Linear Variable Filters and Xenon flash lamps

The purpose of this document is to give recommendations on how to use DELTA's linear variable filters in systems where the light is originating from a Xenon flash lamp.

The light source

Information on xenon flash lamps was derived from the Hamamatsu Technical information named 'Xenon flash lamps' and dated TLSX9001E05 Apr. 2005 IP. Figures 1–3 originate from this document.

Figure 1 External View and Construction (L2189)

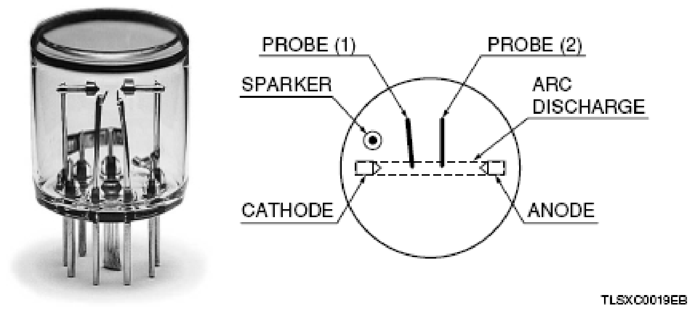


Figure 1

Figure is included to give a clear impression of a possible construction of the xenon flash lamp. Light emitted from the spark through the front glass is collected by an external lens. It is possible to buy lamps with different length of the arc. (Figure copied from the Hamamatsu tech note.)

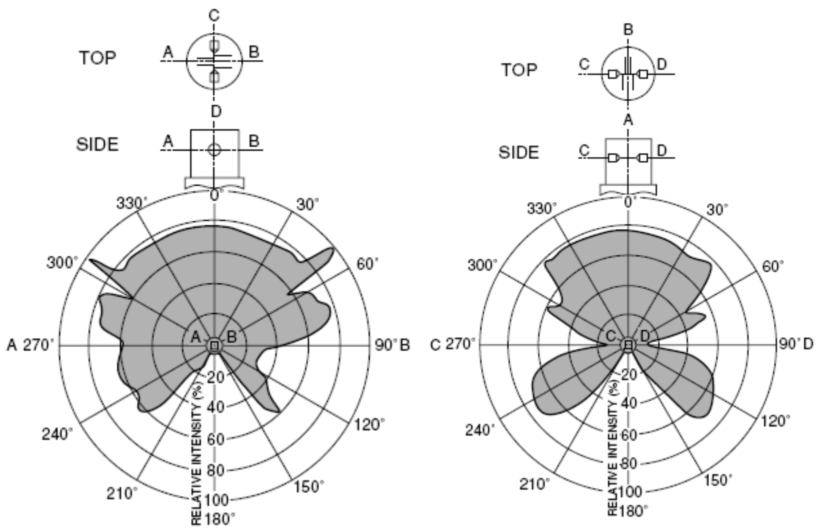


Figure 2

The intensity of the light is nearly constant in the angular range from -45 degrees to +45 degrees. In this angular range light is rayed directly from the flash in the xenon gas through the front window in the glass housing. Technically seen we may describe the profile as a cosine raised to zero order emission.

