Quality Criteria of Lenses

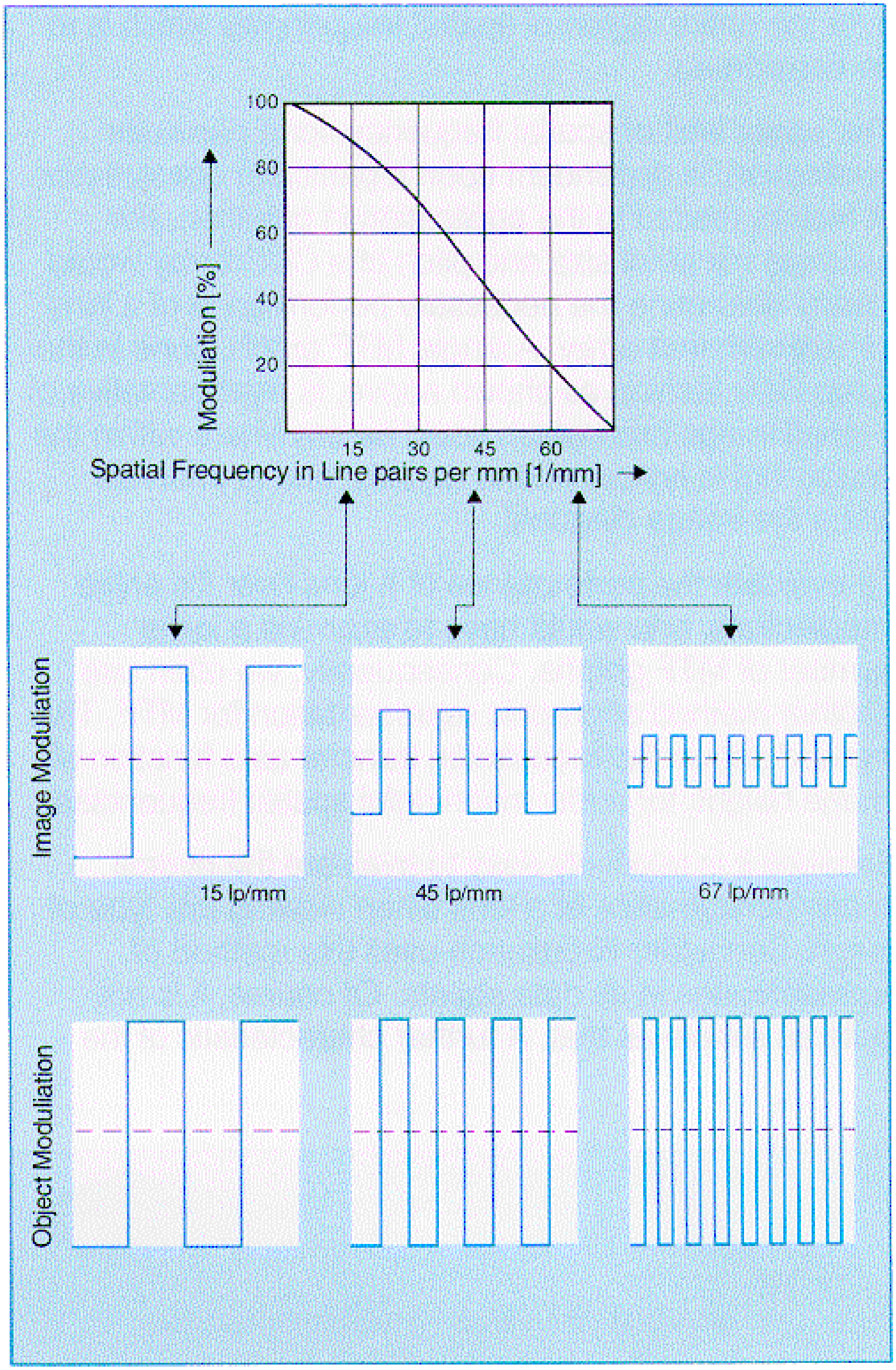
The quality of a lens cannot be expressed with a single number or a simple statement. A number of factors must be evaluated in calculating the quality of a lens. Some of these factors include sharpness, contrast, color correction, relative illumination, spectral transmission, and distortion.

