

Information imaging

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In this paper, a system for information imaging has been presented with its elements, parameters and characteristics. The perceptive characteristics of the operator together with the limitations resulting from them have been discussed. The types of displays and the requirements on the operator's working station have been reviewed.

1. The operator – display – electronics system information visualisation system

The **display**, being an interface element between the electronic system acquiring and processing information, and the operator as the addressee of that information, must fulfil the conditions defined by the features of both sides of that composition – on the one hand, electronics and informatics, and on the other hand, the area of physiology and psychophysics of the operator – a human being in various conditions.

The **display** – is an electro-optical transducer transforming the information prepared in the system in the form of electrical signals into information encoded in a stream of light perceived by the human operator. The input state is defined by the parameters of the electrical signal, while the output state is the reaction of the operator, who undertakes action as a result of the reception of the information presented to him.

The **electro-optical transducer** is an electro-optical element directly responsible for the process of modulation of the light stream by means of a particular set of physical phenomena, e.g. optical and electrical anisotropy in liquid crystal cells, electroluminescence in LED, electrical discharges in gases – in plasma panels, cathodoluminescence in cathode ray tubes and field emissive displays, etc.

The **System-Operator interface** can be presented schematically as a combination of the physical sphere

(hardware) and the sphere characterized by the psychophysical features of the human operator.

In Fig 1 the elements constituting the System-Operator interface have been schematically presented.

The information that is the result of the electronic system's work is coded in values characterizing the electrical signal passed to the input of the electro-optical transducer. The encoding process is determined by the perceptive features of the operator as well as by the operating parameters of the transducer. After converting the signal data into information encoded in a stream of light, a picture – constituting the object perceived by the operator – is formed.

The features of this part of the interface, are determined by the physical phenomena upon the base of which the transducers work, the conditions in which

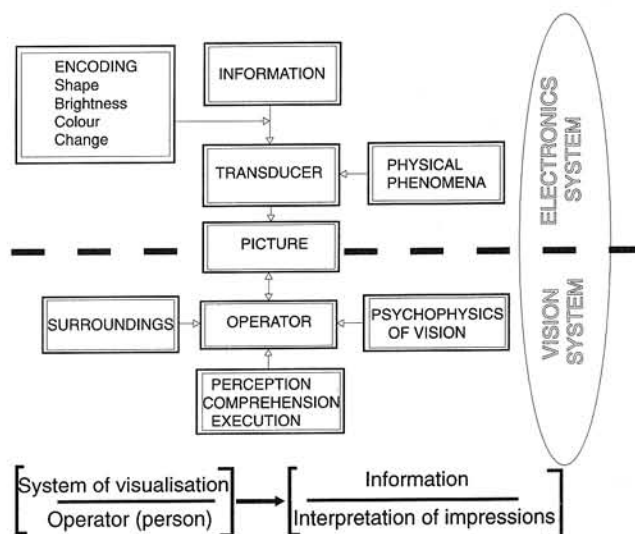


Fig. 1. The Electronics System – Operator Interface.

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they work, the influence of surrounding conditions (especially temperature), the type and construction of the display modules.

Information encoded in characteristic values of a stream of light (intensity, shape, colour, etc.) is presented to the operator, who should notice this information, understand it, and undertake appropriate action.

Optimal methods of encoding information are strongly dependent on working conditions, defined for the application in question. Therefore, the following elements must be taken into account when selecting the encoding mode: – the choice, range and type of coding alphabet; – the organisation and structural ordering of the information presented on the display; for the desired discrimination between sets of information with different priorities, or e.g. for deliberate forcing of movement-action by the operator; – matching the optical parameters of the display to the requirements of the operator's visual system, its characteristics and limitations.

The process of perceiving, and especially understanding information depends upon the psychophysical features of the operator working in particular surrounding conditions. These conditions include both the optical parameters of the surroundings (the illumination intensity of the workplace), and working conditions in general (noise, temperature, interferences, etc.). A complete description of the process of preparing, presenting and receiving information consists of an analysis of the electronic part, the optoelectronic part, the optical part, and the process of human perception.

2. Perceptive features of the operator

2.1. The configuration of the human vision system

The human visual system reacts to light in two ways – by perceiving the level, or changes in luminance of light, and by perceiving the wave frequency of the electromagnetic radiation of light – by the impression of colour. Human vision is characterized by a wide dynamic range of perception of light – approximately equal to 160 dB, – from the visual threshold; for an eye adapted to full darkness, to the threshold of pain. The perception of light is limited to the range of radiation from 380 nm (violet-blue) through 500 nm (green) to 780 nm (red).

The human visual system consists of the eye, the optic nerve, and visual cortex in the brain, in which further processing of the signal takes place, and information is extracted. The schematic structure of the eye has been presented in Fig. 2.