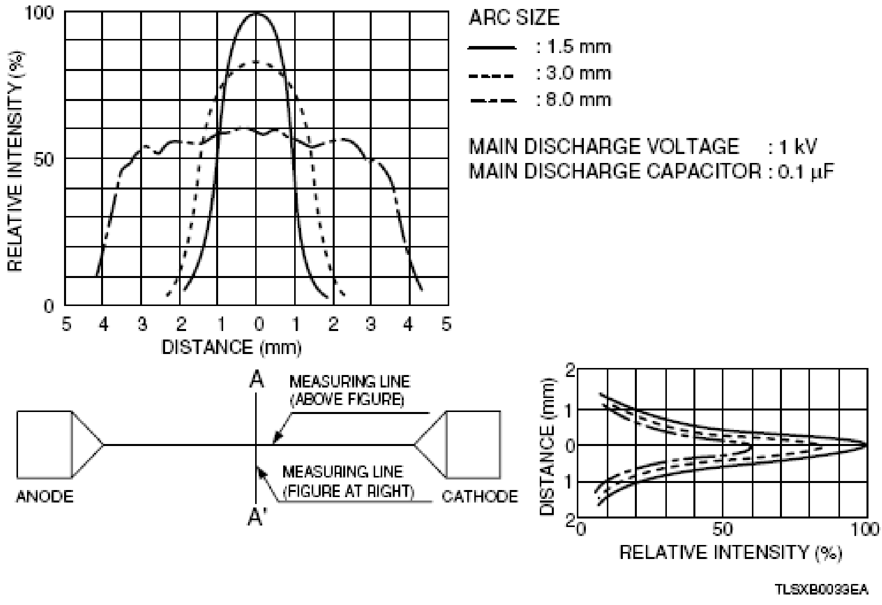


Figure 3 Figure shows the estimated intensity profiles in the longitudinal and transversal direction. Curves are shown for three different types of Hamamatsu flash lamps. It is not recommended to use the arc size 8mm type for demanding applications. (Figure is copied from the Hamamatsu tech note – according to the tech note no guaranty is given on the validity of the information found in it.)

Details in the Hamamatsu tech note are only intended as guidelines on the functioning of the flash lamps. However, it is the best information we have on the subject. This information was used to derive several equations used in the DELTA design software for making simulations of the functioning of linear variable filters in systems with xenon flash lamps.

Analysis on the content of figure 2 made us decide to describe the emission profile as a cosine raised to zero order in the angular range from –45 degrees to +45 degrees. Please notice that angles of incidence (AOI) of light incident on the optical filters may be different from the angles of emission from the xenon flash lamp due to the optics involved (lens system). In the following we will assume that the applied lens system is aberration free, and we will use the word zoom factor to describe the relation between the size of the image of the arc on the filter and the size of the arc itself.

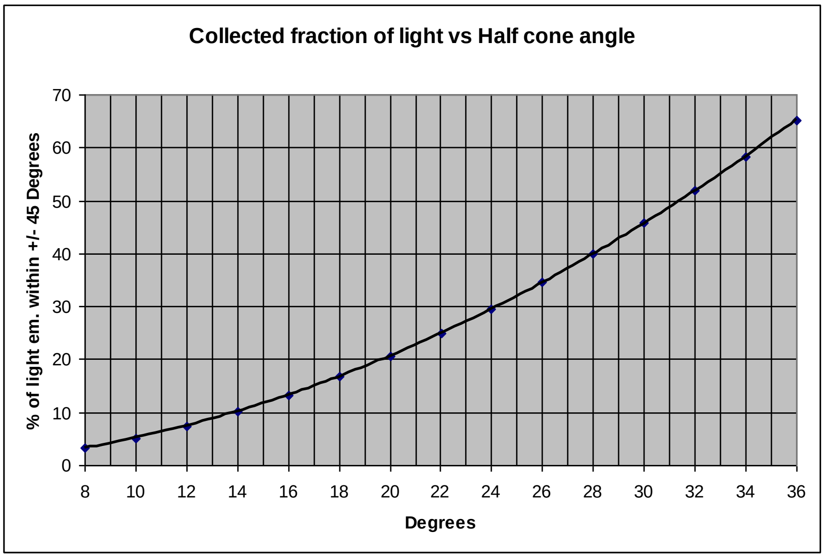


Figure 4

Figure shows the estimated fraction of light contained in a light cone as function of the half cone angle – relative to the amount emitted in the angular range from –45 degrees to +45 degrees.

The filter system is assumed to consist of a linear variable SWP filter and a linear variable LWP filter in series. We will assume that the beam diameter is the same on both filters. It may be necessary to use a second lens to image the spot on the first filter on the second filter to make it work like that. It is up to the customer to decide on that.

Light distribution in a rectangular aperture

In our modelling the light from the arc in the flash lamp is imaged onto a rectangular slit with variable height and width.

