

Description

The invention relates to an image projection system comprising at least one display tube and a multi-element projection lens system for imaging a display tube picture on a projection screen, said display tube comprising a display screen in an evacuated envelope, the display screen being arranged on the inside of a display window in the wall of the envelope and being provided with a luminescent material, a multi-layer interference filter being arranged between said material and the display window. The invention also relates to a projection device provided with such an image projection system.

A display tube with interference filter is described in European Patent Application No. 0.170.320 which also describes that this tube can be used advantageously in a television projection system. As is described in the said Patent Application the use of an interference filter consisting of a large number of layers, for example fourteen to thirty, may considerably improve the display tube properties regarding the intensity distribution within and the monochromaticity of the beam emitted by the tube. The interference filter passes light of the desired wavelength in the direction perpendicular to the display screen and in directions which extend at angles of, for example 30° at a maximum to the normal on this screen. These directions may be designated the forward directions. Light emerging from the luminescent layer at larger angles to the normal, up to approximately 90° , is reflected to this layer by the interference filter. This light is dispersed within the luminescent layer and is then emitted in the forward directions so that the brightness in these directions is enhanced.

The light of wavelengths shorter than the desired wavelength is passed by the filter also at larger angles, so that for these wavelengths the gain in intensity in the forward directions is smaller than that for the desired wavelength. For wavelengths which are larger than the desired wavelength, the maximum angle at which the light passes through the filter is smaller than that for the light of the desired wavelength and the filter can even completely block the larger wavelengths in the forward directions. The interference filter therefore not only ensures that the emitted light is concentrated into a smaller solid angle thus enabling the amount of light received by the projection lens system to increase but it has also a wavelength-selective effect so that the risk of chromatic aberrations in the projection lens system is reduced and the projected image may have a better contrast.

It has been found that satisfactory results can be achieved when using display tubes provided with an interference filter in projection systems if such tubes are combined with projection lens systems having relatively larger focal lengths, for example of the order of 130 mm. For such a projection lens system the entrance pupil is at a relatively large distance from the display screen of the tube. The entrance pupil is defined as the image of the physical boundary or "stop" in the lens system, which image is formed by the lens elements which are present at the object end of this boundary. The entrance pupil is located at the position in which the chief ray of a beam obliquely incident on the lens system intersects the optical axis of this system. If the entrance pupil is located at a relatively large distance from the display screen of the tube, the field angle of the projection lens system is relatively small so that only the light emitted by the display tube in the forward directions is received by the lens system.

Within the present Patent Application the object or image field angle is to be understood to mean the angle between the optical axis of the lens system and the chief ray of a beam originating from the corner of the object and a beam being directed onto the corner of the image, respectively, which beam passes through the lens system with a still acceptable vignetting. The corner of the object is the end of a diagonal of the image written on the display window of the picture display tube. The corner of the image is the end of the diagonal of the picture formed on the projection screen.

In connection with the increasing demand for projection systems, notably colour television projection systems which can be accommodated in a cabinet having a smaller volume there is an increasing need of a projection lens system having a relatively small focal length, for example smaller than 80 mm because then the overall required optical path length from the display tube to the projection screen is also relatively small. Decreasing the focal length of a projection lens system in a projection system will generally result in that the entrance pupil of the lens system will be located closer to the display screen of the display tube. This means that the object field angle becomes larger and that notably in the corner of the display window light which is emitted in the non-forward directions is received by the projection lens system and thus reaches the projection screen. The picture on the projection screen observed by the viewers then exhibits a variation in brightness from the centre of the picture to the edge thereof. This is a result of the fact that the interference filter in the display tube reduces the amount of light in the non-forward directions. This first variation in brightness is still augmented by a second type of brightness variation which is caused by the larger angle at which the chief ray of a beam originating from the corner of the display tube passes through the projection lens system and by vignetting at the lens elements.

A second result of increasing the field angle is that a colour shading occurs on the projection screen due to the colour-selective effect of the interference filter in the display tube. In this case the colour shading implies that there is a shift to shorter wavelengths, thus to blue, from the centre of the projection screen to the edge.

In order to eliminate the problems of brightness variation and colour shading it could be considered to arrange an interference filter in the display tube which passes light of the desired wavelengths also at larger angles. However, there will be a considerably smaller gain in brightness while moreover colour shading will still occur.

The present invention has for its object to improve the image projection system described in the opening paragraph by eliminating the said drawbacks while maintaining the advantages of the use of an interference filter in the display tube and even making better use thereof.

The image projection system according to the invention is characterized in that a first lens element of the projection lens system, viewed from the image end, i.e. from the projection screen, is constituted by a positive lens element having a first refractive aspherical surface facing the image end and a second refractive surface facing the object end, i.e. the display screen, which surface is convex and whose centre of curvature is located in the image end half of this lens element, in that the projection lens system comprises at least a second lens element having a negative power and whose surface facing the image end is concave and whose surface facing the display tube has a curvature which is substantially similar to that of the display window and in that the entrance pupil of the projection lens system viewed from the projection screen is located in the image end half of the first lens element.

The projection lens system has a relatively small focal length, for example 78 mm or 90 mm whilst in addition the field angle as defined in the foregoing is small. In principle the first lens element can ensure that, with the field angle at the image end remaining equal, the field angle at the object end is reduced by a factor which is equal to the refractive index of the material of this element. Viewed in the reverse radiation path, hence from the projection screen to the display tube, the first lens element may form an intermediate image which exhibits substantially no coma and astigmatism.

To reduce the spherical aberration in the intermediate image, the first refractive surface of the first lens element, i.e. the surface directed towards the projection screen, is aspherical.

This projection lens system is further preferably characterized in that the aspherical surface of the first lens element, viewed from the image end, is convex in a zone around the optical axis and is concave outside said zone.

At the reduced field angle the further imaging in the reverse radiation path, with the beam already rendered converging by the first lens element, can in principle be realized by means of only the second, concave lens element. This element may be referred to as field curvature correction lens element or field flattener. The concave surface of this lens element may be aspherical.

A projection lens system having a first and a second lens element only is further preferably characterized in that the second refractive surface of the first lens element is aspherical.