1-cornea, 2-iris, 3-lens,
4-aqueous humour,
5-retina
a-layer neural tissue
b-receptors
c-pigment epithelium
6-fovea
7-choroid
8-sclera

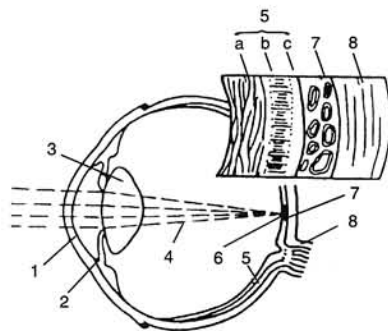


Fig. 2. Schematic structure of the eye.

The elements of the eye taking a direct part in the reaction to the stream of light photons are: the cornea, aqueous humour, the iris, the lens, vitreous humour, and the retina.

The optical configuration of the eye shows considerable chromatic aberration leading to a dissimilarity of images the coloured objects formed on the retina. This causes the impression that among two objects with different colours, e.g. a blue one and a red one, one (the blue object) is perceived as more distant than the other (blue) object.

The retina covers the inside surface of the eye (Fig. 2) and consists of two types of receptors: rods and cones. Rods, of which there are about 120 million, are about 500 times more sensitive to light than cones, but react only to the intensity of light. Cones (about 6 million), react to the spectral content of light, enabling the perception of colour. The density of spacing of cones and rods is very uneven, causing considerable differences in perception by the eye at different angles (Fig. 3).

The number of receptors

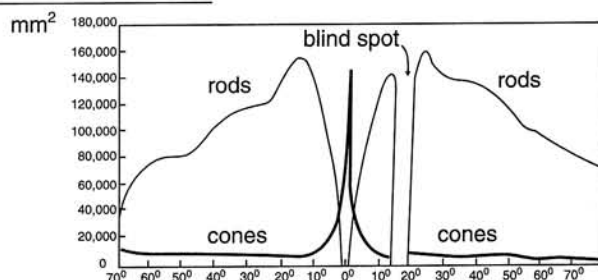


Fig. 3. The distribution of photoreceptors in the human retina.

In the centre of the retina (on the optical axis of the eye) there is the "fovea", which consists only of cones in high density (about 150 000 per mm^2), constituting the area of greatest sharpness of vision – perceiving the

smallest differences in the structure of the picture. In the area of the so-called blind spot – where the eye nerves exit the eyeball, there are no photoreceptors at all, and hence the lack of sensitivity to stimulation by light in this spot. Rods cover the inside surface of the eye to 70-80° away from the eye's optical axis. Such a wide angle range allows for peripheral vision i.e. being able to notice small changes of the light signal in a very wide angle (e.g. the movement of an object), while the sharpness of sight is very limited. This is why the angle range of colour vision is limited to about 40°, while the angle range of perception of changes in the intensity of light is about 70°-80°.

2.2. The perceptive characteristics of the human visual system

The perceptive characteristics of the human visual system are defined by the optical characteristics of the vision systems and by the processing of information in the structures of the retina's nerve connections and in the visual cortex in the brain.

The whole of the vision system determines the adaptive abilities and ranges of reactions to physical stimulation by light.

Perception of changes of light

After receiving the stimulus – an impulse of light, the visual system reacts with a delay before the stimulus is perceived. Similarly, after the light disappears, the impression of the stimulus remains active for another 150-250 ms.

The eye reacts to dynamic changes in the intensity of light, depending on the duration of the stimulus impulse. After short stimuli ($t < 20$ ms), we can observe the reaction of the eye proportional to the energy value of the light, i.e. the duration of the stimulus and the intensity of the light are equivalent, while the energy of the stimulus remains constant. When the duration of the stimulus increases ($t > 250$ ms) this replaceability disappears, and the perceived factor is the intensity of the light.

For many displays, the driving signal is a function variable in time, which causes periodical changes of luminance or contrast of the display. These changes can be perceived by the observer as a flickering of the picture – the information presented on the display. To eliminate this undesired situation, the frequency of the driving signal should be sufficiently high – higher than the minimal frequency at which the flickering is perceived. Sensitivity to flickering increases together with

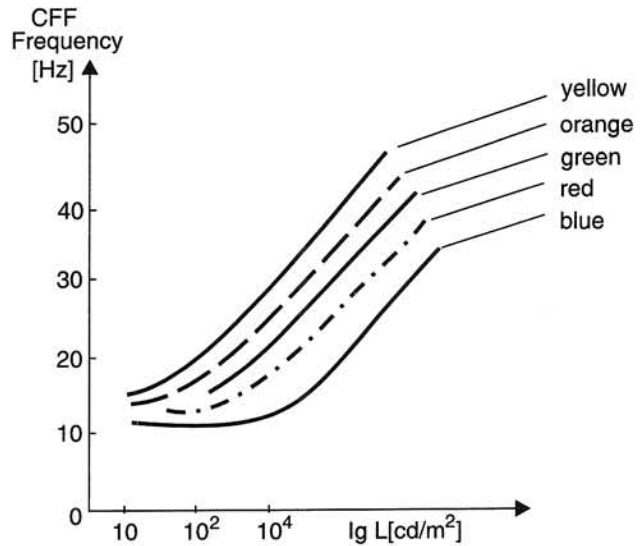


Fig. 4. Dependence of the critical flicker frequency, CFF, upon the luminance.