Modulation Transfer Function (MTF)

An ideal lens would be one which is able to produce an image which represents an object exactly. An ideal lens could transfer all of the details of the object to the image without any variations. An ideal lens, however, could only exist under ideal conditions, and in the real world ideal conditions can not be achieved. As such, we must deal with real lenses, and real lenses produce slight variations between the object and the image. In order to show this, we represent the ability of a lens to transfer information from the object to the image as a Modulation Transfer Function (MTF).

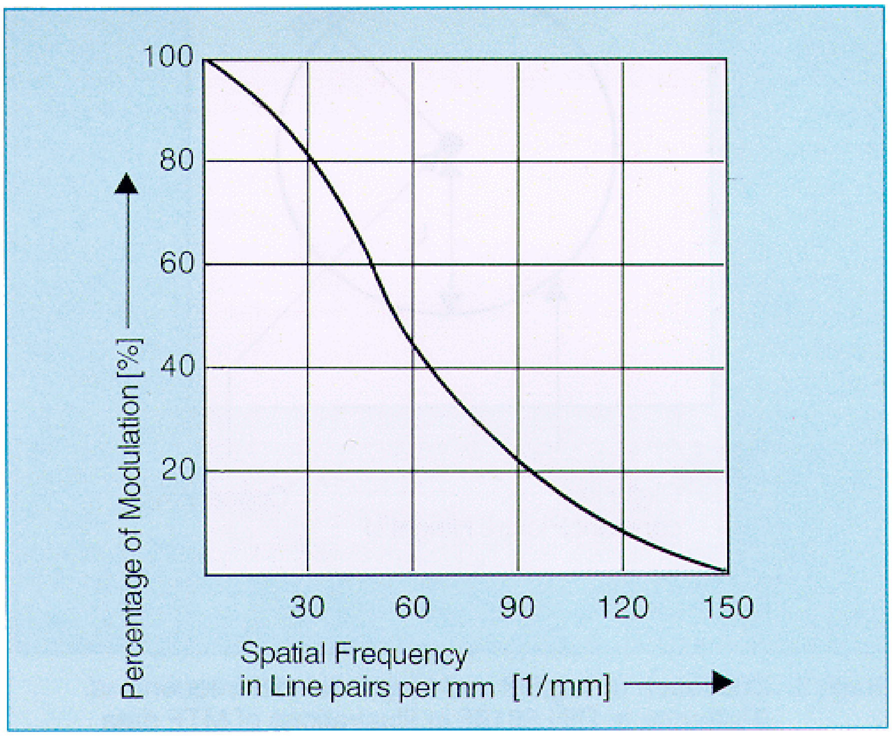
Coarse structures (such as coarsely spaced lines) are usually transferred to the image with better contrast, or modulation. Fine structures (such as finely spaced lines) are usually transferred with poorer modulation.

Therefore, it is useful to graph the way contrast varies with respect to spatial frequency. This is usually expressed in line pairs per mm. A lens's MTF is a measure of how well the original contrast of the object is transferred to the image. MTF is expressed in percent (the image has X percent of the original contrast remaining), as a function of spatial frequency.



Graph 1: Illustration of MTF

It is apparent that the modulation transfer decreases as the spatial frequency increases. As the spatial frequency increases, it will reach a point where the modulation will be zero. In the example below, this frequency is 150 lp/mm. This limit is often called the resolution limit, or the resolving power of the lens.



Graph 2: Modulation as a Function of the spatial Frequency

It should be pointed out that the resolving power of the lens is not a complete measure of the quality of a lens, because it neglects to consider the contrast of the image. A balance must be found between resolution and contrast. To ensure this, the modulation transfer function of the lens should be high over the entire region of spatial frequencies which is to be considered.