The remaining aberration in the image formed can then be reduced.

A preferred embodiment of the image projection system is, however, further characterized in that a third bi-convex lens element supplying a part of the overall optical power of the projection lens system is arranged between the first and the second lens element. The optical power of the third lens element is preferably approximately equal to that of the first lens element.

By addition of the third lens element the numerical aperture can be increased and aberrations can be reduced, whilst the focal length remains equal. In this embodiment of the projection lens system the physical pupil is located closer to the centre of the first lens element in order to prevent vignetting but this pupil is still located in the first portion, i.e. in the image end half, of this lens element.

A first embodiment of the projection lens system comprising three lens elements is further characterized in that the surface of the third lens element facing the image end is aspherical. This contributes to a reduction in aberrations of oblique beams in the projection system.

A second embodiment of the projection lens system comprising three lens elements is characterized in that the surfaces of the first and third lens elements facing the object end are aspherical. This projection lens system thus has four aspherical surfaces.

The most preferred embodiment of the projection lens system is characterized in that the first lens element has a third surface which is reflective and substantially directs all rays of radiation from the second towards the first refractive lens surface.

This first lens element may be designated as a folded lens element. The optical path length in this lens element is equal to that in a lens element which is twice as thick, but the required quantity of optically high-grade lens material and consequently the weight amount to only half that of the corresponding thick

lens element. In addition the reflecting surface changes the direction of the imaging beam in such a way that the radiation path of this beam can be folded in an optimum manner while maintaining the overall optical path length so that the projection system can be accommodated in a cabinet of relatively small volume.

5 It is to be noted that United States Patent No. 4,526,442 describes a projection lens system having a reflecting surface. However, in the known system the reflector is arranged between the first and the second lens element and this reflector does not form part of the first lens element. Moreover, the known projection lens system has a relatively large focal length.

Optimum use is made of the inventive idea in an image projection system which is further characterized
10 in that the display window of the display tube, viewed from the image end, is concave and has an angle of curvature ϕ wherein ϕ is the angle between the normal in the centre of the display window and a line perpendicular to the edge of the display window, which angle ϕ has a value in the range between 5° and 25° . By using a concave display window the design of the projection lens system can be simplified. The concave shape of the display window ensures an increased concentration of the radiation of the display
15 tube in the direction of the entrance pupil of the projection lens system and hence a better light distribution across the projection screen is obtained. By combination of a concave display window and an interference filter in the display tube an improvement of the projected image is obtained which is greater than the sum of the improvements obtained by the separate use of the concave display window and the interference filter, respectively.

20 The concave display window need not be spherical but may have a different shape, for example an aspherical shape.

It is to be noted that it is known per se from British Patent Application No. 2,091,898 to use a concave display window in order to be able to simplify the design of the projection lens system. However, this Patent Application does not reveal that the light output, notably in the corner of the display window, can be
25 considerably increased by combination of a concave display window and an interference filter between this display window and the luminescent material.

The invention may be used in a projection system with one display tube for forming, for example a black-green image on the projection screen.

The greatest advantage of the inventive idea can be achieved when using it in a colour picture
30 projection device. An embodiment of such a device, which has three separate colour channels which converge on a common projection screen and which are each provided with a display tube and a projection lens system, is characterized in that at least one of the colour channels is provided with an image projection system as described above.

The use of the inventive idea is most desirable in the green channel, because the electron current in
35 the display tube must be large for this channel in order to obtain the desired light intensity. However, the combination of the interference filter and the projection lens system according to the invention may also be arranged in the red channel and possibly in the blue channel.

The invention will now be described in greater detail with reference to the accompanying drawing in which

40 Figure 1 is a diagrammatic perspective view of an embodiment of a colour picture projection device provided with three image projection systems according to the invention,

Figure 2 is an elevational view, partly broken up, of a display tube for image projection,

Figures 3 and 4 are partial cross-sections of display tubes having straight and curved display windows, respectively, and an interference filter,

45 Figure 5 diagrammatically shows the composition of the interference filter,

Figure 6 shows different spectra of radiation emitted by a green phosphor display tube,

Figure 7 shows the basic shape of the first lens element of the projection lens system according to the invention,

Figure 8 shows a first embodiment of the projection lens system according to the invention,

50 Figure 9 shows a second embodiment of this projection lens system,

Figure 10 shows the preferred embodiment of this system,

Figure 11 shows the magnitude of the angle of acceptance as a function of the focal length of the projection lens system in projection systems having a conventional and the novel projection lens system, respectively.

55 Figures 12 and 13 show the difference in brightness variation across the projection screen when using a conventional and the novel projection lens system, respectively, for two different focal lengths.

The colour television projection device of Figure 1 includes a colour television receiver 1. An input of this receiver which is coupled to, for example an antenna 2, receives a colour television signal which is split

up into a red, a green and a blue signal. These signals are applied to three separate display tubes 3, 4 and 5 whose display windows show a red, a green and a blue picture. These pictures are projected on a projection screen 10 by the projection lens systems 6, 7 and 8 shown diagrammatically and associated with the separate tubes. For the sake of clarity only the chief rays of beams imaging a point of a display window on a point of the projection screen are shown. The radiation emitted by each display tube and passing through the associated projection lens system covers the entire projection screen 10. A mirror 9 reflecting the beams emerging from the projection lens systems to the projection screen is arranged between the projection lens systems and the projection screen. This mirror folds the radiation path so that the projection system can be accommodated in a cabinet having a relatively small depth without having to shorten the radiation path.

The three single-colour pictures must be superimposed on the projection screen. To this end the aligned display tubes are slightly bent towards each other, that is to say the normals on the screens of the tubes 3 and 5 extend at a small angle to the normal on the screen of the tube 4.

In the projection screen 11 the radiation of the three beams is dispersed over a relatively large angle in the Y-direction, that is to say in the horizontal direction for the viewer W, while in the Z-direction, the vertical direction for the viewer W, the radiation is dispersed through a smaller angle. The viewer W sees a picture which is the superimposition of the magnified pictures of the display tubes.

