**Teleconverter**

A teleconverter is an optical component that is placed between your camera lens and camera to increase the focal length of the lens. Common varieties are 2X and 3X teleconverters. A 2X converter used with a 135 mm lens will result in an effective system focal length of 270 mm. A teleconverter consists of a fixed group of elements (consider it to be an equivalent singlet) in a tube of fixed length. It has no moving components and will work with any camera lens.

In addition to its focal length, the other two parameters you need to know about the teleconverter are the tube length $D$ and the position of the singlet from the detector plane $L$. Both of these are fixed and independent of the camera lens used.

![Diagram of teleconverter setup](image)

a) Determine the focal length of an N-X teleconverter. Assume that the object is at infinity. Provide the necessary equations to show that the system focal length is increased by $N$ and the image is still in the film plane. Show that $D$ and $L$ are related.

b) What happens to the $f/#$ of the system with a teleconverter?

c) Provide a typical design for a 3X converter with $D = 50$ mm.
Solution:

a) The distance between the rear Principal Plane of the camera lens and the detector plane is \( D + f_1 \). Remember that the camera lens is now spaced away from the camera lens by the thickness \( D \) of the teleconverter.

\[
\frac{f}{N} \quad \phi = \frac{\phi_1}{N} = \phi_1 + \phi_2 - \phi_1 \phi_2 t
\]

\[
t = D + f_1 - L
\]

\[
\phi = \frac{\phi_1}{N} = \phi_1 + \phi_2 - \phi_1 \phi_2 \left( D - L + 1 / \phi_1 \right)
\]

\[
\frac{\phi_1}{N} = \phi_1 + \phi_2 - \phi_1 \phi_2 \left( D - L \right) - \phi_2
\]

\[
\frac{\phi_1}{N} = \phi_1 - \phi_1 \phi_2 \left( D - L \right)
\]
\[
\frac{1}{N} = 1 - \phi_2 (D - L)
\]
\[
\phi_2 = \frac{1}{N} - 1 = \frac{N - 1}{N(D - L)}
\]

To get the correct new focal length with the Teleconverter:

\[
f_2 = \frac{N(D - L)}{N - 1}
\]

The image plane must also be on the detector.:

\[
d' = \delta' = -\frac{\phi}{\phi} t = -\frac{\phi_1}{\phi_1 / N} (D + f_1 - L)
\]
\[
\phi = \phi_1 / N
\]
\[
d' = -N(D + f_1 - L) = -Nf_1 - N(D - L)
\]

To match the image plane, the system Rear Principal Plane location must be f from the detector. This gives the relationship between L and D:

\[
f = Nf_1 = L - d'
\]
\[
Nf_1 = L - d' = L + Nf_1 + N(D - L)
\]
\[
L = -N(D - L)
\]
\[
L = \frac{ND}{N - 1} \quad \text{or} \quad (L - D) = \frac{L}{N}
\]

Simplifying the expression for \(f_2\):

\[
f_2 = \frac{N(D - L)}{N - 1}
\]
For $N > 1$, the focal length of the teleconverter lens must be negative.
Other expressions are possible ($f_2$ in terms of $D$, for example).

b) Since the entrance pupil diameter remains constant, and the focal length increase by a factor of $N$:

$$f / \#_{NEW} = f / D = Nf_1 / D = Nf / \#_{ORIGINAL}$$

$$f / \#_{NEW} = Nf / \#_{ORIGINAL}$$

c) Example: 3X teleconverter with $D = 50mm$

$$L = \frac{ND}{N-1} = \frac{3 \times 50mm}{3-1} = 75mm$$

$$f_2 = \frac{L}{1-N} = \frac{75mm}{-2} = -37.5mm$$