The upper limit of spatial frequency (resolution) to be considered for a particular application is dependent upon a number of factors specific to that application.

Some examples:

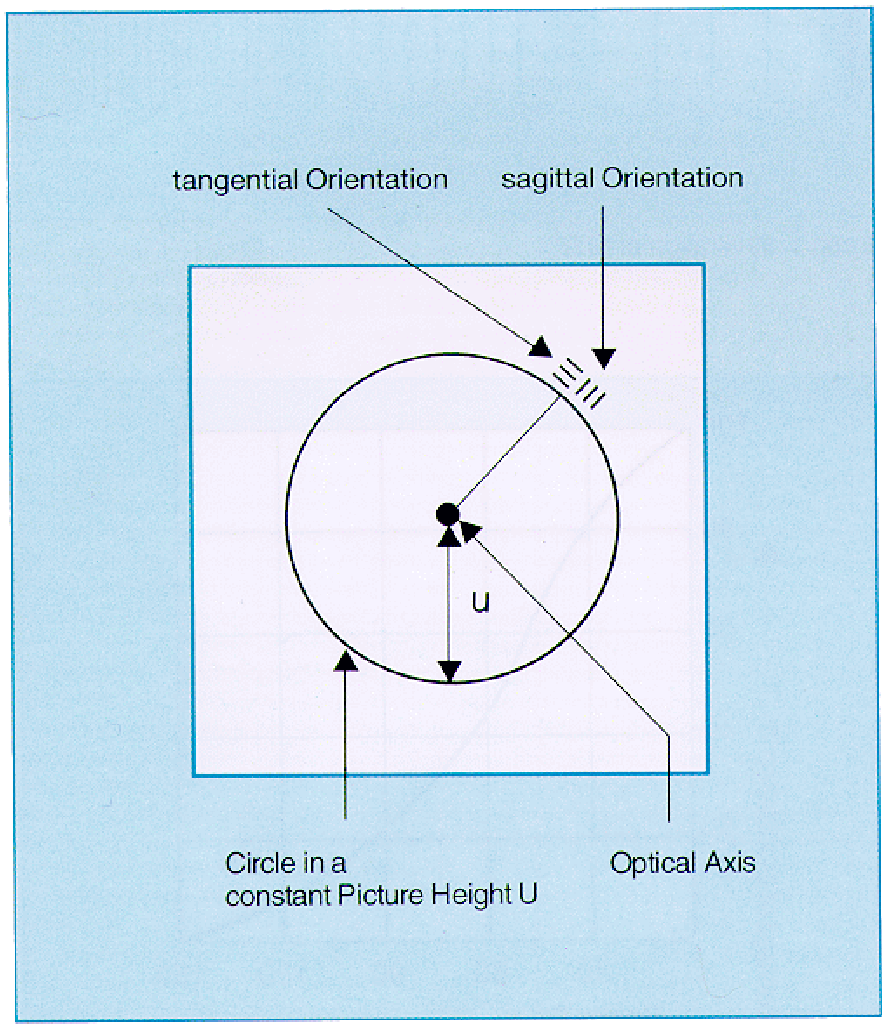
- The pixel size and pitch of a CCD array would clearly determine the necessary performance of a lens for use with that array.
- The resolving power of the film used in a camera would limit the required resolution of a lens used on that camera. If the film in the camera was capable of resolving 20 lp/mm, for example, it would be unnecessary to have a lens with higher resolution.

A single MTF graph, in the style shown in graph 1, represents the MTF performance of the lens at a single point in the image. To evaluate the performance of a lens over it's entire image area, one would have to examine a large number of MTF graphs. Consequently we often use another method of graphic representation for MTF. This method shows the modulation transfer as a function of image height, for a few meaningful spatial frequencies.

