Camera Adaptor and Digital Microscope

1 Principle of the digital microscope

The optical microscope has been a standard tool in life science as well as material science for more than one and a half centuries.

The optical microscope is often referred to as the “light microscope”, which is a type of microscope, using visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope. Historically optical microscopes are easier to develop and popular because they use visible light so that samples may be directly observed by eye.

A digital microscope is a microscope equipped with a digital camera allowing observation of a sample via a computer. Microscopes can also be partly or wholly computer-controlled with various levels of automation. Digital microscopy allows greater analysis of a microscope image, for example measurements of distances and areas and quantitation of a fluorescent or histological stain.

Digital Microscope=Camera+Adaptor+Microscope

Some hobbyists prefer to modify generic cameras for use with a microscope. This can be accomplished by adding an attachment to the camera so that it can be used with a microscope eyepiece. Scientific supply companies sometimes sell kits for this purpose, and people who are skilled at such things can also fabricate specialty attachments to make a microscope camera. The image quality may not always be the best, but this option can be much easier to use and much less expensive than a specialized microscope camera.

When choosing a regular camera, there are a number of options to consider. The choice between a digital and film camera is an important issue, as lens quality, resolution, the sensitivity of the camera's sensor, and the ability of the camera to interface smoothly with existing equipment. For those who have an opportunity to do so, it can be a good idea to test several models in a lab to see which one feels most comfortable to use, and to look at samples from various microscope cameras to get an idea of the kind of image quality to expect.

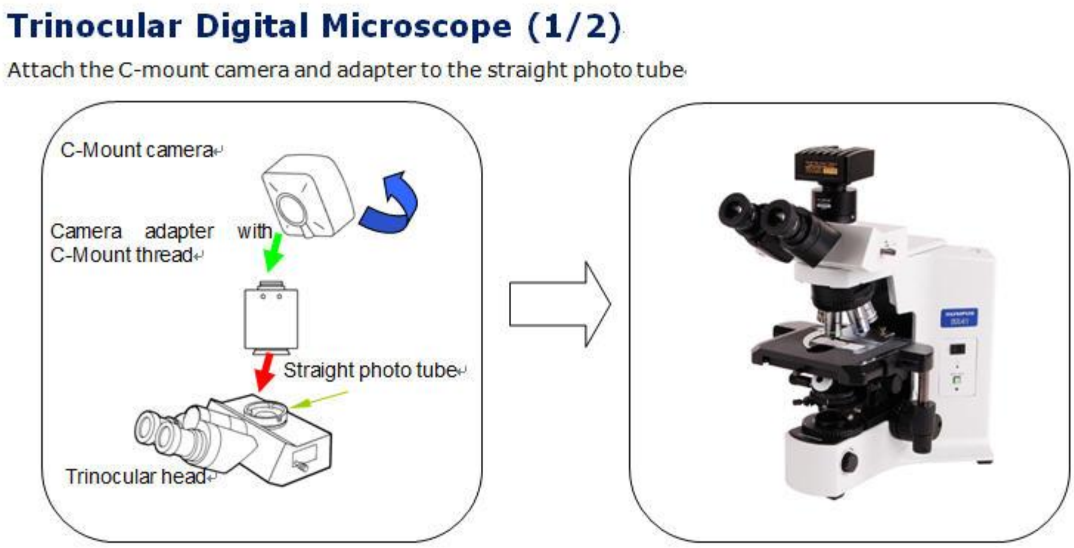
We here will pay more attention on the basic principle of how to configure a digital camera for the microscope. Camera performance and parameters will not discuss in this paper.

2 Basic configuration of the digital microscope

Basically, there are 3 options for connecting a camera to a microscope to form what user called digital microscope. They are

1. Straight photo tube;
2. Trinocular head or 3rd ocular tube;
3. One of the microscope's eyepieces tube or ocular tube;

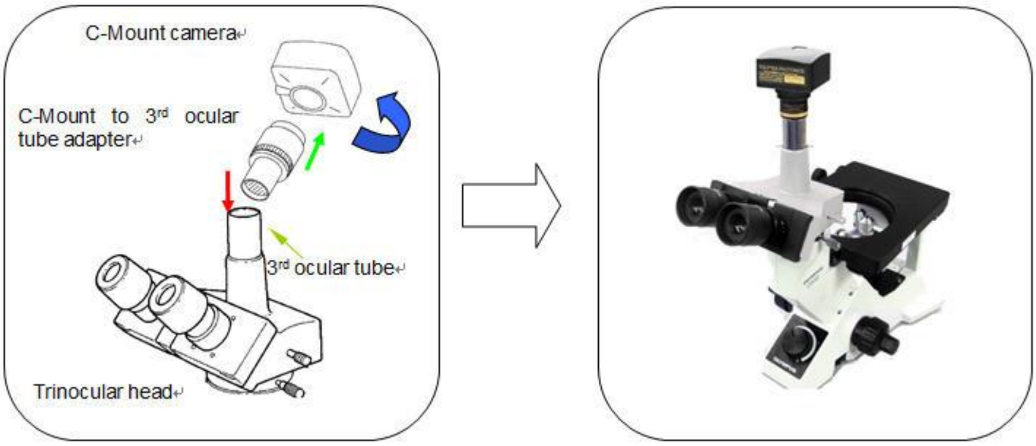
Actually, options 2 and 3 have the same connecting optics and they have the same principles? I will discuss it late. Here we discuss all of these 3 configurations as below:



Connecting a camera to a straight photo tube with C-Mount camera adaptor

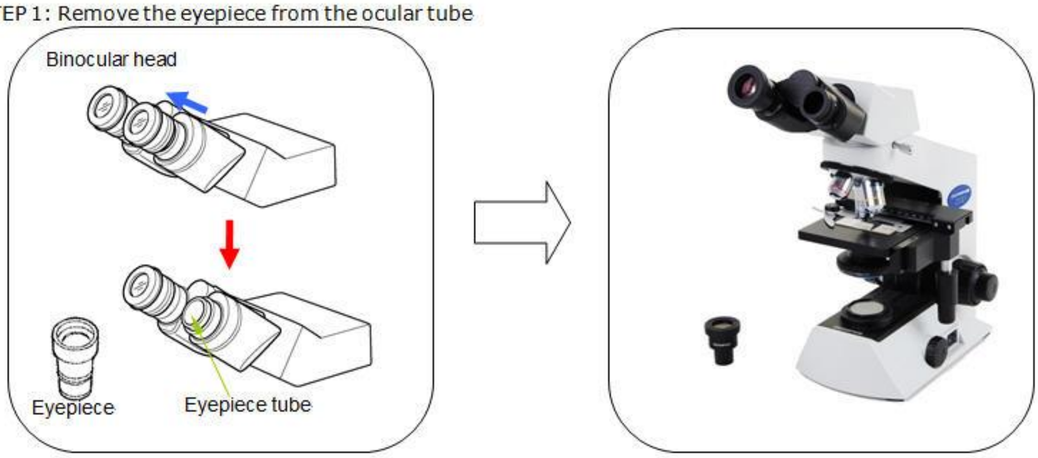
Trinocular Digital Microscope (2/2)

Attach the C-Mount camera and adapter to the 3rd ocular tube

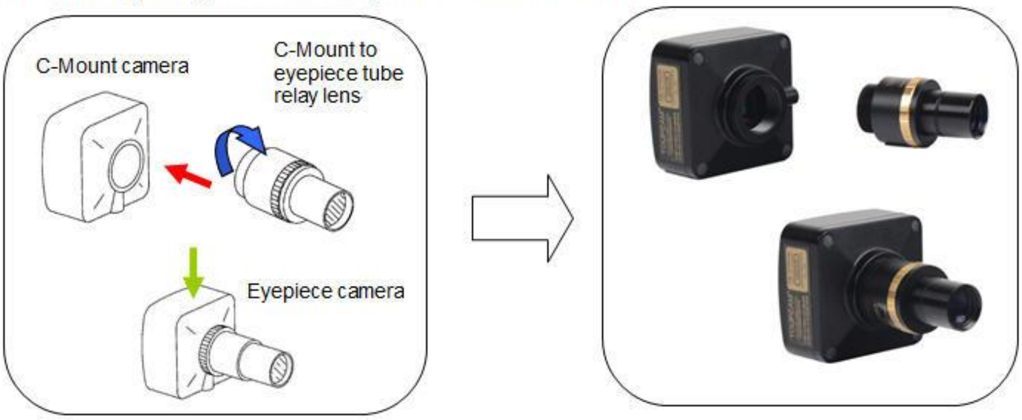


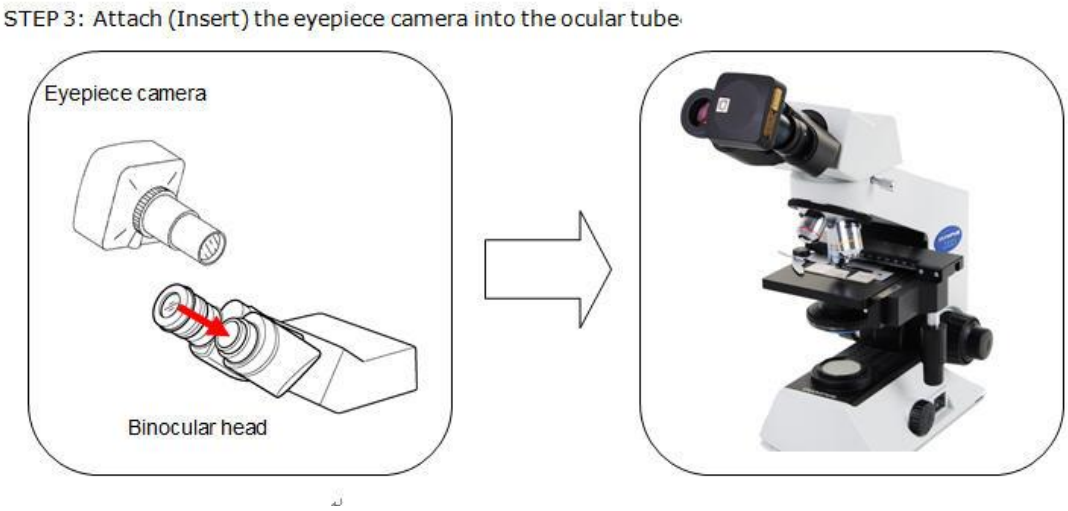
Connecting a camera to the 3rd ocular tube with eyepiece adaptor
(with Reduction Lens inside to adapt different sensor size)