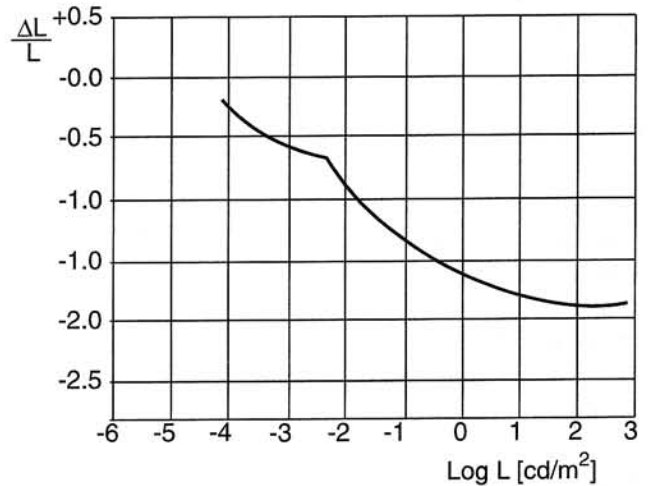


Fig. 5. Dependence of threshold sensitivity, $\Delta L/L$, upon the luminance of the object.

the luminance of the display and is strongly dependent upon the dimensions of the object and its position in the field of vision (for peripheral vision – with rods – sensitivity is higher).

When the vision system is stimulated by a series of stimuli with a particular frequency, the impression of constant stimulation can occur.

This state will occur at the critical frequency (CFF – Critical Flicker Frequency), above which we will observe constant stimulation. The value of the CFF is determined by the conditions of perception of the stimulus.

For an impulse of light with a decreased intensity we observe a decrease of CFF. For sight with rods

(peripheral vision – with the outer field of vision, at low levels of illumination) – we can notice flickering, which, in the centre of our field of view, seen with the area dominated by cones, we would perceive as stimulation of constant value.

The critical flickering frequency depends on the luminance and colour of the stimulus. In Fig. 4 the dependence between the flickering frequency and the luminance and colour of the stimulus has been shown. The CFF for a stimulus of a blue colour is a half of that of a yellow one with the same luminance.

Another very important phenomenon taking place in the vision system is quick disappearance of the impression of a stimulus when the eye is stimulated with a constant signal with a constant value, creating a picture on the stationary retina. Such a stationary situation causes the disappearance of the impulses of the nerve stimuli and a limitation of the perception of pictures. To eliminate this process, the eye makes a series of spontaneous movements (30 per second) – causing the image to shift into neighbouring areas of detectors on the retina.

Spatial resolution

The resolution ability of the vision systems is directly dependent on the density of receptors on the area of the retina. The maximum density of photoreceptors occurs on the fovea which covers an angular area of about 1 degree. Single receptors are about 1' away from each other and that constitutes the limit of spatial resolution. However, to discriminate between two points close to each other in an image, there should be two receptors stimulated, with one receptor between them, that is not stimulated, which determines the limits of defining points of an image as 3'. If the perceived image is in colour, then for its colour analysis on the retina, the participation of different types of receptors is required – which considerably decreases the resolution ability of the eye.

The maximum resolution in the eye occurs in the fovea. When the imaging point is shifted towards the edge of the eye, the resolution decreases rapidly. Five degrees away from the fovea, it equals 30% of the maximum resolution, and 20° away, it is only 10% of the maximum, hence the constant movements of the eyeball in order to place chosen objects of the image in the area of maximum resolution.

Recognizing the distance to the object (depth of space) is a result of many mechanisms at work – accommodation, convergence (the movement of the optical axes of the eyes towards each other while ap-

proaching an object), perspective, visual memory, dispersion, experience. Three dimensional vision is a result of minimal differences in the images perceived by eyes placed at a distance (about 65 mm) from each other, with parallax of approximately 2' – 4'. The turning of the eyes by the angle of convergence (to bring the optical axes of the eyes to the incoming object), causes an increase of tension of the eyeball muscles, which constitutes information about the distance to the object. A further mechanism carrying information about distance is the accommodation of the eye lenses.

