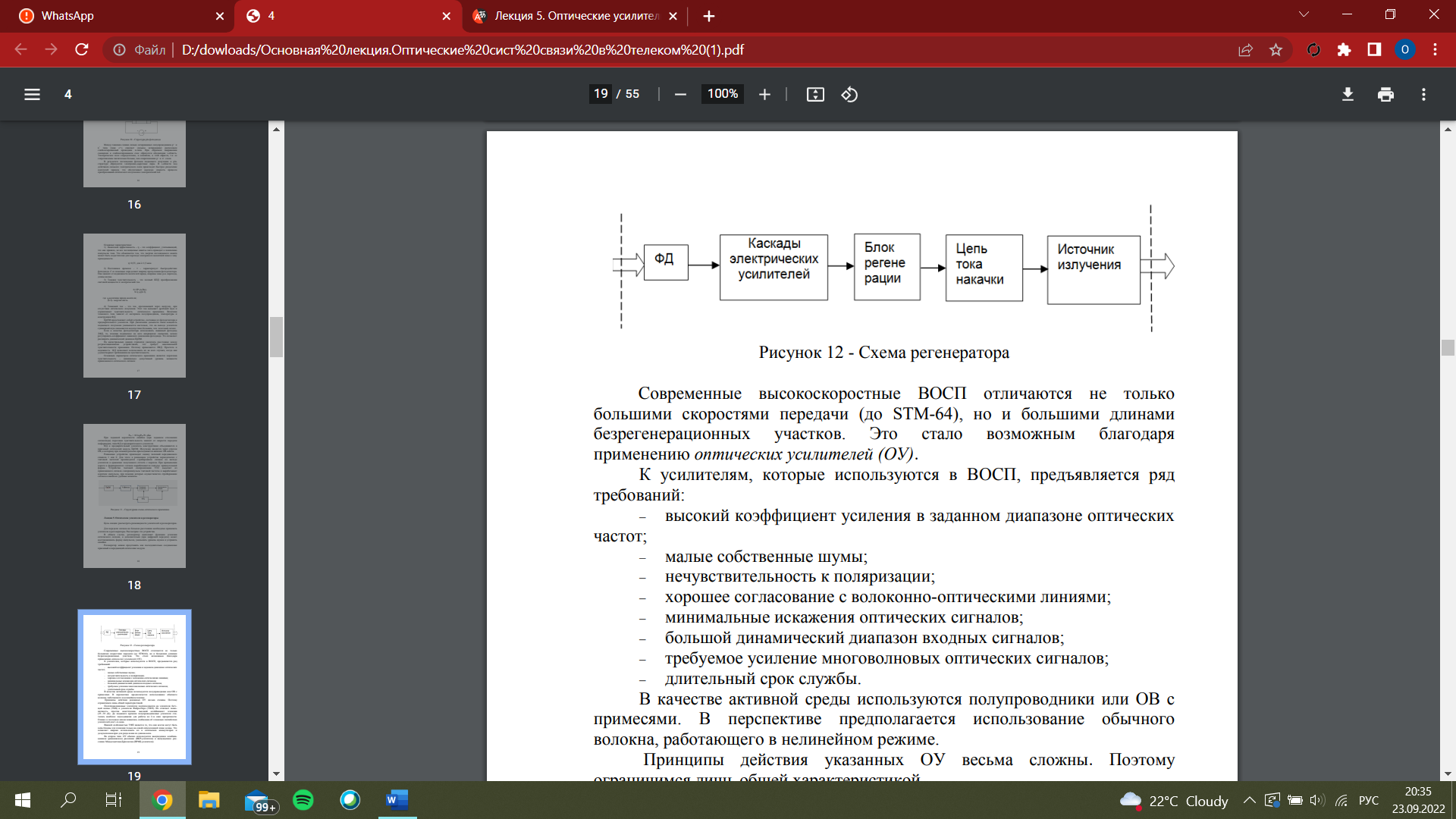
4) Dark current is the current flowing through the load in the absence of optical radiation. This current causes shot noise and limits the sensitivity of the optical receiver. The magnitude of the dark current depends on the semiconductor material, temperature, and the design of the PD. PrOM is a device consisting of a photodetector and a pre-amplifier. With an increase in the communication range, the power of the incident radiation decreases so much that at the output of the amplifier the total noise turns out to be unacceptably greater than the useful signal. If an avalanche photodiode is used as a photodetector LFD, then, by changing the bias voltage applied to it , the avalanche multiplication coefficient of the photodiode can be adjusted. This allows you to expand the dynamic range of the PROM.On trunk lines, they tend to increase the distance between relay devices, which requires maximum sensitivity of the receiver. Therefore, LFD is used. The simplicity and reliability of PD allow them to be used in all cases when they meet the requirements for sensitivity. The main parameter of the optical receiver is the threshold sensitivity – the minimum allowable power level of the received optical signal:

For a given error probability (for a given signal-to-noise ratio), the threshold sensitivity depends on the information transfer rate, the type of FD and the pre-amplifier. The FD and the pre-amplifier are structurally combined into a receiving optical module of the PROM. Radiation is introduced through the segment The OV to which the external OV of the cable is connected using the connector. The resolver evaluates the values of the transmitted symbol 1 or 0. To do this , the output signal is periodically gated at a clock frequency in the resolver amplifier and comparison of the received reference with the threshold. When the threshold is exceeded, a rectangular pulse is generated in the signal generator . The TCB clock synchronization device extracts clock frequency synchro pulses from the received signal and generates short pulses, with the help of which the signal is gated at the most convenient moments.



Lecture 5. Optical amplifiers and regenerators

The purpose of the lecture: to consider the types of amplifiers and regenerators.To transmit a signal over long distances, it is necessary to use amplifiers and regenerators. Consider these devices. In general, the regenerator performs the function of amplifying the optical signal, and additionally (with digital transmission) can restore the shape of pulses, reduce noise and eliminate errors. The regenerator can be represented as a series of connected receiving and transmitting optical modules.



Modern high-speed networks are distinguished not only by high transmission speeds (up to STM-64), but also by long lengths of non-regenerative sections. This was made possible by the use of optical amplifiers (OP amps). A number of requirements are imposed on the amplifiers used in the VSP:

 high gain in a given range of optical frequencies;

 small intrinsic noises;

 insensitivity to polarization;

 good matching with fiber optic lines;

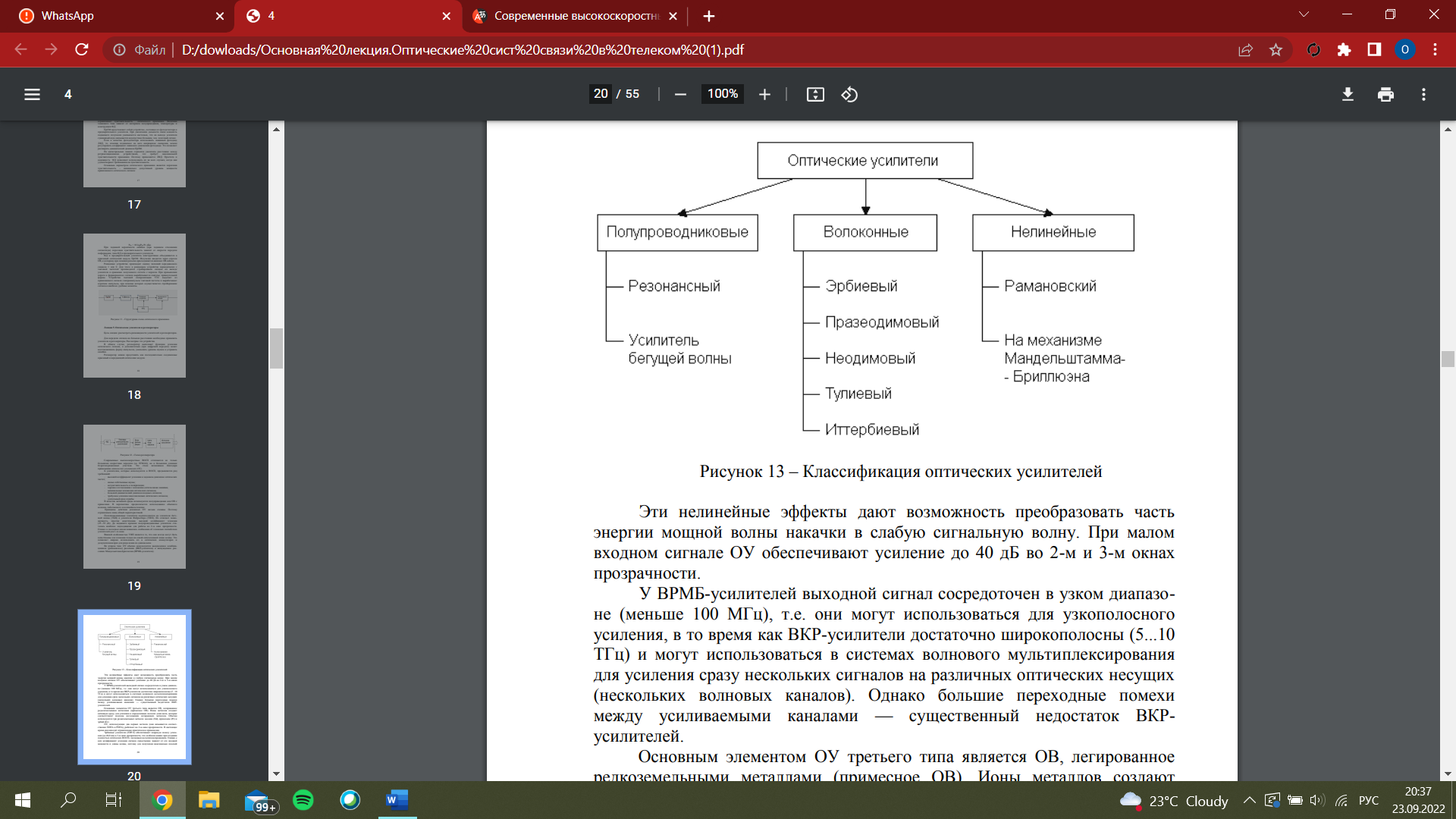
 minimal distortion of optical signals;