STEP 1: Remove the eyepiece from the ocular tube



STEP 2: Attach (Screw) the camera adapter to the C-mount camera





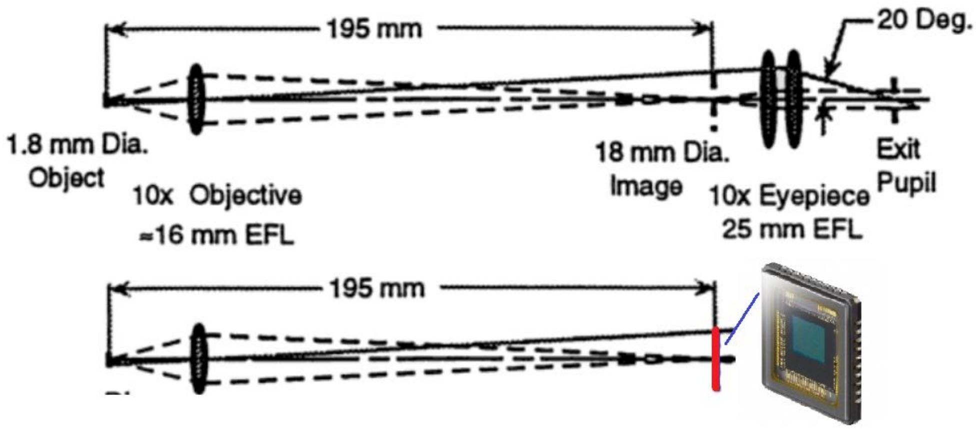
Connecting a camera to one of the ocular tube of the microscope

3 Ways to pick up the microscope image

Depending on the set-up, it can be with intermediate optics (Reduction Lens or Camera Adaptor) between the camera and the microscope's objective, or without it.

3.1 Directly pick up method

The image produced by the microscope objective can be directly picked up by the sensor of a camera, without an eyepiece or other intermediate optics. Here objective of a microscope produces a ***real image*** directly on the camera's sensor. The objective produces a relatively large image (**for 18mm ocular tube, it is 18mm, for 20 or 22mm ocular tube, it is 20 or 22mm**), compared to the small sensor of many cameras. Unless the sensor is large, there may be quite much empty magnification and low bright image (the larger the field, the lower the light).



Directly pickup method

3.2 Photo Project Ocular Method

The image produced by the microscope objective is passed through a photo projection ocular (photo eyepiece), which then projects a real image on the sensor of an SLR camera. There are no camera objectives involved. The projection eyepiece corrects optical errors which are produced by the microscope objective. These photo projection eyepieces are compensating optical elements. This means that they are designed to correct various lens errors that the objectives produce, including field curvature and chromatic aberration. These projection oculars are therefore manufacturer dependent and must correspond to the objectives of the manufacturer. Besides image quality, another advantage is, that parfocality is maintained between the camera and the eyepieces (i.e. both images are in focus at the same, and there is no focus deviation).

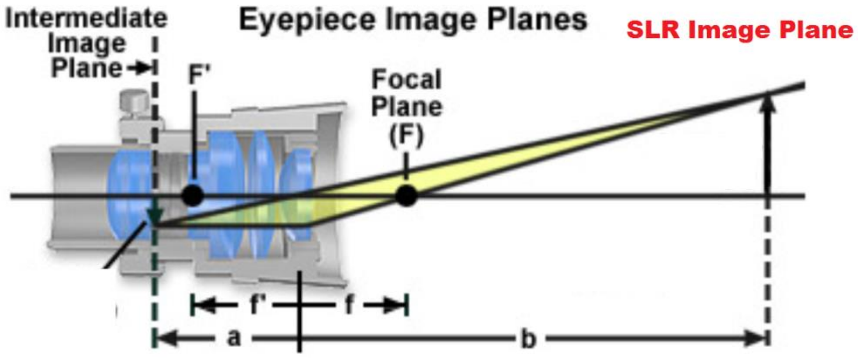
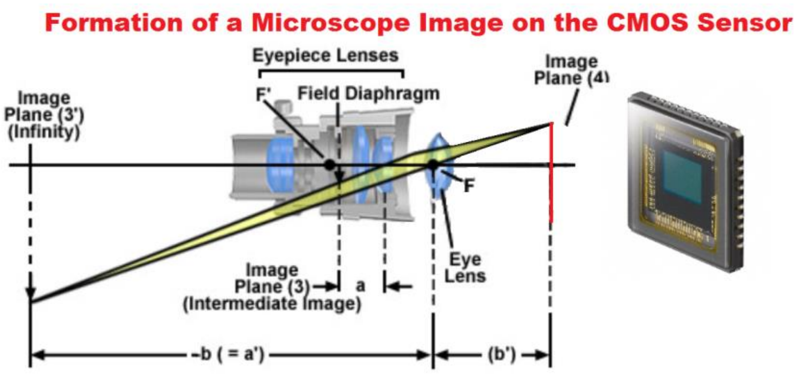