Sensitivity of vision

The eye, as an instrument measuring the level of luminance is very inaccurate, and because of the influence of surrounding conditions – unreliable. However, it is a very precise tool for comparison – of the brightness or of colour of two objects side by side, or presented one after the other. Perception of details of the image – symbols, signs, etc. is dependent not only upon the difference in their brightness, but also on the illumination of the surroundings, the width of the beam of light falling on the retina, the colour of the surroundings, etc. The sensitivity of the eye to luminance – (to the contrast $\Delta L/L$ between the points of an image and the surroundings), increases together with the increase of luminance of the surroundings (to $L \sim 10$ cd/m²), to remain almost constant until luminance reaches $L \sim 10^3$ cd/m². In daylight vision ($L \sim 100$ – 500 cd/m²), the eye is capable of perception with a maximum sensitivity of $\Delta L/L \cong 0.01$, while for a decreasing level of illumination (scotopic range) the contrast required for perception increases quickly. For a level of luminance 10^{-4} cd/m², for proper perception, the difference of luminance must be at least 55% of the luminance of the background (see Fig. 5).

The dependence $\Delta L/L = C$ (Weber-Fehner's law) is an approximated description and is used only in a narrow range of average luminances. For luminances above 10 cd/m², the eye is able to perceive, in neighbouring areas, differences of luminance smaller than 5%, i.e. elements with a contrast ratio of $CR = 1.05$. These extreme values are strongly dependent upon the size of the testing area (the pixel).

Stimulation of the vision with a stream of light quantitatively defined by the value of its **luminance** causes a psychophysical reaction – called **brightness** – which is an impression dependent on the parameters of the stimulation (luminance) and also on the conditions of the experiment – i.e. the duration of observation, the

distribution of luminance in the whole field of view, the luminance prior to the observation (adaptation), the colour of the objects, the background, and the state of stimulation of the nerve system. The relation between brightness and luminance is given

$$B = k (L - L_0)^n$$

k = constant,

L_0 – threshold luminance

n – exponent/index dependent on the adaptation of the eye

$n = 0,33$ – an eye adapted to darkness

$n = 0,44$ – an eye adapted to $L \sim 3000 \text{ cd/m}^2$.

Spectral sensitivity of vision

The vision system is characterized by very good sensitivity in perceiving differences in colours (comparing), while, at the same time, its ability to quantitatively define colours is very limited.

Measuring the dependencies of sensitivity of cones and rods in function of wavelength, can show the functions of the spectral sensitivities of both mechanisms of perception.

The differences in the values of the threshold intensities and a mutual shift of spectral layouts, presented in Fig. 6 characterize the spectral characteristics of vision for various levels of luminance.

This phenomenon causes the vision system to show

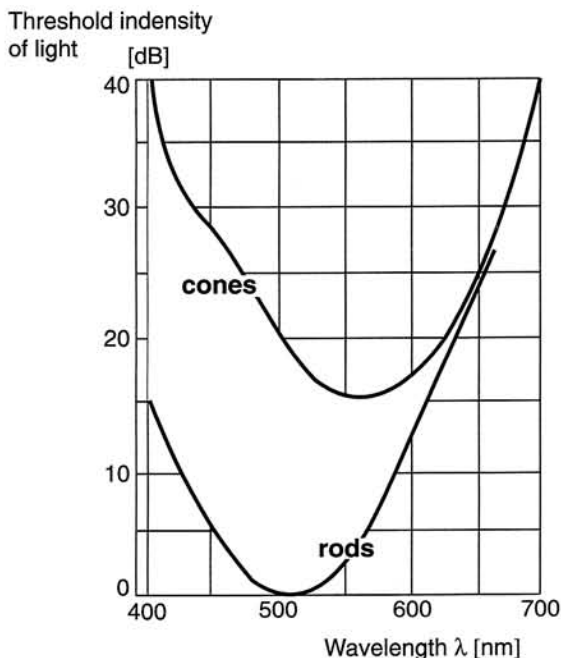


Fig. 6. The spectral function of threshold intensity of light.

Luminous efficiency

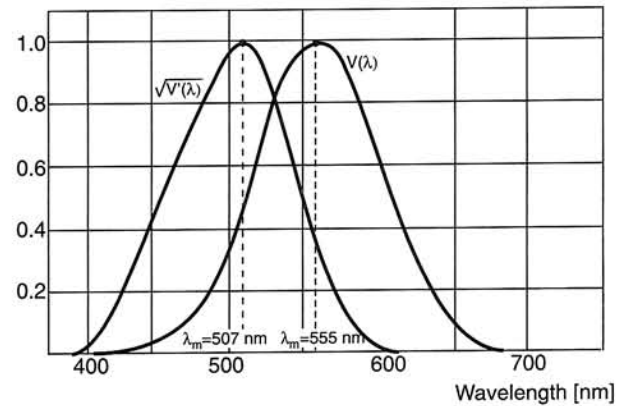


Fig. 7. The function of relative light efficiency.

various threshold and spectral sensitivities, depending on the surrounding conditions (illumination). Depending on the luminance of the stimulus (and the adaptation of the eye to that level), we discriminate three ranges in the vision process:

- night vision (scotopic) $\sim 10^{-3} \text{ cd/m}^2$
- intermediate vision ($10^{-3} \div 3 \text{ cd/m}^2$)
- day vision (photopic) above 3 cd/m^2

For day vision (photopic) the spectral luminance efficiency function has a maximum at 555 nm and the spectral efficacy coefficient is equal $K_m = 683 \text{ lm/W}$.