Because it is relatively easy to evaluate the overall image performance of a lens while viewing one of these graphs, Schneider-Kreuznach uses this method of representation in it's data sheets.

Of course, it is not quite as simple as that. A further characteristic of the imaging process is that a beam of rays emerging from a lens exhibits differing properties dependent upon its incident angle. What this means in a very practical way is that object patterns with different orientations will reproduce differently.

Therefore, it is necessary to select more than one orientation of the test pattern used, in order to be sure of an accurate evaluation of the lens. Under normal circumstances it is sufficient to select two mutually perpendicular orientations of the line elements, as illustrated in the graph on the right.



Graph 3: Illustration of sagittal and tangential test frequencies. (Referring to DIN 58185 in Illustrations of MTF data sheets the relation of Object-/Imagesize is called u/u')

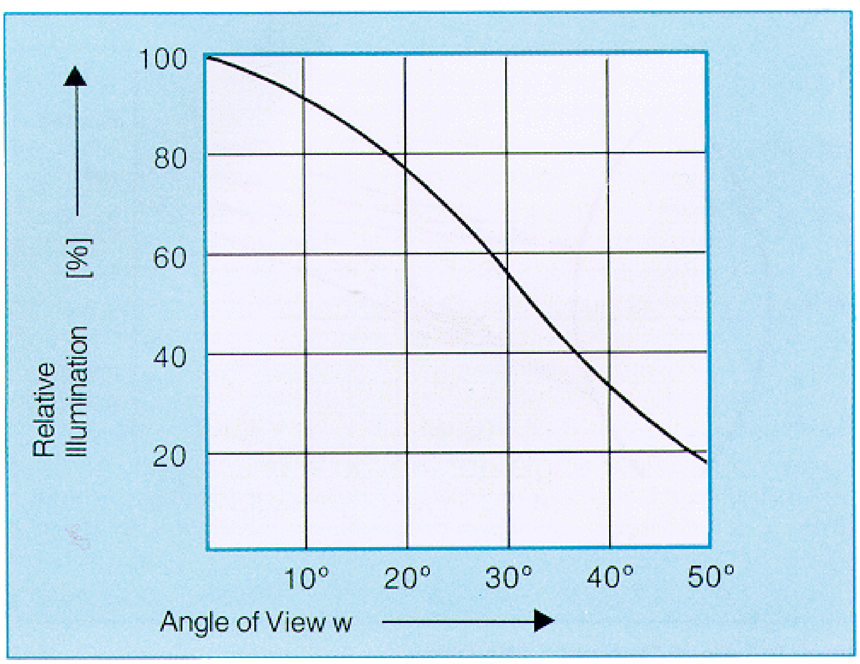
There will, therefore, be two different sets of MTF data representing radial and tangential orientation for test patterns. In our graphs, the data for the tangential orientation is shown with dashed lines.

It is possible to use a lens in a variety of ways and this can affect the performance of the lens as represented by the MTF data. In particular, the image magnification and the aperture at which the lens is used have a large effect on the performance of a lens.

For a particular optical system, there is always a theoretical limit to performance. This limit also depends on the field angle, so this becomes quite important for wide angle systems. Generally there is a decrease in MTF values with the cosine of the field angle for the radial orientation, and with the third power of the cosine of the field angle for the tangential orientation. The graph shown below gives an example of a diffraction limited (perfect) optical system for 20 lp/mm at f/22 and a wavelength of 546nm.

Relative Illumination

All images from lenses vary in intensity from the center to the edge of the image. The center of the image is brighter than the edges of the image. Since this can affect the suitability of a lens for a particular task, it is often necessary to examine the performance of a lens in this area.