Figure 2 shows one of the display tubes 4 in a perspective view in which a part of the glass envelope 20 is broken away. The glass envelope constitutes a display window 21 on the front side and comprises a cone 22 and a neck portion 23. A luminescent screen not shown in Figure 2 is provided on the inside of the display window and an electron gun 24 is arranged in the neck of the tube. A system 25 of deflection coils around the neck of the tube ensures that the electron beam scans the luminescent screen in two mutually perpendicular directions Y and Z. The electrical connections to the receiver are established by means of connection pins 27 in the base 26.

Figure 3 and 4 show cross-sections of a flat display window 21 and a display screen 27, and of a concave display window 21' and a display screen 27', respectively. The insets in these Figures show the display windows 21 and 21', the multilayer interference filters 28 and 28' and the display screen 27 and 27', respectively. The display screen consists of a layer of luminescent material, a phosphor 29 and 29' respectively and a thin aluminium film 30 and 30', respectively, the so-called "aluminium backing".

The curved display window of Figure 4 has an angle of curvature ϕ and is preferably spherical with a radius of curvature ρ . The display window may be alternatively aspherical, for example.

The interference filter is diagrammatically shown in Figure 5. This filter comprises a large number of layers, for example, twenty alternately having high (H) and low (L) refractive indices. These layers are approximately $0.25 \lambda_1$ thick at an average in which $\lambda_1 = p \cdot \lambda$ where λ is the desired central wavelength which is selected from the spectrum emitted by the luminescent material and where p is between 1.18 and 1.32. The layers L comprise, for example SiO_2 having a refractive index $n = 1.47$ or MgF_2 having a refractive index $n = 1.38$. The layers H may comprise TiO_2 with $n = 2.35$, Ta_2O_5 with $n = 2.00$ or Nb_2O_5 with $n = 2.15$. The last layer 32 on the side of the display screen 27 is covered with, for example a $0.125 \lambda_1$ thick separation layer 31 having a low refractive index.

For further particulars of the interference filter and embodiments thereof reference is made to the European Patent Application No. 0,170,320 in the name of the Applicant. As is described in this European Patent Application, the provision of the interference filter has the advantages that

- the quantity of light which is emitted by the display tube within a given solid angle which may be, for example 25° but also 40° can be, for example 40% to 50% larger than in the case of a display tube without such a filter and
- the intensity of the desired wavelength is increased at the expense of that of the unwanted wavelengths, so that the beam emitted by the tube becomes more monochromatic.

For a projection system as a whole these advantages result in:

- a greater brightness on the projection screen,
- an improvement of the colour in the picture on the projection screen, particularly noticeable in the green colour in the case of a colour picture projector,
- less chromatic aberration in the projection lens system, particularly noticeable in the green and blue channels in the case of colour picture projection and
- a better contrast in the picture on the projection screen.

For the purpose of illustration Figure 6 shows by way of example the spectra emitted by the green display tube under different circumstances. The luminescent material of this tube is a phosphor of the composition YAg:Tb . The curve 6A shows the spectrum which is emitted if no interference filter is present in the display tube. The curves 6B to 6E show the spectra which in the presence of an interference filter are

emitted in the directions which extend at angles of 0° , 15° , 30° and 45° respectively, to the normal on the display window. A comparison of the curves 6A and 6B shows that the interference filter enhances the brightness of the desired spectral range in the direction perpendicular to the display window, whilst the brightness of the spectral line at 545 nm is enhanced in comparison with the other, blue spectral line at wavelengths of less than 500 nm. These advantages are maintained for directions which extend at angles up to a maximum of 30° to 35° to the normal on the display window as is shown in Figures 6c and 6d. Curves analogous to those of Figure 6, but of course with different spectral lines apply to the blue and the red display tubes. For directions at angles of more than 30° to 35° to the normal the brightness of the green spectral line decreases in Figure 6, whereas that of the blue spectral line remains approximately equal as is shown in Figure 6 by the curve 6E which applies to a direction at 45° to the normal on the display window.

In order to prevent that colour shading occurs across the projection screen due to the relatively larger contribution of the blue spectral line with respect to the green spectral line and to prevent the brightness decreasing to a considerable extent from the centre of the projection screen to the edge thereof due to the decrease in brightness of the green spectral line, it is ensured according to the invention that light which is emitted at angles of more than 30° to 35° to the normal on the display window is not received by the projection lens system. A projection lens system is provided which has a small field angle at the object end, whilst the focal length is also small.

The principle of the first lens element L_1' of the projection lens system is shown in Figure 7, which element is the result of a novel concept in the design of projection lens systems. In this novel concept the starting point is a thick plano-convex lens L_1' in which the centre of curvature M of the convex lens surface S_3' is located on the flat surface S_1' . Although in the projection system the rays extend from right to left, the ray path in Figure 7 is shown from left to right. This inversion is permitted in this type of optical systems and is used here because it simplifies the insight into the operation of the system. The beam b_1 shown in Figure 7 is an imaginary beam which originates from the centre of the projection screen. Due to the relatively large distance between the lens element L_1' and the projection screen the beam b_1 is only slightly diverging. This beam whose chief ray coincides with the optical axis $00'$ of the lens element L_1' is converged in the point F_1 on the optical axis. The reference symbol b_2 denotes a likewise imaginary, slightly diverging beam which originates from the edge of the projection screen and passes through the lens element L_1' with a still acceptable vignetting. The chief ray of this beam intersects the optical axis in the point M. For this lens element the pupil PP' , the entrance pupil viewed from the projection screen, and the exit pupil viewed from the image source, is therefore located at the area of the first refractive surface S_1' of the lens element L_1' . The chief ray of the beam b_2 is perpendicularly incident on the convex surface S_3' and passes this surface without refraction. The peripheral rays of the beam b_2 are refracted towards the chief ray by the surface S_3' so that the beam b_2 is focussed in the point F_2 .