Photo project ocular method

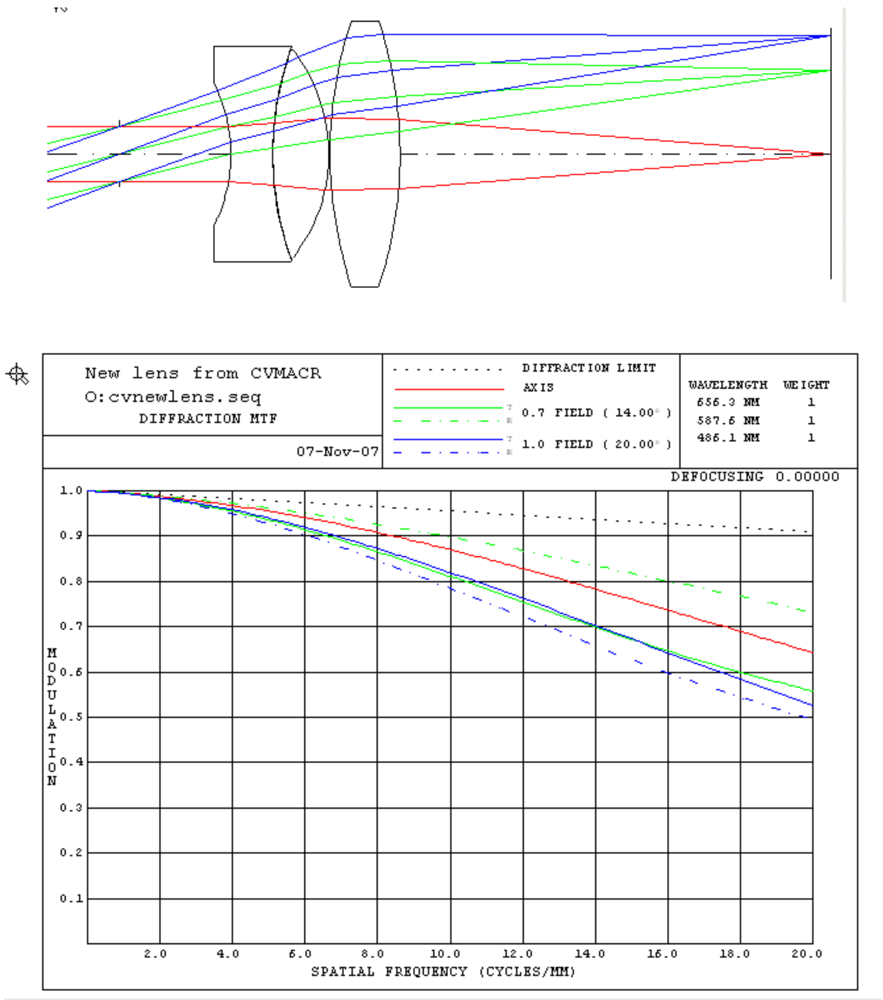
3.3 Eyepiece first, then adaptor Lens:

The image produced by the microscope objective is first passed through a regular eyepiece. A *virtual image* is produced this way, which cannot be used to directly make a picture. A camera (with its own objective) then picks up the virtual image and projects it on the sensor. The camera works like the eye, which converts a virtual image to a real image. This system is used in a focal photography, in which a regular compact camera (with its own objective and all) is attached in front of the eyepiece.



CMOS sensor after the eyepiece method

From the above discussions, one can find that this is with bad quality because of the eyepiece is a large aberration system for only human eye. Human eye has the ability to compensate the image shift in the focal plan so that an amount of accommodation is allowed for the eyepiece. For the low price eyepiece, the image quality is even worse. So that high quality eyepiece with high MTF value is needed. Here we show the moderate eyepiece and it's MTF for your reference.

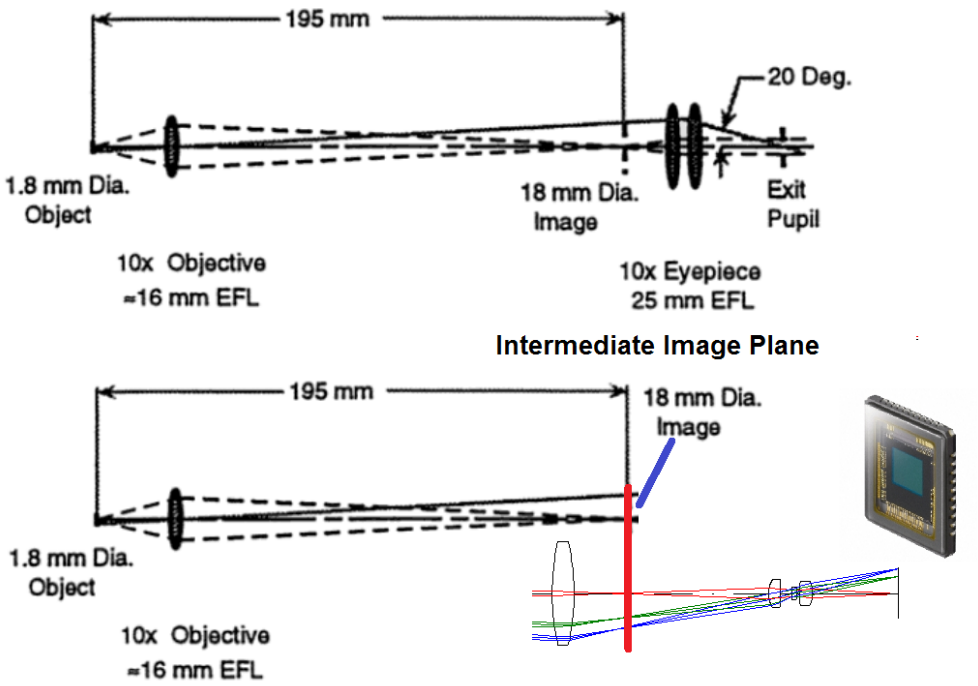


Kellner eyepiece and its MTF

3.4 Pick up through intermediate reduction lenses

The image produced by the microscope objective can also pass through a **reduction lens** (or **camera adaptor** or **eyepiece adaptor**) before reaching the camera sensor. In this way the image produced by the microscope objective is reduced in a more precisely size to match the small sensor size of the digital camera.