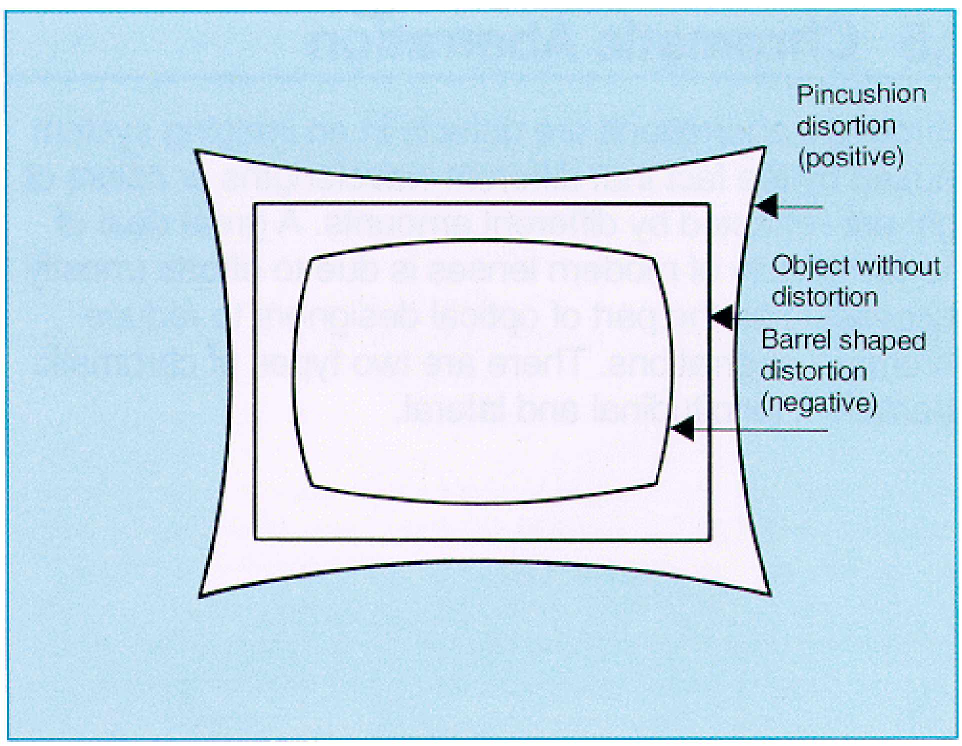


Graph 4 : Non-uniformity of illumination by natural vignetting

There are two primary factors involved in this non-uniformity of illumination. First, there is a natural decrease in illumination from the center to the edge of the image circle. This varies with the fourth power of the cosine of the field angle. Second, there is often some mechanical vignetting of the image within the lens. This simply means that some rays are blocked by mechanical parts within the lens. The effect of vignetting can be greatly reduced by using a smaller aperture. It is therefore necessary to represent several apertures on graphic representations of relative illumination.

Distortion

The term distortion refers to a change in the geometric representation of an object in the image plane. A rectangle might be reproduced with a pincushion or barrel shape.
A pincushioned image represents a positive distortion. A barrel shaped image represents a negative distortion. Distortion, either positive or negative, may change with image height. Distortion also is affected by the magnification at which the lens is used.