Investigations of details in the profiles shown in figure 3 made us describe the intensity in the x-direction by a Gaussian profile

$$I_x(x) = I_0 \cdot e^{-2x^2/W^2} \qquad (1)$$

1.5mm Arc	3.0mm Arc	8mm Arc
W = 0.881mm	W = 0.692mm	W = 0.724mm

Table 1 Derived values for W needed for equation 1

We would recommend to cut-of the light from the two ends of the arc, in order to reduce instability in the system. Figure 5 shows that it is possible to describe the variation in the intensity in the longitudinal (y) direction by a polynomial fit of the fourth degree.

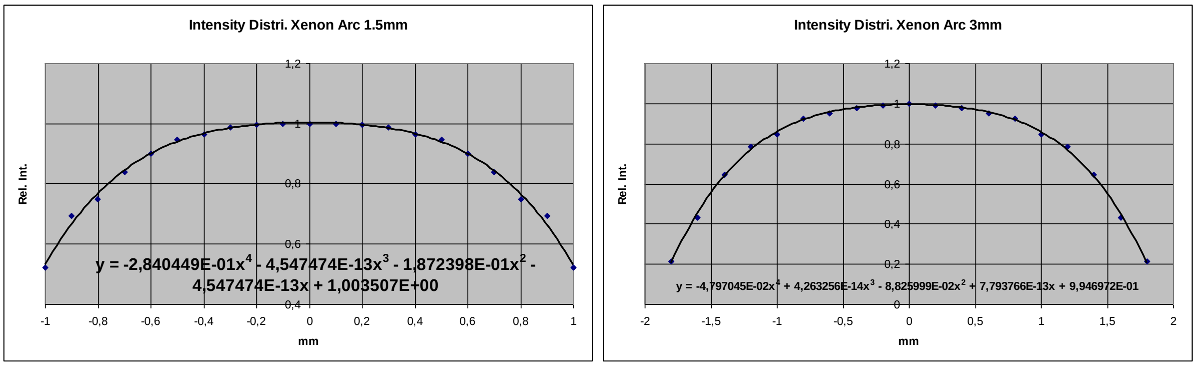


Figure 5 It is possible to describe the intensity distribution along the y-axis by a polynomial of the fourth degree. No fit was established for the 8mm type. However, it is reasonable to assume a constant intensity along the y-axis in case of that type of flash lamp in case length is limited to 6mm.

$$I_y(y) = A_y y^4 + B_y y^3 + C_y y^2 + D_y y + E_y \qquad (2)$$

Assuming a zoom factor of 1, and aberration free imaging, the intensity at a point (x_i , y_i) inside the rectangular aperture is described by

$$I(x_i, y_i) = I_x(x_i) \cdot I_y(y_i) \qquad (3)$$

The power in a small segment dA is described by

$$dP_{ij} = I(x_i, y_i) \cdot dA \tag{4}$$

where

$$dA = dx \cdot dy \tag{5}$$

Analysing the light-spot

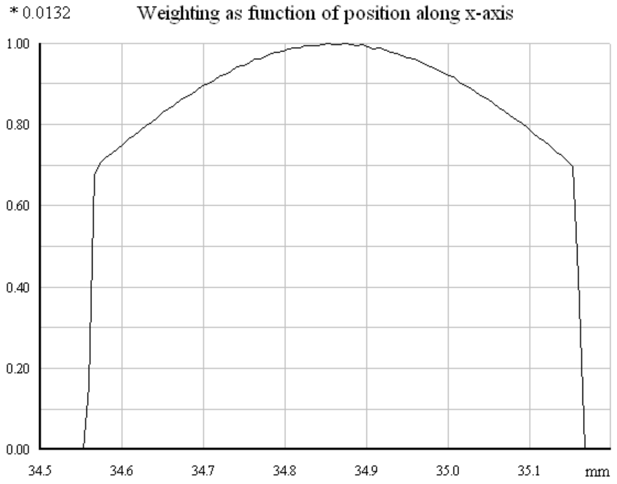
The calculations take into account the variations in the thickness of the layers in the coatings in the length direction and normal to that on the substrate.