 large dynamic range of input signals;

 required amplification of multi-wave optical signals;

 Long service life.

Semiconductors or S with impurities are used as the active medium. In the future, it is planned to use a conventional fiber operating in a nonlinear mode. The principles of operation of these OUS are very complex. Therefore , we will limit ourselves to a general characteristic. Semiconductor amplifiers are divided into traveling wave amplifiers (UBV) and Fabry-Perot amplifiers (UFP). They are distinguished by economy, simple design, high gain (25...30 dB). Until recently, semiconductor amplifiers were considered the most suitable for operation in the 2nd transparency window. However, recently there have been reports of successful developments of amplifiers for the 3rd window. An important feature of UFPs is that they can always be rearranged to amplify only at one specific wavelength. This allows them to be widely used in optical switches and demultiplexers for wavelength separation.In the second type of op-amp, forced Raman scattering (WRC amplifiers) and forced Mandelstam-Brillouin scattering (VRMB amplifiers) are usually used.



These nonlinear effects make it possible to convert partof the energy of a powerful pumping wave into a weak signal wave. With a small input signal, the op amps provide amplification up to 40 dB in the 2nd and 3rd transparency windows. In VRMB amplifiers, the output signal is concentrated in a narrow range (less than 100 MHz), i.e. they can be used for narrowband amplification, while WRC amplifiers are sufficiently broadband (5-10 THz) and can be used in wave multiplexing systems to amplify several signals on different optical carriers at once (multiple wave channels). However, large transient interference between the amplified channels is a significant drawback of the amplifiers. The main element of the third type of op-amp is the OP-Amp doped with rare earth metals (impurity op-AMP). Metal ions create an active medium for amplification in certain wavelength bands that correspond to the absorption bands of alloying metals. Three rare earth metals are commonly used: neodymium (Nd), praseodymium (Rg) and erbium (Eg). Op-amps using the first two metals (they are called NDFA and PDFA, respectively) work in the 2nd transparency window. Currently , they find limited practical application.Erbium amplifiers (EDFA) provide a wide gain band (up to 40.8 nm) in the 3rd transparency window, which is especially important when creating fully optical VPS with wave multiplexing. However, their signal gain significantly depends on its input power and wavelength, therefore, to obtain the most flat Gain characteristics it is necessary to use various equalizing filters. In the best industrial EDFA amplifiers, the gain reaches 40 dB in the 1530...1570 nm band with an uneven characteristic of 0.6...1.5 dB. EDFA amplifiers with a working band of 84.3 nm (1530... ...1614 nm) in the 3rd and 4th transparency windows have already been developed. A comparative analysis of the LR and OU parameters allows us to draw some conclusions. LR regenerates the digital optical signal, but has a complex design and, as a result, high cost and relatively low reliability. In addition, the LR is usually designed to operate at a certain information transfer rate and does not allow simultaneous transmission of several wave channels, which makes it difficult to use it in a wave multiplexing OSS. The op-amp has a simple and highly reliable design, and its cost is constantly decreasing. It is not tied to the speed of information transmission, which allows you to increase the bandwidth of existing OSS without significantly increasing equipment costs. The creation of modern super-heavy engines is impossible without LR. However, in some cases, the use of op-AM is very effective. This, first of all, applies to intra-zone OSS on a single-mode OK with low dispersion at relatively low information transfer rates. High reliability of the op-amp is an important advantage when creating relay devices for underwater OSS. Very effective is the joint use of LR and OP (and in some cases, dispersion compensators) on high-speed super-stretched OSS. In them, there may be from 4 to 8 linear op-amps per LR. The latter are used not only as relay devices. They are often installed directly behind the optical transmitter, providing a high signal level (boosters), directly in front of the optical receiver (preamps), as well as inside or at the output of devices that introduce unwanted losses (for example, dispersion compensators).

Lecture 6. Methods of compaction of VOLS

The purpose of the lecture: to study the existing methods of compaction. There are the following methods of compaction:

 temporary (at the level of electrical signals; at the level of optical signals);