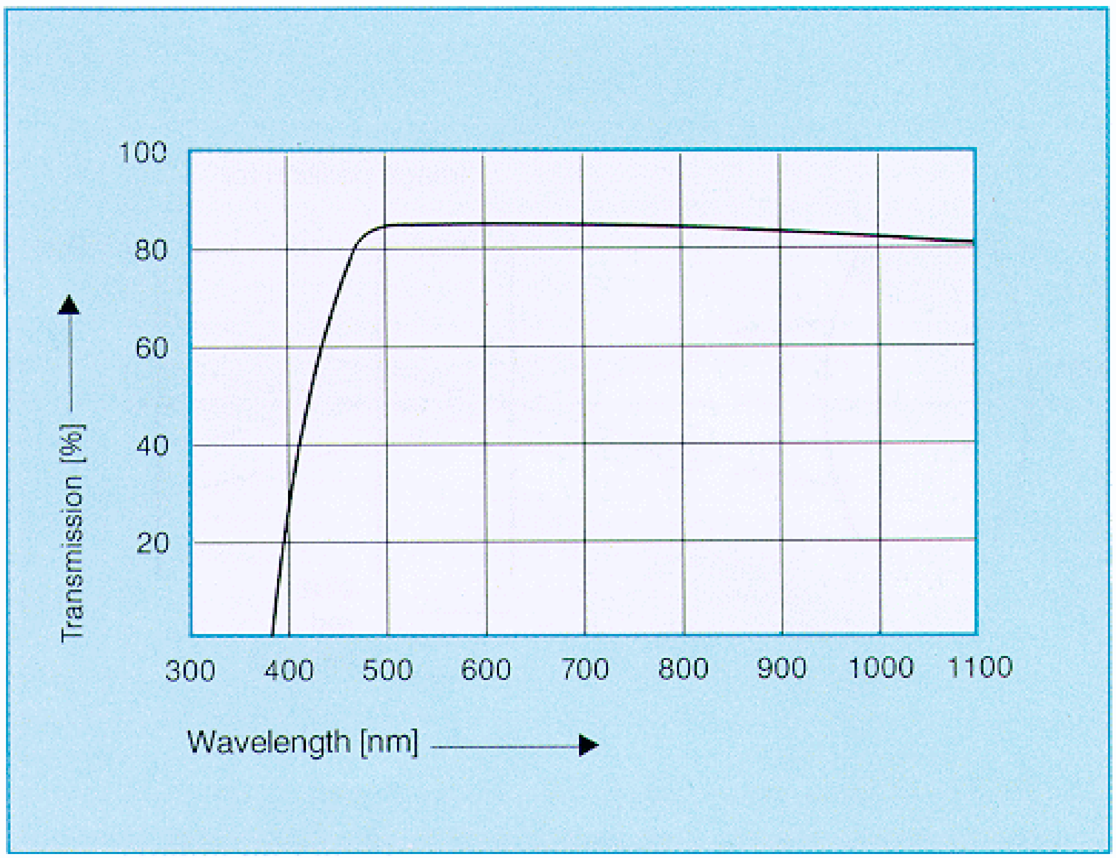


Graph 5: Pincushion and barrel shaped distortion

Spectral Transmission

All optical materials transmit certain wavelengths with more or less efficiency. Some wavelengths are reflected or absorbed by these materials in varying amounts.

Lenses are manufactured from optical glass. One precision lens may use many different types and combinations of glass in various lens elements. Each type of glass and each type of surface coating will show distinct spectral transmission characteristics. Therefore it is important to study the actual transmission data that is furnished in our spectral transmission curves, when evaluating a lens.