By using a lens element L_1' in accordance with Figure 7 in a projection system, it is achieved that the field angle at which the edge of the projection screen is viewed by the elements of the projection lens system located between the image source and the lens element is reduced. The field angle is the angle α at which the chief ray of the beam b_2 incident on the surface S_1' intersects the optical axis. After refraction by this surface this chief ray extends at an angle β to the optical axis. The field angle reduction is given by

$$\frac{\sin \beta}{\sin \alpha} = \frac{n_1}{n_2}$$

wherein n_2 is the refractive index of the lens material and n_1 is that of the surrounding medium. If this medium is air for which $n_1 = 1$ the field angle is reduced by a factor which is approximately equal to n_2 .

For this reduced field angle and the convergence of the beams brought about by the lens element L_1' the further imaging may be realized with only several simple additional lens elements. In certain uses it would be sufficient to use only a concave lens L_3 as shown in Figure 8. This lens element is the field curvature correction lens or "Field Flatteners". The concave surface of the lens element L_3 is denoted by S_6 in Figure 8. The curvature of the second surface S_7 of the lens element L_3 is adapted to that of the display window FP of the display tube not further shown. In the embodiment shown in Figure 8 this display window and thus also the surface S_7 is concave as viewed from the image end.

A plate-shaped holder CP may be arranged between the display window FP and the surface S_7 of the lens element L_3 . A coolant comprising, for example water and glycol flows through this holder. Such a cooling is desired in connection with the fact that the display tube must have a high brightness and without

cooling the temperature of the luminescent material which is provided in the display screen behind the display window could increase considerably so that the brightness of the tube could decrease.

The lens L_1' may form an intermediate image which is diagrammatically shown in Figure 7 by the points F_1 and F_2 , which image has substantially no coma and astigmatism but is still beset with spherical aberration. This aberration may be reduced by giving the first surface S_1' of the lens element L_1' an aspherical shape. In order to realize a further reduction of aberrations, the second surface S_3'' of the lens element L_1' may also be aspherical. Since also the concave surface S_6 of the lens element L_3 is preferably aspherical, the projection lens system of Figure 8 totals three aspherical surfaces. This system may have a focal length of 78 mm and a numerical aperture at the object end of 0.30 to 0.35.

A considerable increase of the numerical aperture and a reduction of aberrations at the same focal length can be obtained by adding a third biconvex lens element. Such a projection lens system, which is not only extremely suitable for projecting present-day television images but also for projecting future high-definition television images, is shown in Figure 9. The optical power of the projection lens system is now distributed over the first thick lens element L_1' and the third lens element L_2 . These lens elements preferably have approximately the same optical powers. To this end the lens element L_1' is slightly adapted but its basic shape has been maintained. The pupil PP' of the system is shifted slightly to the object end but is still located fairly close to the first refractive surface S_1 so that the field angle reduction is comparable to that which is obtained in the systems according to Figures 7 and 8. If the surfaces S_1 , S_4 and S_6 are aspherical surfaces, a numerical aperture of more than 0.40 at a focal length of 78 mm can be realized.

The lens element L_1' in Figures 7 and 8 is a thick glass lens element and is thus relatively costly and heavy. As already shown in Figure 9, the projection lens system is designed in such a way that this lens element becomes even slightly thicker so that a diagonal plane d can be provided through the lens element. By leaving out the lens material under this plane, rendering the surface reflective at the location of this plane and providing the surface S_1 on the upper side of the lens element, a folded lens element (L_1 in Figure 10) is obtained which exhibits the same behaviour as the lens element L_1' of Figure 9. The folded lens element L_1 has the advantage that it requires half the quantity of optically high-grade lens material needed for the lens element L_1' of Figure 9 so that the folded lens element is considerably lighter and less costly. Besides the surface S_2 reflects the projection beam in a direction which is optimum for further folding the radiation path in the projection system.

The surface S_2 of the lens element L_1 may be rendered reflective by providing a silver layer, for example by means of vapour deposition.

Also in the projection lens system of Figure 8, having only two lens elements, the first lens element may be replaced by a folded lens element. This projection lens system preferably comprises three aspherical surfaces S_1' , S_3' and S_6 .

In the embodiments of Figure 10 the surfaces S_1 , S_4 and S_6 may be aspherical.

The optical behaviour of the lens elements L_1 and L_2 , which determine the optical power and the focal length of the projection lens system, must be independent of variations in temperature or humidity of the surrounding medium. On the other hand these lens elements must have aspherical surfaces which are difficult to realize in glass. Therefore these lens elements preferably consist of glass substrates $L_{1,s}$ and $L_{2,s}$ which on their aspherical sides carry thin layers $L_{1,a}$ and $L_{2,a}$ of a transparent synthetic material with aspherical outer profiles S_1 and S_4 , respectively. $S_{1,a}$ and $S_{4,a}$ are the inner surfaces of the thin layers $L_{1,a}$ and $L_{2,a}$ respectively. Since the layers are thin, a variation of the refractive index or of the shape of these layers as a result of variations in the ambient parameters has only a slight effect on the behaviour of the lens elements as a whole.

The projection lens system according to Figure 10 may have four instead of three aspherical surfaces, namely the surfaces S_1 , S_3 , S_5 and S_6 . A glass having a lower refractive index can then be used for the lens elements L_1 and L_2 .

The aspherical layers may be provided on the lens substrates by means of a so-called replica process. In this process use is made of moulds having inner profiles which are the reverse of the desired outer profiles of the layers to be formed. A transparent synthetic material brought to a sufficiently soft condition, for example, a synthetic material which can be polymerized by ultraviolet radiation is provided on a lens substrate whereafter a mould is pressed into it. Subsequently the synthetic material is cured, for example by irradiation by ultraviolet light and the mould is removed and the lens becomes available without any further processing operations being required.

The correcting lens element L_3 may entirely consist of a synthetic material, for example, polymethylmethacrylate (PMMA) or polycarbonate (PC). The aspherical profile on the surface S_6 may already be provided during moulding of the lens element by making use of a mould having an aspherical profile. It is alternatively possible to provide the aspherical profile after forming the lens element L_3 by means of the

replica process.

The aspherical surfaces, for example, S_1 , S_4 and S_6 of Figure 10 may be characterized by

$$Z = \sum_{i=1}^6 a_{2i} Y^{2i}$$

wherein Y is the distance between a point on the aspherical surface and the optical axis of the lens element and Z is the distance between the projection of this point on the optical axis and the point of intersection of the optical axis with the aspherical surface.