In night vision conditions, perception takes place with the use of rods. Colour objects are perceived as achromatic (grey). Maximum sensitivity of the function of spectral sensitivity $V'(\lambda)$ occurs at 505 nm (Fig. 7) – calibration coefficient – spectral efficacy coefficient $K'_m = 1700 \text{ lm/W}$. For the eye completely adapted to darkness, (after 0,5 hour), rods are able to register stimuli with a minimal luminance of $\sim 10^{-6} \text{ cd/m}^2$. Once the level of luminance exceeds $\sim 125 \text{ cd/m}^2$, the rods cease to take further part in the process of perception.

In the intermediate range (between photopic and scotopic vision), we observe an overlapping of these "mechanisms" of vision. Together with a decrease of intensity of stimuli and conditions determining the adaptation of the eye – there occurs a gradual loss of perception of colours, beginning from red through orange and yellow. An example of the change of colours connected with changes in the intensity of light is Purkinj's phenomenon – relying on different perception of colour stimuli (e.g. red and blue) depending on the eye's state of adaptation. For stimuli perceived identically in conditions of day vision, [photopic function $V(\lambda)$], together with a decrease of illumination, and a transition to night vision [scotopic – function V'

(λ), the blue stimulus ceases to be perceived as brighter than the red one. The process of perception of colour by humans is a complex one, in which physical, chemical, physiological and psychological effects take part, leading to a complex impression of colour by the human when subjected to a stimulus of radiation with a particular spectral content.

In the action of the vision system, we notice a series of circumstances complicating an unambiguous, quantitative description of colour impressions, e.g. colour information presented on displays. These are:

adaptation to brightness	– adaptation of vision to the level of illumination
adaptation to colour	– a decline of perception of differences in colour impressions of identical spectral characteristics, and observed one after the other in different (spectral) illumination conditions.
consecutive colour contrast	– appearance of temporary after-images of a colour complementary to that of the stimulus perceived before
simultaneous colour contrast	– differences in colour impressions of spectrally identical objects lighted by the same (spectrally) source, but placed in surroundings of different colours.
contrast of simultaneous luminance	– testing fields with identical luminance are perceived differently – depending on the luminance of the background. Of two identical fields, the one surrounded by a darker background is perceived as brighter.

- Colour is characterized by three attributes:
- quantitative – luminance [cd/m^2]
 - chromaticity
 - hue
 - saturation

The hue attribute of a colour perception denoted by blue, green, ... and so on, – a feature of the vision impression causing the colour of the observed stimulus to be similar to one of the perceived colours (e.g. red, yellow or green), or a combination of them.

Saturation is the attribute of a visual sensation which permits a judgment to be made of the degree to which a chromatic stimulus differs from an achromatic stimulus regardless of their brightness.

For a quantitative analysis of the features of colour objects there are methods of colorimetric analysis, together with standards of measurement procedures proposed by the CIE (Commission Internationale d'Eclairage).

These methods allow for the definition of quantitative parameters of colour objects, the results of additive or subtractive mixing of colours – synthesis of colours, the differences between colours of objects.

3. Optoelectronic displays

3.1. Classification of displays

Displays, as elements of data imaging, are a very broad group of electronic elements, from huge elements for presenting colour information in stadiums, to miniature monitors in specialized medical technology (endoscopy, etc.), from large information boards, to monitor and portable laptop screens, and systems of image presentation in Virtual Reality.

Depending on the place and method of image creation, displays can be divided into three groups (Fig. 8):

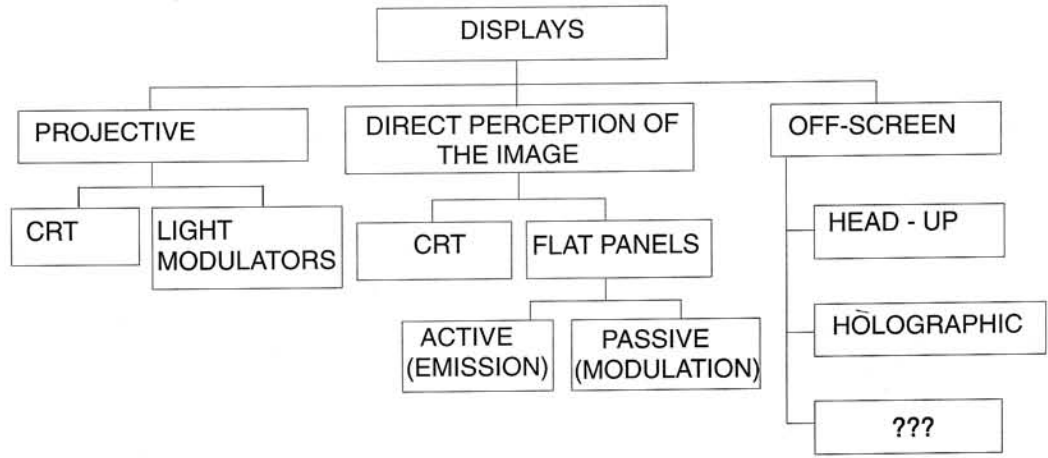


Fig. 8. Classification of displays.