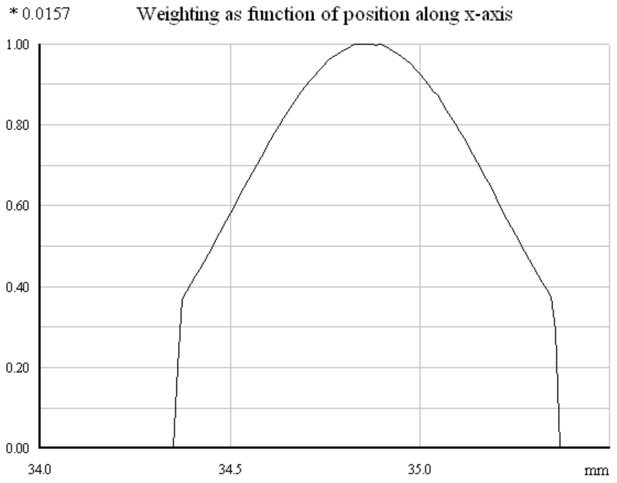
The spectral performance of the linear variable filter in a specific section is believed to be equal to a similar section on a line along the central part of the filter (x-axis). The part of the x-axis where the spot is present is split into 97 parts of equal size. The design software splits the rectangular aperture into millions of small sections. Each of those parts makes a weighted contribution to one of the 97 parts created on the x-axis.

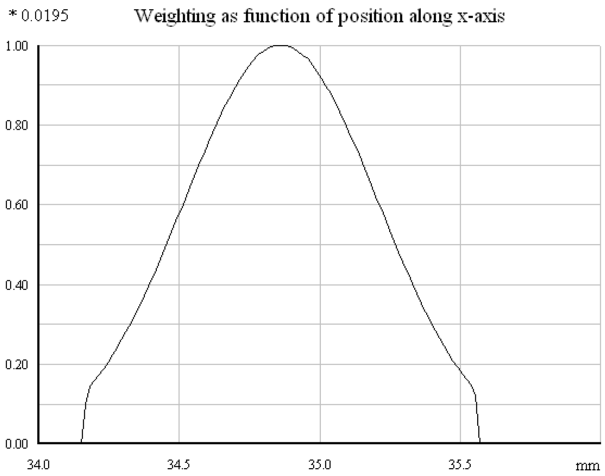
Each contribution to the weighting is described by

$$dWeight = dP_{ij} / I_0 \tag{6}$$

Centring the rectangular aperture with a height of 3mm, with the light spot from the xenon arc (3.0mm type) at the X-axis at 60% of the full length of the coating on the filter – different width of the rectangular aperture gives us the weighting along the x-axis shown in figure 6.







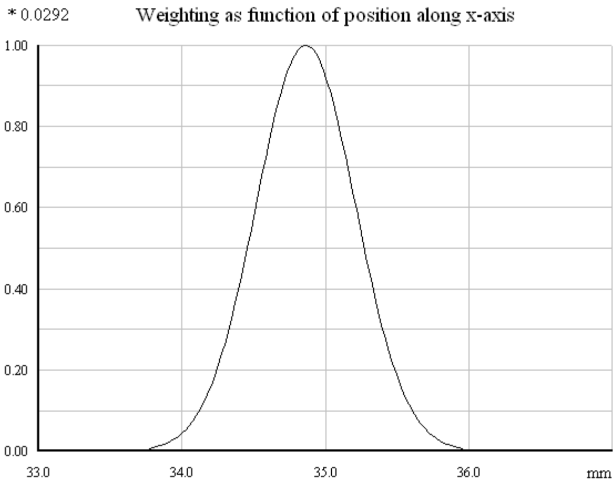


Figure 6 Resulting weightings of contributions from different sections of the filter along the x-axis- calculated by analysing the energy distribution inside the whole rectangular aperture. Height of the aperture is assumed to be 3mm and the xenon flash lamp is of the type named Arc 3.0mm. Width of the aperture is different in the four cases. Starting from the top left, width is 0.6mm, 1.0mm, 1.4mm and 2.2mm.

The diameter of the lens is typically much larger than the light spot on the filter. This means that it is clearly acceptable to assume that the angular distribution of light is the same through every segment of the rectangular aperture. An angular segmentation of 1º was used in all calculations in this work.