The following values apply, from the image end, to the axial surface curvatures C , the axial distances d_i between these surfaces and the refractive indices n for an embodiment of the projection lens system according to Figure 10 in which the lens element L_1 consists of glass of the type number SF₂ from Messrs. Schott and the lens elements L_2 and L_3 consist of polycarbonate, whose focal length is 78 mm and the numerical aperture is 0.425.

		$C \text{ (mm}^{-1}\text{)}$	$d_i \text{ (mm)}$	n
	S_1	0.005679		
L_1			84.00	1.654
	S_3	-0.009203		
			0.100	
	S_4	0.007552		
L_2			16.00	1.573
	S_5	-0.003645		
			45.48	
	S_6	-0.015772		
L_3			5.00	1.573
	S_7	-0.028571		

whilst the aspherical coefficients a_{2i} of the surfaces S_1 , S_4 and S_6 are equal to

S_1	$a_2 = 0.283935 \times 10^{-2}$
	$a_4 = -0.390136 \times 10^{-6}$
	$a_6 = -0.750233 \times 10^{-9}$
	$a_8 = 0.839881 \times 10^{-12}$
	$a_{10} = -0.564121 \times 10^{-15}$
S_4	$a_{12} = 0.142924 \times 10^{-18}$
	$a_2 = 0.377615 \times 10^{-2}$
	$a_4 = 0.301339 \times 10^{-6}$
	$a_6 = 0.243433 \times 10^{-9}$
	$a_8 = -0.190848 \times 10^{-12}$
	$a_{10} = 0.873343 \times 10^{-16}$
	$a_{12} = -0.138625 \times 10^{-19}$
S_6	$a_2 = -0.788596 \times 10^{-2}$
	$a_4 = -0.486486 \times 10^{-6}$
	$a_6 = 0.201054 \times 10^{-9}$
	$a_8 = -0.821263 \times 10^{-12}$
	$a_{10} = 0.192444 \times 10^{-15}$
	$a_{12} = -0.140404 \times 10^{-19}$

For an embodiment of the projection lens system according to Figure 10 in which the lens element L_1

consists of glass of the type number SFH64 and the lens elements L_2 and L_3 consist of polycarbonate and whose focal length is 90 mm, the following values apply:

		$C \text{ (mm}^{-1}\text{)}$	$d_i \text{ (mm)}$	n
5				
	S_1	0.003714		
	L_1		102.00	1.712
10	S_3	-0.007749		
			0.50	
	S_4	0.006226		
	L_2		19.00	1.573
15	S_5	-0.003162		
			57.35	
	S_6	-0.011750		
20	L_3		5.00	1.573
	S_7	-0.002857		

whilst the aspherical coefficients a_{2i} of the surfaces S_1 , S_4 and S_6 are equal to

25	S_1	$a_2 = 0.185676 \times 10^{-2}$
		$a_4 = -0.249319 \times 10^{-6}$
		$a_6 = -0.274689 \times 10^{-9}$
		$a_8 = 0.181459 \times 10^{-12}$
		$a_{10} = -0.761700 \times 10^{-16}$
30		$a_{12} = 0.123104 \times 10^{-19}$
	S_4	$a_2 = 0.311297 \times 10^{-2}$
		$a_4 = 0.187661 \times 10^{-6}$
		$a_6 = 0.297361 \times 10^{-10}$
		$a_8 = -0.811958 \times 10^{-14}$
35		$a_{10} = 0.241555 \times 10^{-17}$
		$a_{12} = -0.232393 \times 10^{-21}$
	S_6	$a_2 = -0.587496 \times 10^{-2}$
		$a_4 = -0.336531 \times 10^{-6}$
		$a_6 = 0.156573 \times 10^{-8}$
40		$a_8 = -0.690708 \times 10^{-12}$
		$a_{10} = 0.203958 \times 10^{-15}$
		$a_{12} = -0.266676 \times 10^{-19}$

Thanks to the novel design of this projection lens system the distance between the display window and the entrance pupil of this system can be increased by a factor of, for example 1.25 as compared with a conventional projection lens system. This increase in distance results in a reduction of the angles at which the chief rays of the beams which originate from the display tube and are accepted by the projection lens system are passed. For the purpose of comparison the following Table shows the angles of acceptance α_{acc} for different relative positions p_{FP} on the display window for a conventional projection lens system PL_C and for a projection lens system PL_I according to the invention with a focal length of both 78 mm and 90 mm.

	$f = 78 \text{ mm}$		$f = 90 \text{ mm}$	
P_{FP}	$\alpha_{acc-PLC}$	$\alpha_{acc-PLI}$	$\alpha_{acc-PLC}$	$\alpha_{acc-PLI}$
0	0.0	0.0	0.0	0.0
0.25	10.7	10.2	8.8	6.7
0.50	20.5	20.3	17.1	13.8
0.75	29.2	27.9	24.9	20.2
1.00	37.6	31.2	32.8	24.0

These values apply to a display window having a radius of curvature $\rho = 350 \text{ mm}$.

The angle of acceptance at a given position on the display window is the angle between the normal of this position on the display window and the chief ray of a beam starting from this position and passing the projection lens system.

The effect of the improved projection lens system is greatest in the corners of the display window for which the relative position $P_{FP} = 1.00$ for which position also the field angle is defined. The reduction of the angle of acceptance in the corner of the display window is thus 6.4° and 8.8° for a projection lens system having a focal length of 78 mm and 90 mm, respectively.

In Figure 11 the angle of acceptance $\alpha_{acc,M}$ in the corner of the display window is plotted as a function of the focal length f of a conventional projection lens system for both a display tube having a flat display window, the solid-line curve 30, and a display tube having a concave display window with a radius of curvature $r_c = 350 \text{ mm}$, the broken-line curve 31. In this Figure is also indicated by the points 32 and 33 the maximum angles of acceptance $\alpha_{acc,M}$ for the focal lengths 78 mm and 90 mm in a projection system having a display tube with a concave display window in which $r_c = 350 \text{ mm}$ and a projection lens system according to the invention.