Table 1. Characteristic parameters of flat display panels.

DISPLAY	PASSIVE	ACTIVE				
	LCD	PDP	EL	VFD	LED	CRT
U _s (V)	A.C. 2-5 MUX12 – 20	AC/DC 90 – 250	A.C. 160 – 220	D.C. 12 – 40	D.C. 2 – 5	10-30 × 10
I _s	1-10 μA/cm ²	1 – 10 mA/cm ²	1 – 10 mA/cm ²	~X mA/cm ²	~10 mA/cm ²	X0 – X00 mA
Cr	~10 – 50	~30	~40	~50	~40	
t	30 – 150 ms	10 – 20 μs	~100 μs	~10 μs	< μs	1 μs
L (cd/m ²)		90 – 170	60 – 100	360 – 400	~150	100 – 300
η (lm/W)		0,3 – 0,1	0,3 – 1,5	~10	0,1 – 1,5	10C/30M
COLOUR	B/W Full colour	Red-orange Red-orange etc + Full colour	Yellow-orange etc.	Green etc. + multi colour	Red-orange, yellow, green, blue	Full colour Monochr. B/W
MEMORY	+	+	+	–	–	±

– projective displays – with direct perception of the image, and – off screen displays.

In the process of optical processing of information, optoelectronic elements are used, in various versions (Fig. 9.)

The largest group consists of displays, among which two types can be drawn: active – emitting light, and passive – modulating light created in an external source. The most popular and most widely used are collected in Fig 9 and in Table 1.

Displays use various physical or chemical phenomena as the basis for their operation.

In a very large group of active displays, the most numerous are those, whose operation – emission of light is based on the phenomenon of luminescence

(cathodoluminescence, electroluminescence, electrical discharges in gases etc.).

In the group of passive displays which modulate the stream of light, the dominating role is played by liquid crystal displays in which anisotropic features (optical and electrical anisotropy) of liquid crystal mixtures are applied. During the last 25 years, there has taken place, and still is, rapid development of new technologies of construction and production of liquid crystal displays. The basic advantage of LCD displays is control by means of an electric field (very low driving power, small amplitudes of signals), which is why LCD displays have found many uses – from portable panels of colour laptops to TV projective systems. Among many types of LCD displays (Fig. 10) each one is charac-

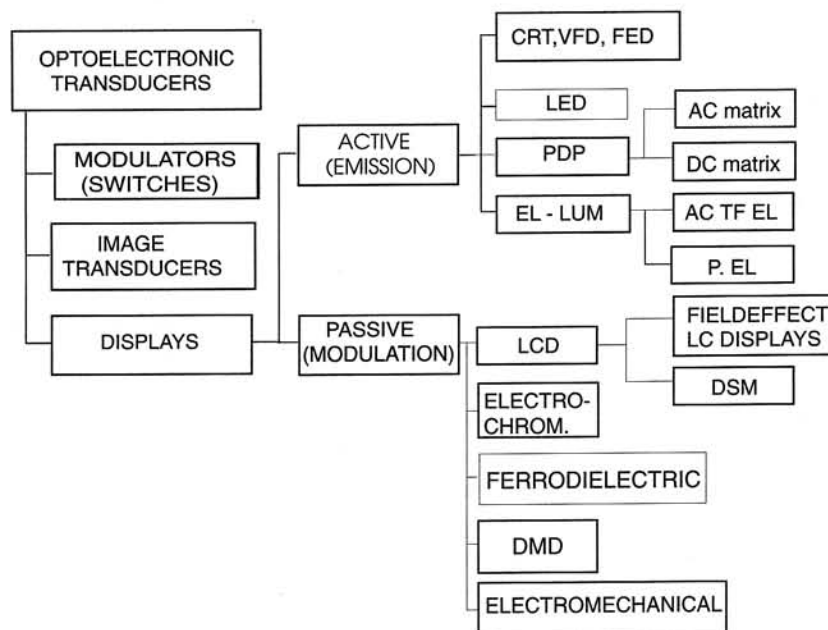


Fig. 9. Types of electronic displays.

terized by unique features, that make it possible to select the optimal LCD display module for the requirements and limitations resulting from the usage.