The **reduction lens** produces a real image on the camera sensor. Without the reduction lens the image would be magnified too much. The reduction lens also results in a brighter image. This is an improvement to the first point from above. Eyepiece cameras for microscopes use this system. The Reduction Lenses is not a compensating photo eyepiece and therefore does not correct lens errors produced by the objectives.



Pick up through intermediate reduction lenses

From figure as shown above, it can be found that a field lens is often insert before or after the intermediate image to refract the light toward the CMOS sensor

4 Basic requirement of the Reduction Lenses

Normally, you cannot afford to buy a camera with sensor size larger than 18, 20 or 22mm. Thus a Reduction Lenses or Camera Adaptor is needed to connect a camera to the microscope.

To satisfy different sizes of the sensor, different Reduction Lenses are needed. To cover the most of the sensor size, ToupTek' s optical experts design a series of the Reduction Lenses. What customer needs to do is to choose the C-mount camera and TouTek engineer will choose the right Camera Adaptor for your camera.

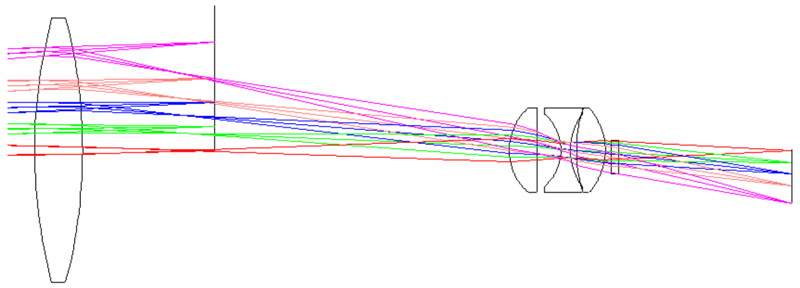
There are many Reduction Lenses on the internet, then how to judge which is better than others. Here, we list some basic rules for your reference:

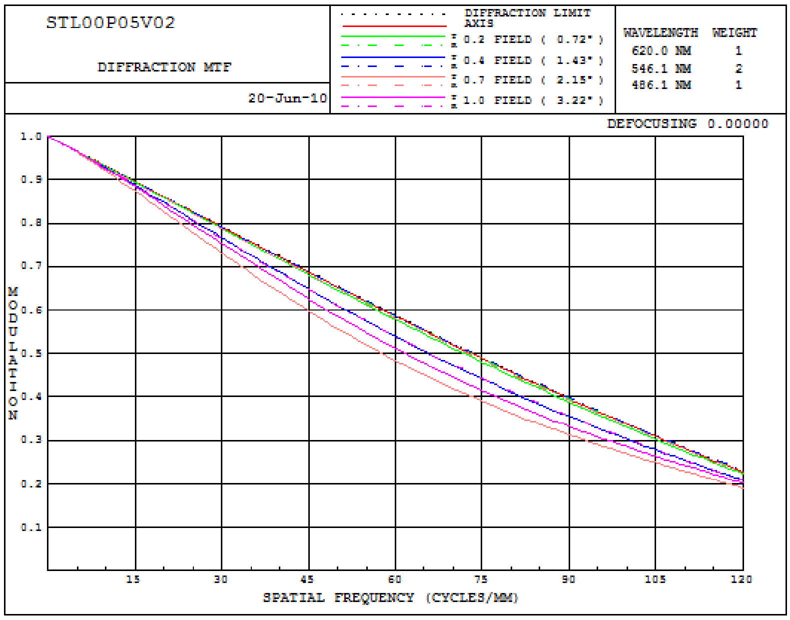
1. Good Reduction Lens should couple with all of the objective lenses
2. Good Reduction Lend should couple with the objective lenses in both stop position and stop size
3. Reduction Lenses should have high transmittance and low reflectivity
4. High quality IR-CUT should be used to cut all of the infrared light to stop these lights participating the imaging process.
5. No ghost image on the image plane.
6. The lenses tube should be absolutely blackened to prevent the stray light from the tube surface.