Figures 12 and 13 show the effect of the reduction of the angle of acceptance on the gain in brightness G_b which is obtained when using an interference filter (with $p = 1.26$) in the display tube. In these Figures the relative position p_{PS} on the projection screen is plotted in the horizontal direction. The solid-line curves 34 and 36 apply if a conventional projection lens system is used and the broken-line curves 35 and 37 apply when using a projection lens system according to the invention. As is shown Figure 12 relates to a projection lens system having a focal length $f = 90 \text{ mm}$ and Figure 13 relates to a system with $f = 78 \text{ mm}$.

The transmission of the interference filter for the selected central wavelength λ is 50% for a direction at 37° to the normal on the display window.

When using a conventional projection lens system with $f = 90 \text{ mm}$, the gain in brightness G_b in the centre is 1.7 and it decreases to 1.0 in the corner of the projection screen. This decrease in brightness is accompanied by a colour shading which cannot be shown in Figure 12. When using a projection lens system according to the invention with a folded first lens element the decrease in the gain in brightness is considerably less: from 1.7 in the centre to 1.5 in the corner of the projection screen. If a conventional projection lens system with $f = 78 \text{ mm}$ is used the gain in brightness is 1.7 in the centre and 0.7 in the corner of the projection screen as is shown in Figure 13. Considerably better results are achieved when using a projection lens system according to the invention with a folded first lens element: the brightness at the edge of the projection screen is then still 1.15 whilst the colour shading is considerably reduced.

Although Figures 8, 9 and 10 show image projection systems with display tubes having a concave display window, the invention is not limited thereto. Also in projection systems in which the display tubes have for example a flat display window a combination of the special projection lens system and the interference filter in the tube may increase the brightness on the projection screen and the colour shading may be reduced at a relatively short focal length of the projection lens system.

The invention may not only be used in a colour picture projection system but also in a single colour projection lens system in order to improve the distribution in brightness on the projection screen, to increase the gain in brightness, to realize a better contrast and to reduce chromatic aberrations.

Claims

1. An image projection system comprising at least one display tube and a multi-element projection lens system for imaging a display tube picture on a projection screen, said display tube comprising a display screen in an evacuated envelope, the display screen being arranged on the inside of a display



		$f = 78 \text{ mm}$		$f = 90 \text{ mm}$	
		$\alpha_{\text{acc}}^{-\text{PL}_C}$	$\alpha_{\text{acc}}^{-\text{PL}_I}$	$\alpha_{\text{acc}}^{-\text{PL}_C}$	$\alpha_{\text{acc}}^{-\text{PL}_I}$
5	P_{FP}				
	0	0.0	0.0	0.0	0.0
	0.25	10.7	10.2	8.8	6.7
	0.50	20.5	20.3	17.1	13.8
	0.75	29.2	27.9	24.9	20.2
10	1.00	37.6	31.2	32.8	24.0

These values apply to a display window having a radius of curvature $\rho = 350 \text{ mm}$.

The angle of acceptance at a given position on the display window is the angle between the normal of this position on the display window and the chief ray of a beam starting from this position and passing the projection lens system.

The effect of the improved projection lens system is greatest in the corners of the display window for which the relative position $P_{\text{FP}} = 1.00$ for which position also the field angle is defined. The reduction of the angle of acceptance in the corner of the display window is thus 6.4° and 8.8° for a projection lens system having a focal length of 78 mm and 90 mm, respectively.

In Figure 11 the angle of acceptance $\alpha_{\text{acc},M}$ in the corner of the display window is plotted as a function of the focal length f of a conventional projection lens system for both a display tube having a flat display window, the solid-line curve 30, and a display tube having a concave display window with a radius of curvature $r_c = 350 \text{ mm}$, the broken-line curve 31. In this Figure is also indicated by the points 32 and 33 the maximum angles of acceptance $\alpha_{\text{acc},M}$ for the focal lengths 78 mm and 90 mm in a projection system having a display tube with a concave display window in which $r_c = 350 \text{ mm}$ and a projection lens system according to the invention.

Figures 12 and 13 show the effect of the reduction of the angle of acceptance on the gain in brightness G_b which is obtained when using an interference filter (with $p = 1.26$) in the display tube. In these Figures the relative position P_{FS} on the projection screen is plotted in the horizontal direction. The solid-line curves 34 and 36 apply if a conventional projection lens system is used and the broken-line curves 35 and 37 apply when using a projection lens system according to the invention. As is shown Figure 12 relates to a projection lens system having a focal length $f = 90 \text{ mm}$ and Figure 13 relates to a system with $f = 78 \text{ mm}$.

The transmission of the interference filter for the selected central wavelength λ is 50% for a direction at 37° to the normal on the display window.

When using a conventional projection lens system with $f = 90 \text{ mm}$, the gain in brightness G_b in the centre is 1.7 and it decreases to 1.0 in the corner of the projection screen. This decrease in brightness is accompanied by a colour shading which cannot be shown in Figure 12. When using a projection lens system according to the invention with a folded first lens element the decrease in the gain in brightness is considerably less: from 1.7 in the centre to 1.5 in the corner of the projection screen. If a conventional projection lens system with $f = 78 \text{ mm}$ is used the gain in brightness is 1.7 in the centre and 0.7 in the corner of the projection screen as is shown in Figure 13. Considerably better results are achieved when using a projection lens system according to the invention with a folded first lens element: the brightness at the edge of the projection screen is then still 1.15 whilst the colour shading is considerably reduced.

Although Figures 8, 9 and 10 show image projection systems with display tubes having a concave display window, the invention is not limited thereto. Also in projection systems in which the display tubes have for example a flat display window a combination of the special projection lens system and the interference filter in the tube may increase the brightness on the projection screen and the colour shading may be reduced at a relatively short focal length of the projection lens system.

The invention may not only be used in a colour picture projection system but also in a single colour projection lens system in order to improve the distribution in brightness on the projection screen, to increase the gain in brightness, to realize a better contrast and to reduce chromatic aberrations.