The displays, depending on their type, allow for the creation of the following images:
achromatic – B/W (black/white)

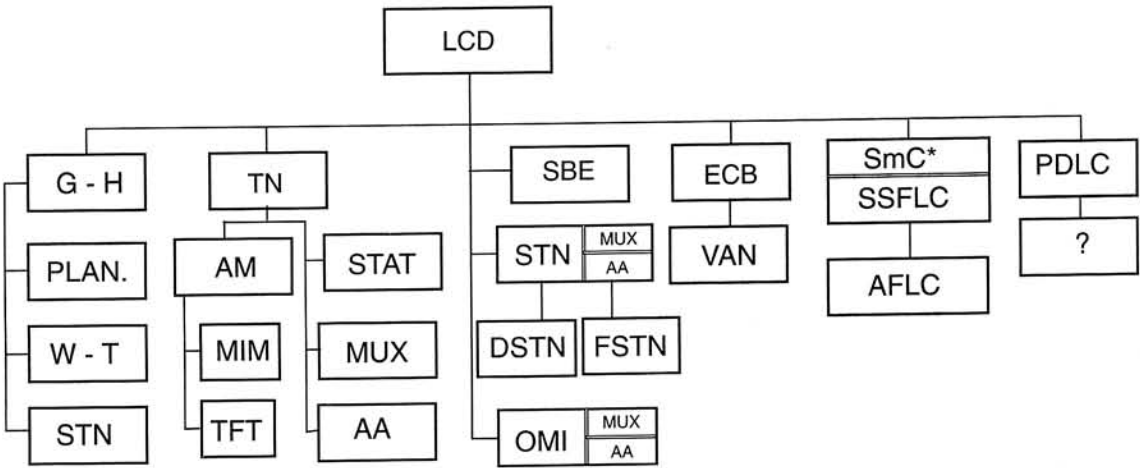


Fig. 10. Classification of liquid crystal displays.

- G – H** guest-host
- PLAN.** Planar Texture
- W – T** LCD phase change
- PDLC** Polymer Dispersed Liquid Crystals
- AC** Active Matrix
- AA** Active Addressing
- SmC** smectic Liquid Crystals (chiral, ferroelectric)

- monochrome
- polychrome
- full colour

The optical characteristics of achromatic or monochrome displays are rendered by the parameters:

- luminance – L [cd/m^2] / reflectance
- the contrast ratio

$$CR = \frac{\text{MAX}(L_{ON}, L_{OFF})}{\text{MIN}(L_{ON}, L_{OFF})} \qquad 1 \leq CR \leq \infty$$

- contrast

$$C = \frac{\text{ABS}(L_{ON} - L_{OFF})}{\text{MAX}(L_{ON}, L_{OFF})} \qquad 0 \leq C \leq 1$$

For polychrome or colour displays, colour difference ΔE can be used as a parameter quantitatively describing the display. ΔE is defined in the CIE LUV 1976 colorimetric system:

$$\Delta E = [\Delta L^2 + \Delta U^2 + \Delta V^2]^{\frac{1}{2}}$$

where: L, U, V are the differences between the colorimetric parameters of the ON and OFF states in the space of the CIE LUV 1976 Colorimetric System.

3.2. Parameters and characteristics of electronic displays

In development trends among displays, a large group consists of flat display panels finding use as computer monitors, TV sets, measurement systems, interactive systems of information presentation, etc.

Depending on the physical principle of their operation, they are characterized by various parameters and features presented in Table 1.

The controlling parameters are: voltage, U_s , and current, I_s of the command signal.

The optical parameters are characterized by the contrast ratio, CR , contrast, C , luminance or reflectance.

The display dynamics, i.e. the speed of switching between the ON and OFF optical states is characterized by the switching time t (t_{ON} , t_{OFF} , t_d – delay).

The size of the stream of light emitted from an image point (pixel) of an active display is characterized by the luminance value L , and energy conversion efficiency η (lm/W).

4. Ergonomics of information presentation

Information presented to the operator is coded:

- in shape – in the form of a pixel or segment,
- in the way the elements of an image are organized,
- in the size or variance of brightness (luminance) of an element of the image,
- in the type or variance of colour of an element of the image.

The correct choice of the coding method allows for considerable shortening of the time necessary for the operator to perceive and process the information, and minimizes the chance of mistakes in its interpretation.

Coding in shape – the form of the symbol – has the advantage of an almost unlimited set of symbols that can be used in encoding. One should, however, bear in mind that without putting the operator through special training, the use of more than 15 symbols misses the point. The coded symbols should allow for direct interpretation, creating associations with the values they represent, and be easily distinguishable. Encoding information in the shape and size of symbols is the simplest and most commonly used method. Use of colour as an element of coding should be limited to technically unambiguous and justified cases. Instances of the free use of colour as a "decorative" element in the display image must be avoided. An overabundance of colours, their number and ambiguity, will cause an effect opposite to that desired – it will distract the operator, confuse perception and the execution of activities resulting from the information presented. Colour codes should be subordinated to generally accepted rules assigning semantic domains to colours (red – hot, danger, hazard; blue – cold, quiet, stable, etc.).

One should also bear in mind that about 8% of men and 4% of women suffer from a deficiency in the perception of colours!