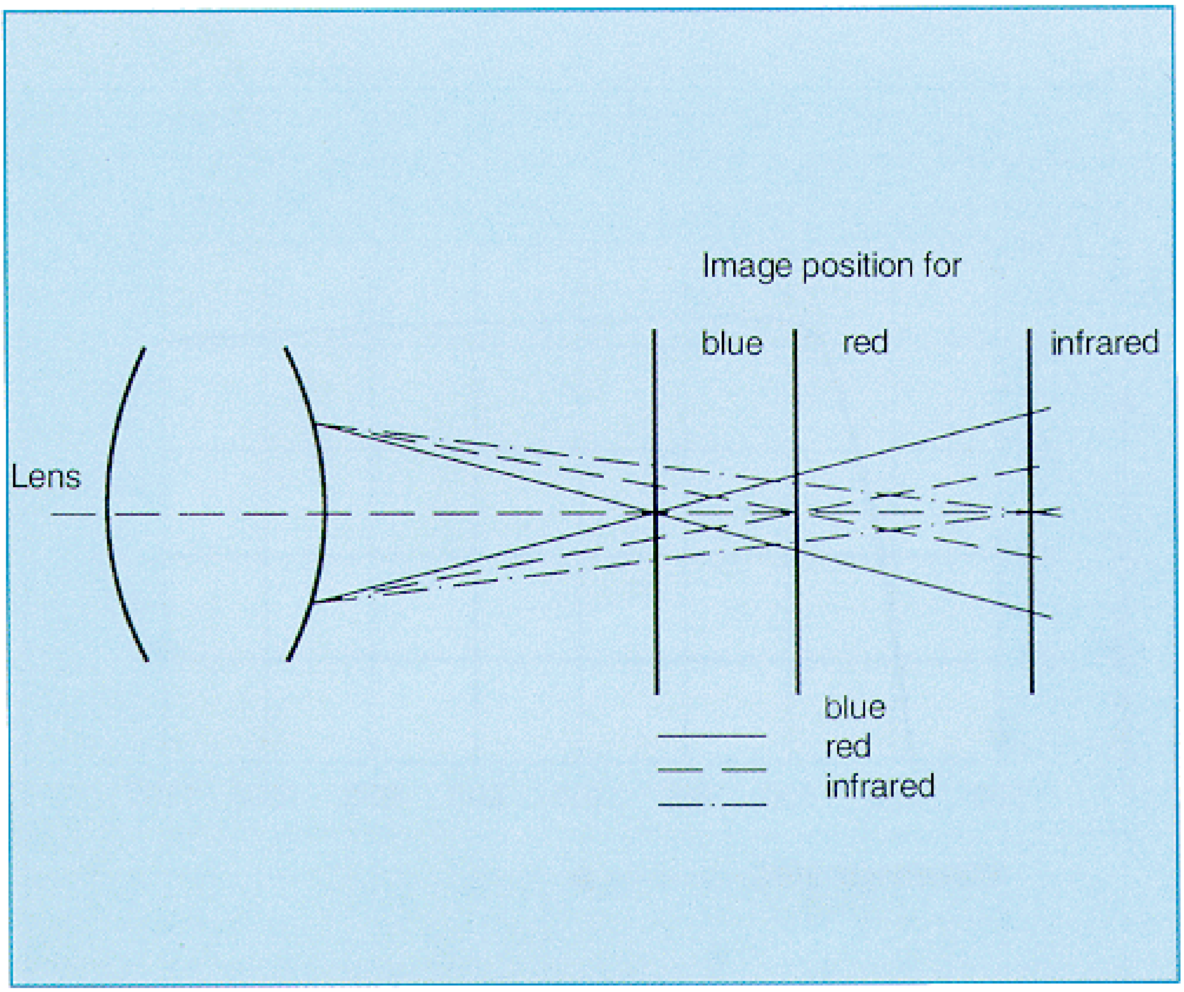
Graph 6: Spectral Transmission

Chromatic Aberrations

Chromatic aberrations are defects in an imaging system caused by the fact that different wavelengths or colors of light are refracted by different amounts. A great deal of the complexity of modern lenses is due to efforts (mostly successful) on the part of optical designers to reduce chromatic aberrations. There are two types of chromatic aberration: longitudinal and lateral.