Claims

1. An image projection system comprising at least one display tube and a multi-element projection lens system for imaging a display tube picture on a projection screen, said display tube comprising a display screen in an evacuated envelope, the display screen being arranged on the inside of a display



- 5 window in the wall of the envelope and being provided with a luminescent material, a multi-layer interference filter being arranged between said material and the display window, characterized in that a first lens element (L_1 ; L_1') of the projection lens system, viewed from the image end, i.e. from the projection screen (10), is constituted by a positive lens element having a first refractive aspherical surface (S_1 ; S_1') facing the image end and a second refractive surface (S_3 ; S_3'') facing the object end, i.e. the display screen (27, 27') which surface is convex and whose centre of curvature (M) is located in the image end half of said lens element (L_1 ; L_1'), said second surface supplying the major part of the optical power of the first lens element, in that the projection lens system comprises at least a second lens element (L_3) having a negative power and whose surface (S_6) facing the image end is concave and whose surface (S_7) facing the display tube has a curvature which is substantially similar to that of the display window (FP) and in that the entrance pupil (PP') of the projection lens system viewed from the projection screen is located in the image end half of the first lens element (L_1 ; L_1').
- 10
- 15 2. An image projection system as claimed in Claim 1, characterized in that the aspherical surface (S_1 ; S_1') of the first lens element (L_1 ; L_1'), viewed from the image end, is convex in a zone around the optical axis (OO') and is concave outside said zone.
- 20 3. An image projection system as claimed in Claim 2, characterized in that the second refractive surface (S_3 ; S_3'') of the first lens element (L_1 ; L_1') is aspherical.
4. An image projection system as claimed in Claim 1 or 2, characterized in that a third bi-convex lens element (L_2) supplying a part of the overall optical power of the projection lens system is arranged between the first (L_1 ; L_1') and the second lens element (L_3).
- 25 5. An image projection system as claimed in Claim 4, characterized in that the optical power of the third lens element (L_2) is approximately equal to that of the first lens element (L_1 ; L_1').
6. An image projection system as claimed in Claim 4 or 5, characterized in that the surface (S_4) of the third lens element (L_2) facing the image end is aspherical.
- 30 7. An image projection system as claimed in Claim 4 or 5, characterized in that the surfaces (S_3 ; S_5) of the first (L_1 ; L_1') and third (L_2) lens elements facing the object end are aspherical.
8. An image projection system as claimed in any one of the preceding Claims, characterized in that the first lens element (L_1) has a third surface (S_2) which is reflective and substantially directs all rays of radiation from the second (S_3) towards the first refractive lens surface (S_1).
- 35 9. An image projection system as claimed in any one of the preceding Claims, characterized in that the display window (21') of the display tube (20), viewed from the image end, is concave and has an angle of curvature ϕ wherein ϕ is the angle between the normal in the centre of the display window and a line perpendicular to the edge of the display window, which angle ϕ has a value in the range between 5° and 25° .
- 40 10. A colour picture projection device comprising three separate colour channels converging on a common projection screen (10) and each being provided with a display tube (3, 4, 5) and a projection lens system (6, 7, 8), characterized in that least one of the colour channels is provided with an image projection system as claimed in any one of the preceding Claims.
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Patentansprüche

- 50 1. Bildprojektionssystem mit mindestens einer Wiedergaberöhre und einem Mehrelement-Projektionslinsensystem zur Abbildung eines Bildes der Wiedergaberöhre auf einem Projektionsschirm, wobei die Wiedergaberöhre einen Wiedergabebildschirm in einer evakuierten Umhüllung umfaßt, der Wiedergabebildschirm an der Innenseite eines Wiedergabefensters in der Wandung der Umhüllung angeordnet und mit lumineszierendem Material versehen ist und ein Mehrlageninterferenzfilter zwischen dem genannten Material und dem Wiedergabefenster angeordnet ist, dadurch gekennzeichnet, daß ein erstes Linsenelement (L_1 ; L_1') des Projektionslinsensystems, von der Bildseite her gesehen, d.h. vom Projektionsschirm (10), von einem positiven Linsenelement mit einer ersten der Bildseite zugewandten
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brechenden asphärischen Fläche ($S_1; S_1'$) und einer zweiten, der Objektseite, d.h. dem Wiedergabebildschirm (27, 27'), zugewandten brechenden Fläche ($S_3; S_3''$), welche Fläche konvex ist und deren Krümmungszentrum (M) in der Bildseitenhälfte des Linsenelements ($L_1; L_1'$) liegt, gebildet wird, wobei die zweite Fläche den größeren Teil der optischen Leistung des ersten Linsenelements verschafft, daß das Projektionslinsensystem mindestens ein zweites Linsenelement (L_3) mit negativer Leistung umfaßt, dessen der Bildseite zugewandte Fläche (S_6) konkav ist und dessen der Wiedergaberöhre zugewandte Fläche (S_7) eine Krümmung hat, die nahezu gleich der des Wiedergabefensters (FP) ist und daß die Eintrittspupille (PP') des Projektionslinsensystems, von dem Projektionsschirm aus gesehen, in der Bildseitenhälfte des ersten Linsenelements ($L_1; L_1'$) liegt.

2. Bildprojektionssystem nach Anspruch 1, dadurch gekennzeichnet, daß die asphärische Fläche ($S_1; S_1'$) des ersten Linsenelements ($L_1; L_1'$), von der Bildseite aus gesehen, in einer Zone um die optische Achse herum konvex und außerhalb dieser Zone konkav ist.

3. Bildprojektionssystem nach Anspruch 2, dadurch gekennzeichnet, daß die zweite brechende Fläche ($S_3; S_3''$) des ersten Linsenelements ($L_1; L_1'$) asphärisch ist.

4. Bildprojektionssystem nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß ein drittes bikonvexes Linsenelement (L_2), das einen Teil der gesamten optischen Leistung des Projektionslinsensystems verschafft, zwischen dem ersten ($L_1; L_1'$) und dem zweiten Linsenelement (L_3) angeordnet ist.

5. Bildprojektionssystem nach Anspruch 4, dadurch gekennzeichnet, daß die optische Leistung des dritten Linsenelements (L_2) ungefähr gleich der des ersten Linsenelements ($L_1; L_1'$) ist.