Linear variable filters

The linear variable LWP filter corresponds to the present product LVLP [301 – 845]nm LF102064.

The Linear variable SWP filter corresponds to the present product LVSV [300 – 850]nm LF102155.

It is necessary to offset the position along the x-axis on the linear variable LWP filter slightly in respect to the position along the x-axis on the linear variable SWP filter in order to form a band. We will refer to the position along the X-axis in the form of a factor X_L running from 0 to 1.

In the following we will assume that X_L is 0.56 in case of the LWP-filter and 0.6 in case of the SWP filter, corresponding to a mechanical offset of around 58.1mm * 0.04 = 2.3mm.

Impact of opening angle

It is necessary to use a lens system to collect light from the arc in the xenon lamp and image the arc on the linear variable filter.

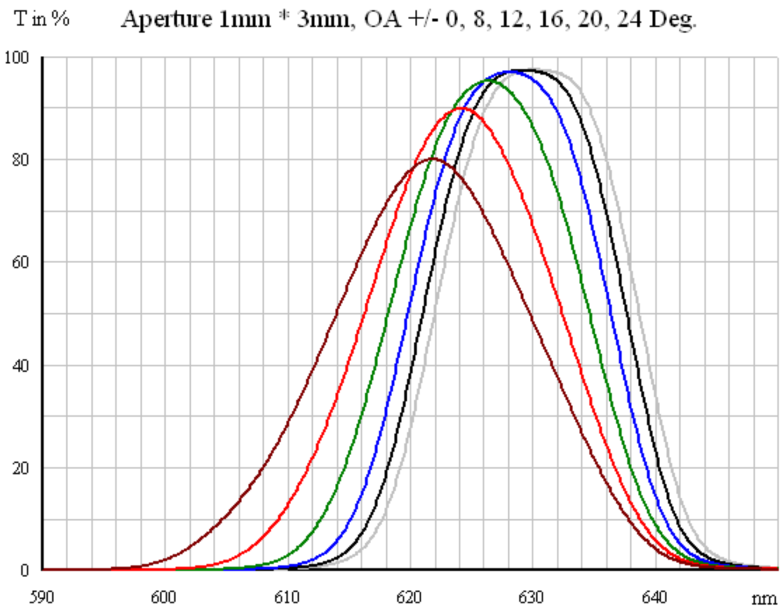


Figure 7

Figure shows the predicted bands formed for opening angles (OA) of 0º (light-gray), ±8º (black curve) ±12º (blue), ±16º (green), ±20º (red), ±24º (brown). The rectangular aperture in front of the linear variable filter has a height of 3mm and a width of 1mm. The central wavelength of the band formed shifts towards shorter wavelength as the OA increases, and the band gets less box-shaped.

Figure 7 shows how the central wavelength of the band shifts towards shorter wavelength as the opening angle (OA) increases. At the same time the band gets less box-shaped. It would not be recommendable to use an OA larger than ±16º in most cases. Please notice that the OA refers to the angles of incidence on the filter. It is equal to the angles of emission from the arc in case of 1:1 imaging (zoom factor = 1).

Blocking of dielectric coatings in general decrease at increasing angles of incidence because of polarisation effects. Figure 8 show wideband plots of the predicted transmission curves for OA = ±12º and ±24º. The degree of blocking is not very different as such in the investigated OA-range.