Longitudinal Chromatic Aberration

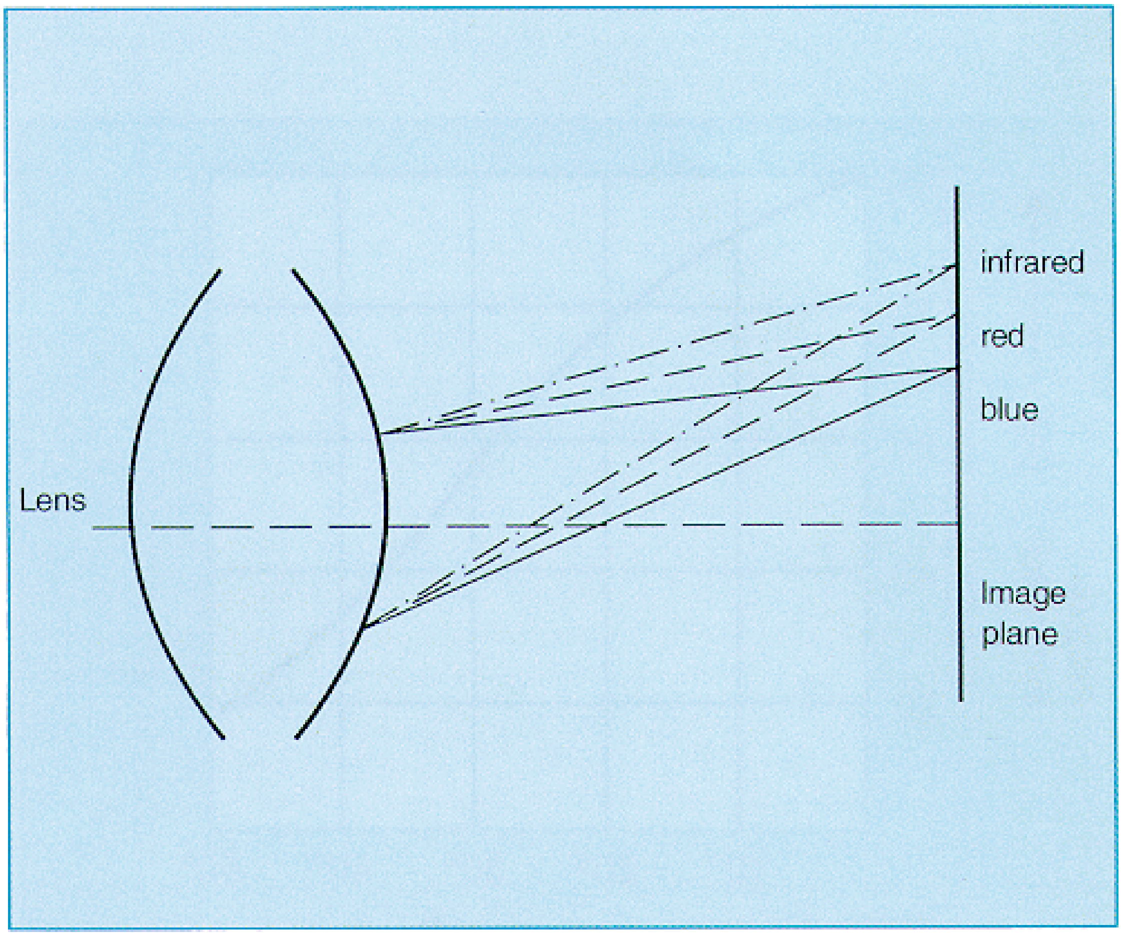
When a lens fails to focus various colors sharply in the same plane, the lens is said to exhibit longitudinal chromatic aberration. It can be seen from the illustration below that a lens with this aberration can be refocused for optimum performance with various wavelengths. If monochromatic light is used with such a lens, then re-focusing will solve the problem. If white light is used, however, the resulting image will be unsharp due to the different focal points of it's component colors. Some colors will be in focus (and therefore sharp) and other colors will be out of focus (and therefore unsharp).



Graph 7: Longitudinal Chromatic Aberration

Lateral Chromatic Aberration

Lateral Chromatic Aberration results in a lateral shift of the image. This results in color stripes, much like a rainbow, around hard edges and a general softening or decrease in resolution or MTF in all areas.



Graph 8: Lateral Chromatic Aberration

Spectral Weighting of Image Quality

The Modulation Transfer Function of a lens will change significantly dependent upon the wavelengths of light in use. A number of factors such as the chromatic aberrations of a lens and the effectiveness of the anti-reflection surface coatings for various wavelengths, contribute to this effect. Typically, a lens may work rather better with monochromatic light than with a full spectrum of wavelengths. Therefore, when evaluating a lens it is necessary to specify precisely the type of light to be used. This is usually expressed as a spectral weighting.