5 Why so many low quality Reduction Lenses in the microscope eyepiece camera market

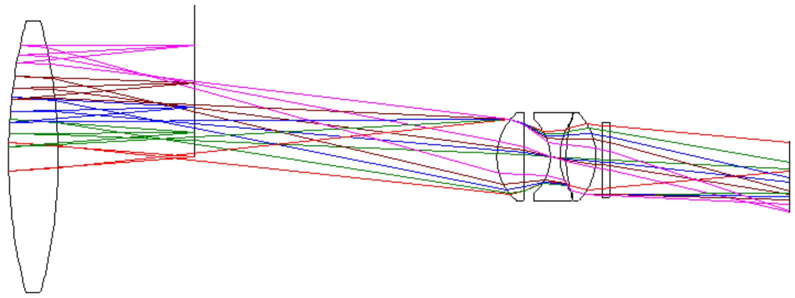
5.1 Wrong stop position and size

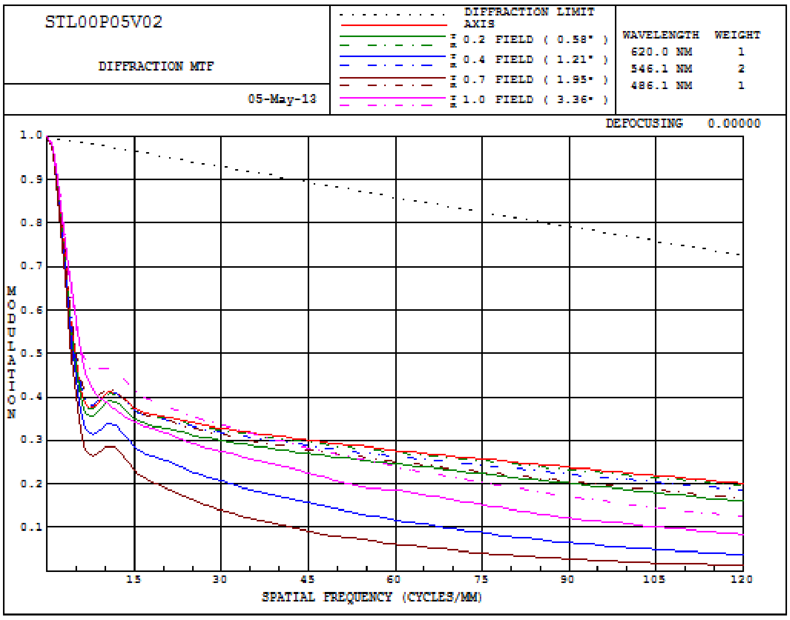
However, most of the Reduction Lenses did not obey the above rules. The most of the design did not consider objective lenses' stop position and size. Here we show an example of the same lens, but with different MTF in coupled or miscoupled conditions





The correct coupled condition: the real image ray fan structure from the objective lenses is not the same at different field. The MTF is reach to the diffraction limited value.

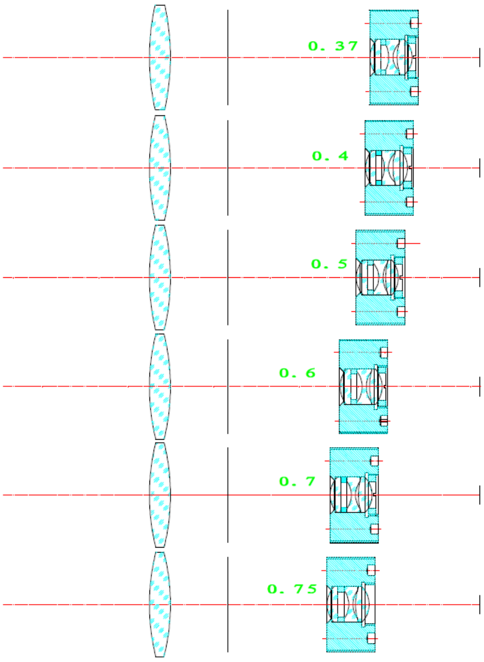




The wrong coupled condition: the real image ray fans from the objective lenses are the same at different field. The MTFs are strayed always from the diffraction limited MTF value.

5.2 Different magnification Reduction Lenses have different sizes

Further, the different Reduction Lenses should have the same conjugate distance between the real image of the objective lenses and the sensor. TouTek engineers designed and optimized all of these lenses at a time to ensure this basic requirement. This often increase the fabrication cost but make microscope eyepiece camera more coordinated.



The different Reduction Lenses have the same conjugate distance

5.3 Long conjugate distance

Another issue is that the conjugate distance should have a moderate distance. Some of the Reduction Lenses in the internet often have long distance (for example 120mm), which will make the whole digital microscope system look ugly and will not match with your beautiful microscope itself.

5.4 Ghost image problem

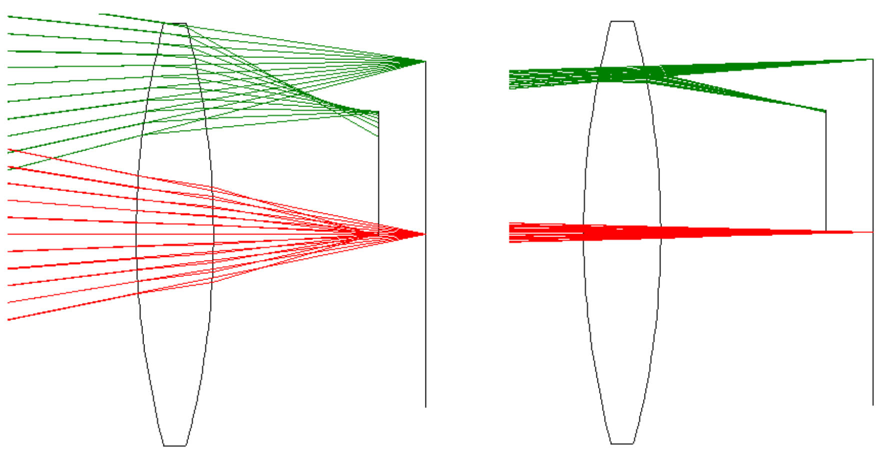
The fourth issue is the ghost image often appeared in the center of the image. The possible reasons may be

1. The lens did not coated with multiple layer thin films
2. The tube is not blackened or blackened with bad quality
3. The IR-CUT is cheap which cannot cut off the infrared light thoroughly
4. Ghost image formed on the sensor plane.