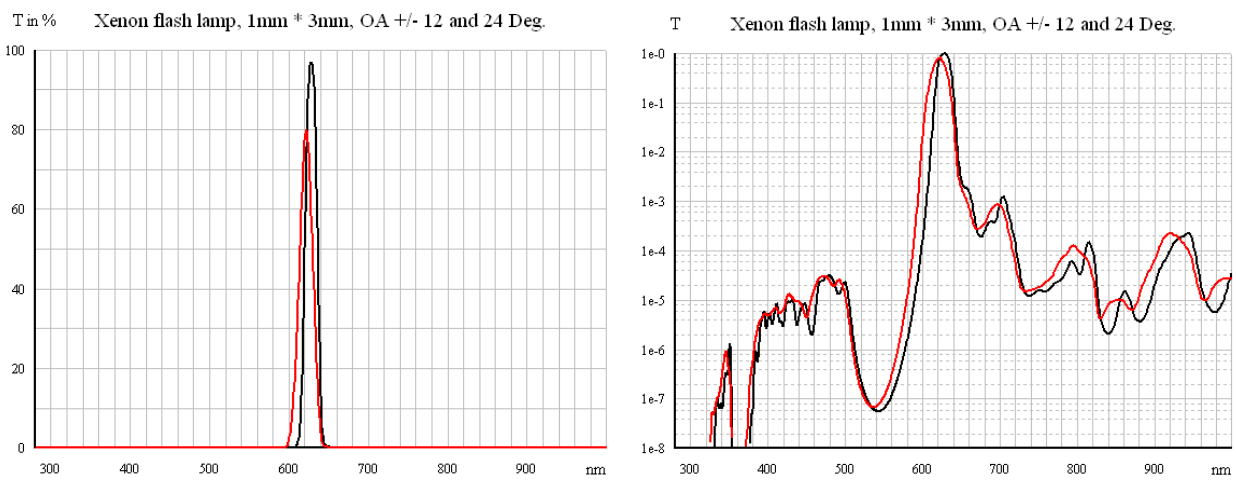


Figure 8 Detailed predicted transmission curves for OA = ±12º (black) and ±24º (red). The degree of blocking is not very different as such. However, it is clearly seen that the bandwidth increases with OA. At the same time the blocking towards longer wavelength is dragged somewhat towards shorter wavelength.

Impact of the width of the rectangular aperture

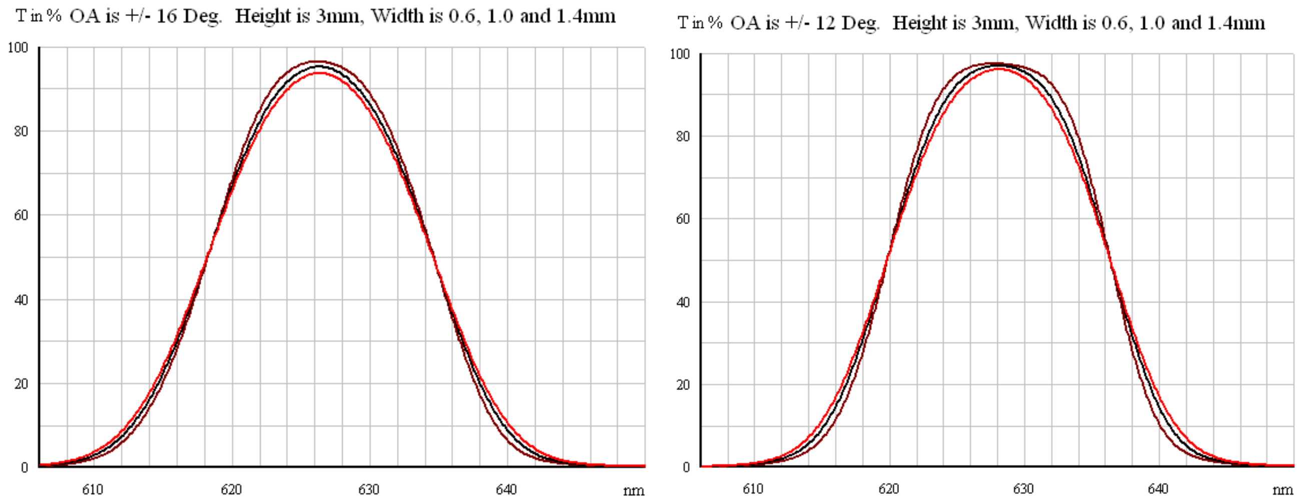


Figure 9 Band gets less box-shaped as the width of the rectangular aperture increases. However, the effect is not as severe as the effect of increasing the opening angle. Brown curves correspond to a width of 0.6mm and red curves correspond to a width of 1.4mm.

It is seen from figure 9 that the band formed gets less box shaped as the width of the aperture increases. However, the effect is not as severe as the effect of increasing the opening angle. Please compare with figure 6 to evaluate how the width influences the collected amount of light from the arc. However, please remember that the emission angle is different from the angle of incidence on the filter except for the situation where the zoom-factor is 1.