6. Bildprojektionssystem nach Anspruch 4 oder 5, dadurch gekennzeichnet, daß die der Bildseite zugewandte Fläche (S_4) des dritten Linsenelements (L_2) asphärisch ist.

7. Bildprojektionssystem nach Anspruch 4 oder 5, dadurch gekennzeichnet, daß die der Objektseite zugewandten Flächen (S_3, S_5) des ersten ($L_1; L_1'$) und des dritten (L_2) Linsenelements asphärisch sind.

8. Bildprojektionssystem nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das erste Linsenelement (L_1) eine dritte Fläche (S_2) hat, die reflektierend ist und nahezu alle Strahlungsstrahlen von der zweiten (S_3) zur ersten brechenden Linsenfläche (S_1) richtet.

9. Bildprojektionssystem nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Wiedergabefenster (21') der Wiedergaberöhre (20), von der Bildseite aus gesehen, konkav ist und einen Krümmungswinkel ϕ hat, wobei ϕ der Winkel zwischen der Normalen im Zentrum des Wiedergabefensters und einer senkrecht zum Rand des Wiedergabefensters stehenden Linie ist und dieser Winkel ϕ einen Wert im Bereich zwischen 5° und 25° hat.

10. Farbbildprojektionseinrichtung mit drei getrennten Farbkanälen, die auf einem gemeinsamen Projektionsschirm (10) konvergieren und von denen jeder mit einer Wiedergaberöhre (3, 4, 5) und einem Projektionslinsensystem (6, 7, 8) versehen ist, dadurch gekennzeichnet, daß mindestens einer der Farbkanäle mit einem Bildprojektionssystem nach einem der vorhergehenden Ansprüche versehen ist.

Revendications

1. Système de projection d'image comportant au moins un tube-image et un système de lentilles de projection constitué de plusieurs éléments pour représenter une image provenant d'un tube-image sur un écran de projection, ledit tube-image comportant un écran situé dans une enveloppe mise sous vide, l'écran étant disposé à l'intérieur d'une fenêtre d'image dans la paroi de l'enveloppe et muni d'un matériau luminescent, un filtre d'interférence à couches multiples étant disposé entre ledit matériau et la fenêtre d'image, caractérisé en ce qu'un premier élément de lentille ($L_1; L_1'$) du système de lentilles de projection, vu du côté d'image c'est-à-dire à partir de l'écran de projection (10), est constitué par un élément de lentille positif présentant une première surface réfractive asphérique ($S_1; S_1'$) située vis-à-vis du côté d'image ainsi qu'une deuxième surface réfractive (S_3, S_3'') située vis-à-vis du côté d'objet, c'est-à-dire en face de l'écran (27, 27'), cette dernière surface étant convexe et son centre de courbure (M) étant situé dans la moitié dudit élément de lentille ($L_1; L_1'$) dirigée vers le côté



- d'image, ladite deuxième surface fournissant la plus grande partie de la puissance optique du premier élément de lentille, en ce que le système de lentilles de projection comporte au moins un deuxième élément de lentille (L_3) présentant une puissance négative et dont la surface (S_6) située vis-à-vis du côté d'image est concave et dont la surface (S_7) située vis-à-vis du tube-image présente une courbure qui est essentiellement similaire à celle de la fenêtre d'image (FP) et en ce que la pupille d'entrée (PP') du système de lentilles de projection vue à partir de l'écran de projection est située dans la moitié du premier élément de lentille (L_1 ; L_1') dirigée vers le côté d'image.
2. Système de lentilles de projection selon la revendication 1, caractérisé en ce que la surface asphérique (S_1 ; S_1') du premier élément de lentille (L_1 ; L_1') vue du côté d'image, est convexe dans une zone autour de l'axe optique (OO') et en ce qu'elle est concave à l'extérieur de ladite zone.
 3. Système de projection d'image selon la revendication 2, caractérisé en ce que la deuxième surface réfractive (S_3 ; S_3') du premier élément de lentille (L_1 ; L_1') est asphérique.
 4. Système de projection d'image selon la revendication 1 ou 2, caractérisé en ce qu'un troisième élément biconvexe (L_2) fournissant une partie de la puissance optique totale du système de lentilles de projection est disposé entre le premier élément de lentille (L_1 ; L_1') et le deuxième élément de lentille (L_3).
 5. Système d'image de projection selon la revendication 4, caractérisé en ce que la puissance optique du troisième élément de lentille (L_2) est approximativement égale à celle du premier élément de lentille (L_1 ; L_1').
 6. Système d'image de projection selon la revendication 4 ou 5, caractérisé en ce que la surface (S_4) du troisième élément de lentille (L_2) située vis-à-vis du côté d'image est asphérique.
 7. Système d'image de projection selon la revendication 4 ou 5, caractérisé en ce que les surfaces (S_3 ; S_5) du premier élément de lentille (L_1 ; L_1') et du troisième élément de lentille (L_2) situées vis-à-vis du côté d'objet sont asphériques.
 8. Système d'image de projection selon l'une quelconque des revendications précédentes, caractérisé en ce que le premier élément de lentille (L_1) présente une troisième surface (S_2) qui est réfléchissante et qui dirige sensiblement tous les faisceaux de rayonnement sortant de la deuxième surface (S_3) vers la première surface de lentille réfractive (S_1).
 9. Système d'image de projection selon l'une quelconque des revendications précédentes, caractérisé en ce que la fenêtre d'image (21') du tube-image (20), vue du côté d'image, est concave et en ce qu'elle présente un angle de courbure ϕ où ϕ est l'angle fait entre la normale au centre de la fenêtre d'image et une ligne perpendiculaire au bord de la fenêtre d'image, cet angle ϕ présentant une valeur située dans la gamme comprise entre 5 et 25°.
 10. Dispositif de projection d'image en couleur comportant trois canaux de couleur individuels convergeant vers un écran de projection commun (10) et munis chacun d'un tube-image (3, 4, 5), et d'un système de lentilles de projection (6, 7, 8), caractérisé en ce qu'au moins l'un des canaux en couleur est muni d'un système de projection d'image selon l'une quelconque des revendications précédentes.