5.5 Black spots

The fifth issue is the black spots appeared on the captured image. This is because of the following drawbacks

1. There are dusts scattered on the sensor. This often caused in the installation process because of the badly polluted workshop and is often appeared for those cheap camera companies.
2. There are scratches or dusts on the IR-CUT. IR-CUT is a focal plane component in the camera and a strict production environment is needed for this part. ToupTek purchase the IR-CUT from our mother company who is a public company and makes the IR-CUT, OLPF used in commercial digital cameras of SONY, NIKON, CANON and OLYMPUS et al. They have 80 sets of high-end coating machine which is the best factory in the field of IR-CUT and OLPF production.
3. There are dusts and scratches on the field lenses. Field lens is also an intermediate image plane component. It has strict requirement for its surface quality.



Field lenses with large NA=0.2(left) and small NA=0.025(right) which is often the case for the microscope

From the above analysis, one can find if there is a small dust on the field lenses with lower NA, most of the light will be blocked by the dust and thus there will be a few or no light impinge on the image sensor, thus a blurred black spot will appeared on the image. ToupTek gives strict requirement for the field lenses and sources the best factory to polish this field lens to ensure the product quality. Even with this strict requirement, they are still 20% substandard lenses that did not pass the examination in our clean room. One can find the strictness of this part.

5.6 Reduction Lens NA and its image quality

The microscope objective's NAs are listed in the table shown below.

Magnification	10X	20X	40X	60X	100X
Object Lenses NA	0.25	0.50	0.65	0.8-0.85	1.25-1.50
Reduction Lenses NA	0.025	0.25	0.0163	0.0133~0.0142	0.0125~0.015

The Reduction Lenses NA can be calculated according to the following equation

Reduction Lenses NA=(Object lenses NA)/Object magnification

From the above table, one can find the largest Reduction Lenses NA is 0.025 for the 10X objective lenses. ToupTek choose 0.025 as the NA of the Reduction Lens to ensure the light from the objective lens can be totally transfer to the sensor plane. Most of the lens in the internet only set the NA to 0.01 or even lower to reduce the pieces so as to reduce the fabrication cost. This will cut most of the light and increase the noise for you camera.

5.7 Reduction Lens with low MTF value

The MTF is an expression describing the reduction in contrast of a sinusoidal signal (60% contrast sine waves) as a function of spatial frequency. The limiting resolution of an electronic detector is the smallest target size that is detectable above the noise threshold, a concept that is often referred to as the frequency of limiting resolution, which is the spatial frequency for which the MTF falls to a value of 3 percent, corresponding to the limit of visible detection.

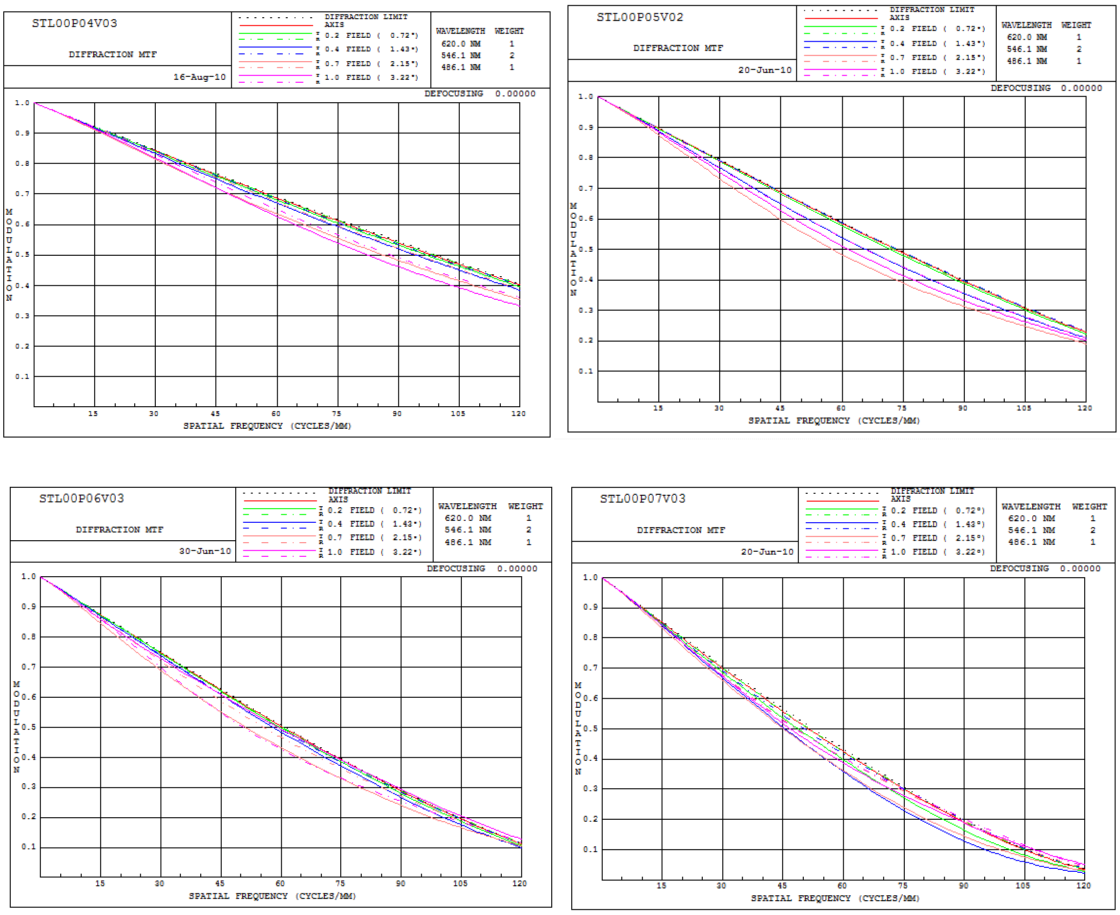
The MTF of the Reduction Lenses should not be lower than that of the Object lenses MTF by the magnification.