Coding in intensity – the flashing frequency of a segment should be limited to warning signals, that attract attention. No more than three levels of flashing frequency should be used (1.0, 2.5, 5.0 Hz).

Analyzing the methods of coding, one can combine optical coding with additional sound signals, increasing the probability of the operator's proper reaction.

In the presentation of a high density stream of information, the information must be structured, i.e. its presentation must be organized, whether in parallel form (where many symbols presented simultaneously, or partial images are presented on the display, as on a control panel of a car, or of a control room) or in

sequential form (i.e. where the information is presented to the operator in the order determined by the priorities). Selection and combination of information allows us to limit the data passed to the operator, to those which are really needed in a given situation. The possibility to make a structure (in a hierarchical type organisation – menus) allows the operator to interfere (interactive operation) in the stream of the information presented, and, at the same time, ensures that information of maximum priority is presented, in accordance with the strategy assumed by the designer of the visualization system.

While creating a system, one must take into account the principles of ergonomics, i.e. ensure the compatibility of the system's construction with the anthropotechnical working conditions of the operator, and with the form of information and visualization coding.

For example, the directions of the indications of value changes should be identical for all variables (indicators) in the operator's field of view, the size and form of the fonts should be adapted to the resolution of the operator's eyesight in the given working conditions, etc.

For a normal viewing distance (~25 cm), the dimension of an individual element of the image (distinguishable from the neighbouring ones) should be larger than 0,075 mm (300 dpi). The minimum size of the signs should be approximately ~25 mm.

Together with an increase of the operator's distance from the display panel, the size of the symbol or font necessary to ensure good legibility – also increases. For the presentation of digital information, a seven-segment symbol is used most often.

Together with an increase of requirements – presentation of alphanumeric information (digits and letters of the alphabet) – more complex symbols and fonts are used – from symbols made from 5×7, 5×9, 7×9 and 7×12 pixel matrices, through 14 – and 16 segment symbols, to special groups of symbols with 110 segments.

A very important factor is the configuration of the display with regard to the operator – ensuring optimal working conditions and taking into account the proper organisation of a workplace – a sufficient level of illumination of the surroundings, securing a possibly constant level of vision accommodation for the operator who will often shift his or her sight from the display to other media of information (paper) or to the surroundings. It is also important to ensure angle ranges of the field of view that will not require unnecessary head or body movements.

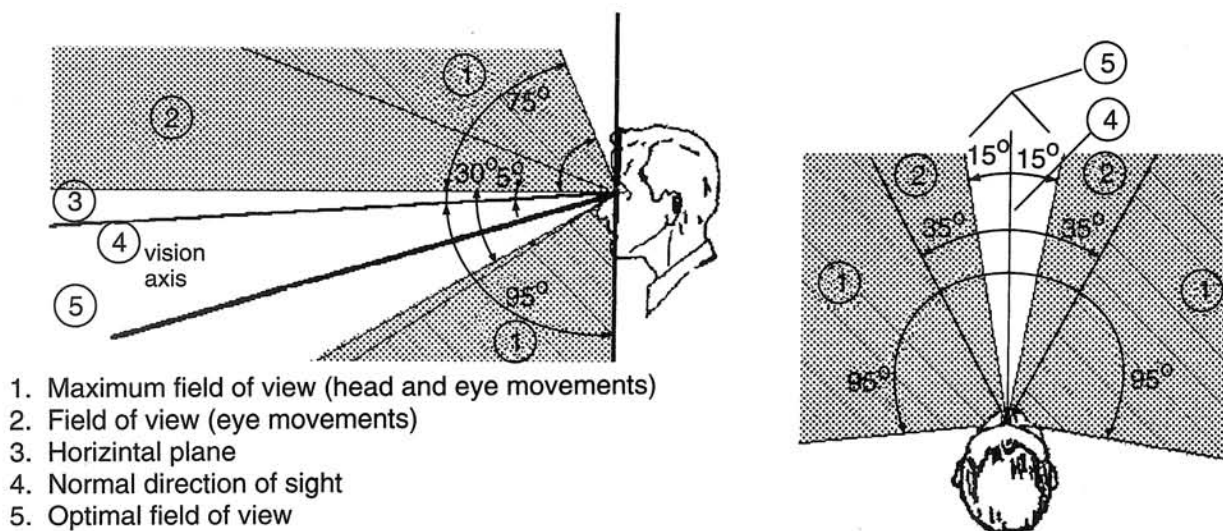


Fig. 11. Optimal angle ranges of the operator's field of view.

The angle area with the highest eye resolution is very narrow and covers an angle of about 1 degree. In order to expand the range of perception of image details, the eye makes movements shifting the axis of optimal vision. To limit eye tiring, the range of eye movements forced by the construction of the display system, should not exceed 15° .

Any further expanding of the operator's angular area of perception takes place through head movements, which should not exceed $\pm 60^\circ$ in a horizontal plane, and $\pm 40^\circ$ vertically.

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