Impact of the length of the filter

Increasing the length of the total filter improves the shape of the band. However, figures 9 and 10 show that the effect of controlling the opening angle is dominating.

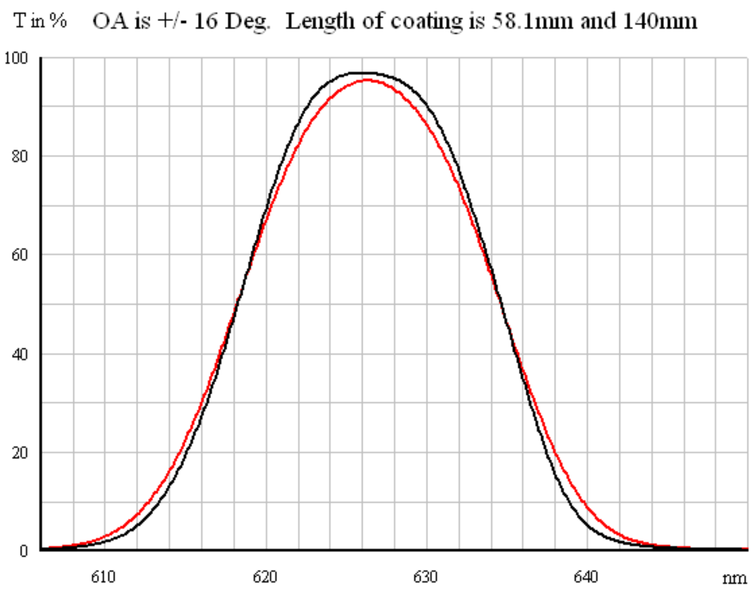


Figure 10

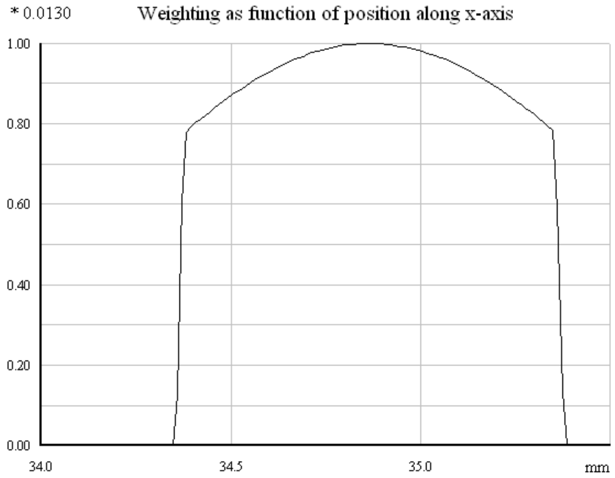
Increasing the total length of the coated area on the filter has a similar effect as decreasing the width of the rectangular aperture. This means that the effect is less pronounced than the effect of changing the opening angle.

Impact of the zoom factor and the height of the aperture

Increasing the zoom factor from 1 to 2 would of course double the dimensions of the image of the arc on the rectangular aperture in front of the filter. However, it would decrease the opening angle of light on the filter by a similar factor. This means that it would be possible to work with an opening angle of emitted light from the arc of ±24º and only have an opening angle of ±12º for the light incident on the linear variable filter. According to figure 4, the collected amount of light from the arc increases by a factor of 3.94 – when the opening angle for emitted light increases from ±12º to ±24º, and by a factor of 8.74 – when the opening angle for emitted light increases from ±12º to ±36º.

Doubling the size of the image of the arc doubles the width as well as the height of the image. However, increasing the height of the rectangular aperture in front of the filter from 3mm to 6mm, or even tripling it to 9mm, only influences the spectral curves marginally.

Keeping the same width of the rectangular aperture – in example 1mm – and doubling the height of it, would lead to a loss of transmitted light of less than a factor 2. This is clearly seen from figure 6. Figure 11 show the resulting weightings of contributions from different sections of the filter along the x-axis calculated by analysing the energy distribution inside the whole rectangular aperture in case of: a) a 6mm * 1mm aperture and a ZoomFactor of 2, b) a 9mm * 1mm aperture and a ZoomFactor of 3.