Magnification	10X	20X	40X	60X	100X
Resolution Distance	0.00112	0.00056	0.000431	0.00035	0.000224
MTF(pairs/mm) of the Object lenses	446	892	1160	1428	2232
MTF of the Reduction Lenses	44	44	29	23.2	22.32

The low quality Reduction Lenses try to use few lenses (for example doublet). This will cause the lower MTF value and thus cannot discriminate the distance which can be resolved by the objective lenses. This will be cause the waste of the objective lens discrimination power.

As show below, all of the ToupTek's Reduction Lenses MTFs reaches to the diffraction limited resolution.

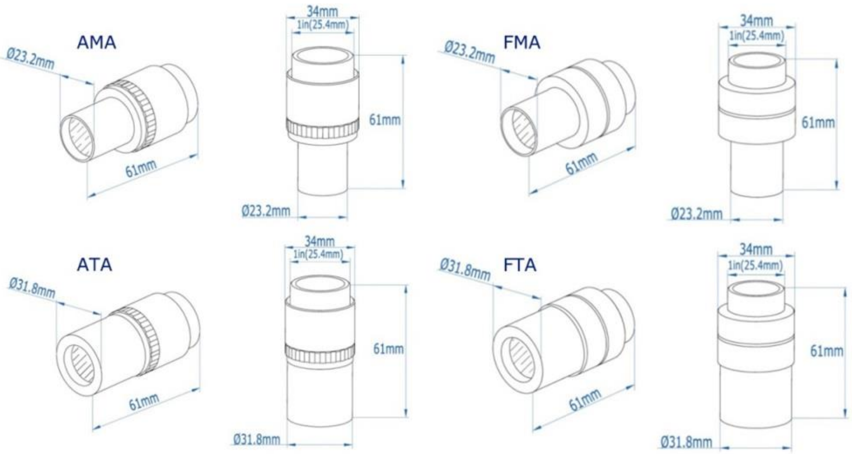
Another interesting phenomenon is that the maximum MTF value is 120, not 40. This is because we select 0.025 as all the Reduction Lens's NA.



MTFs of 0.37X, 0.50X, 0.60X and 0.75X Reduction Lens

6 Reduction Lens and Its Dimension

Most of the ocular tubes are 23.2 mm. The adaptor should insert into this tube in one end while the other end should be screwed into the C-mount camera. This constitute the interface standard of the Reduction Lens as shown below



Basic dimensions of the
AMA(Adjustable Microscope Adaptor), FMA (Fixed Microscope Adaptor),
ATA(Adjustable Telescope Adaptor) and FTA(Fixed Telescope Adaptor)

For the stereo microscope with 30mm or 30.5 mm ocular tubes, the 23.2mm to 30 mm adaptor or 23.2mm to 30.5 mm adaptor for the eyepiece adaptor should be chosen. They are shown as follows

23.2mm to 30 mm adaptor and 23.2mm to 30.5 mm adaptor for the eyepiece adaptor

The final configuration of the Camera+Adaptor should look like this:

Camera+AMA,Camera+FMA,Camera+ATA and Camera+FTA

7 Conclusion

If you configure your optical microscope to digital microscope, you can try any ways to do it. But I think the best way is to directly purchase a C-mount camera and an adaptor. Then screw the adaptor to the C-mount camera, finally insert the 23.2mm end to the trinocular tube or eyepiece tube.

A recommended company for the microscope camera is ToupTek

> ToupTek is formed by a dynamic group of young Ph.Ds from electrical, optical, mechanical and computer engineering field...
>
> ToupTek members try to do something interesting and meaningful in the world...
>
> ToupTek pursuits superior quality for their products...
>
> ToupTek's products are all carefully organized and properly prepared...
>
> ToupTek thinks customer service is the most important part of any business...
>
> ToupTek's products enjoy unlimited service in the world.

Finally,

> ToupTek knows imaging
>
> Touptek makes cameras

We think this is why ToupTek!!