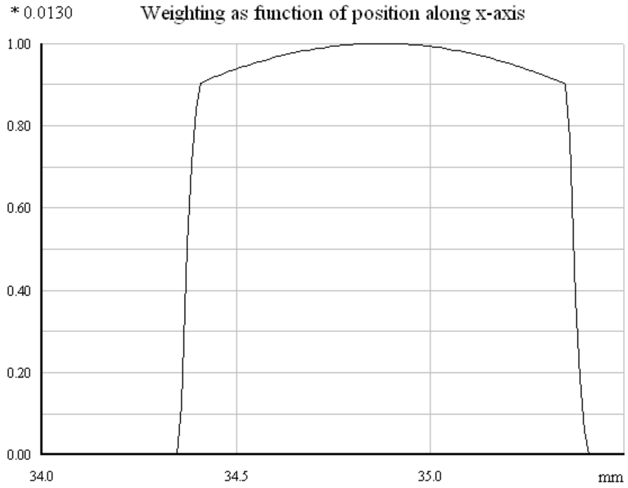


*Figure 11a Resulting weightings of contributions from different sections of the filter along the x-axis calculated by analysing the energy distribution inside the whole rectangular aperture in case of a 6mm * 1mm aperture and a Zoom-Factor of 2. X_L=0.6, Filter in Zone 2. Xenon lamp is of the Arc 3.0mm type.*

*Figure 11b Resulting weightings of contributions from different sections of the filter along the x-axis calculated by analysing the energy distribution inside the whole rectangular aperture in case of a 9mm * 1mm aperture and a Zoom-Factor of 3. X_L=0.6, Filter in Zone 2. Xenon lamp is of the Arc 3.0mm type.*

Figure 12 shows the predicted influence of zoom factors of 1, 2 and 3 (and corresponding heights of the rectangular aperture of 3, 6 and 9mm) on the predicted transmission curves for an opening angle of ±12º.

It is clearly seen that the change in zoom factor and height of the rectangular aperture in front of the filter has only little influence on the band formed.

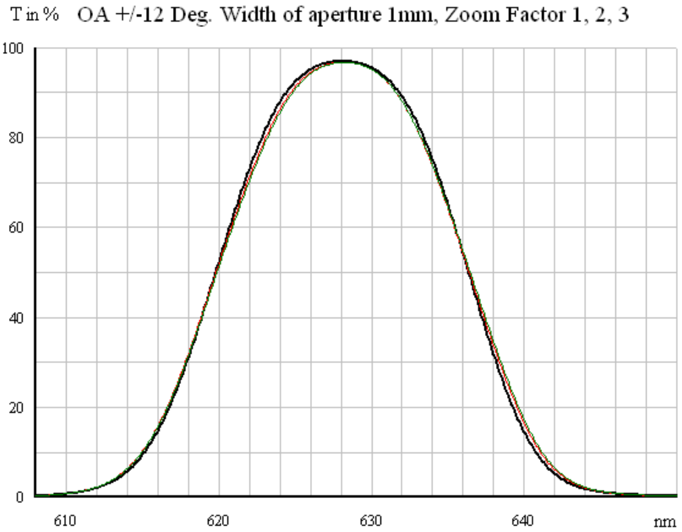


Figure 12

Predicted influence of zoom-factors of 1, 2 and 3 and corresponding heights of the rectangular aperture of 3, 6 and 9mm on the transmission curves for an opening angle of ±12º in for filters produced in zone 2. It is clearly seen that the change in zoom factor and height of the rectangular aperture in front of the filter has only little influence on the band formed.

The height of the present filters is 15mm. It is clearly seen from figures 12 that it is possible to gain a factor of 2 to 3 in energy, practically without losing spectral performance by application of a Zoom-factor of 2 or 3.

Alternatively it would be possible to decrease the opening angle for light through the filter from ±12º to ±8º on the cost of a less pronounced gain in energy in the system.

Rev2 01/06/2011
Rev1 17/11/2010