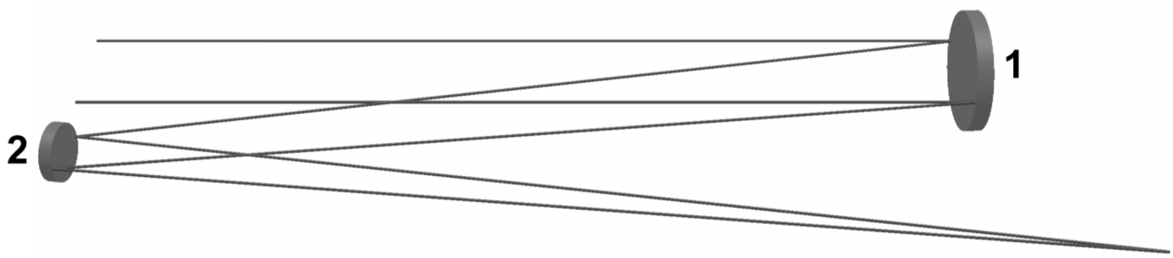
Compact Multi-Schiefspiegler-Telescope

A new optical telescope design of the Schiefspiegler type has been developed by the author. Two different prototypes with apertures of 140 mm and 150 mm have been produced. These new telescopes have been developed to fulfill the needs of amateur astronomers for compact unobstructed mirror telescopes.
Mirror telescopes of the Schiefspiegler type are free from central obstructions by an additional secondary mirror. They allow observations with an almost perfect image quality, like that of highly color-corrected apochromatic refractors. The Schiefspiegler optics consists of two or more concave and convex shaped mirrors which can be produced easily by experienced opticians or even by amateurs. Therefore the costs of the optics is far less than that of a complex refractor objective of comparable size.

The simplest form of a Schiefspiegler has been developed by Anton Kutter from Germany about 60 years ago [1-3]. It conbines a tilted concave primary mirror (**1**) and another tilted convex secondary mirror (**2**). Using a sufficient tilt of the primary mirror, the secondary mirror can be located outside of the incoming light-path and avoids the central obstruction of a secondary mirror which is typical for Newtonian type - or Cassegrain telescopes.
The central disk of a secondary mirror located within the light pass results in some light loss and which is more important – it causes diffraction of light at the rim of the disk. This reduces the image contrast of small details, which is especially important for observations of the moon and planets.

Optical path of the Schiefspiegler-Telescope



The above Fig. shows the Schiefspiegler optics developed by A. Kutter with primary (1) and secondary mirror (2).
The tilt of the primary mirror induces significant image errors (astigmatism and coma) at the central part of the image plane (even for a bundle of rays located on axis). A defined tilt of the secondary mirror can produce the same image error with opposite sign and allows their compensation. Unfortunately, these errors can not be compensated perfectly, because the optical design has not enough degrees of freedom. The image errors can be minimised by realising Schiefspieglers with small apertures of less than 150 mm and low f-ratios (smaller than about f/18). In its simplest design both mirrors use spherical surfaces. For apertures of 150 mm and more an additional correction lens in front of the focusser is necssary to compensate residual errors.

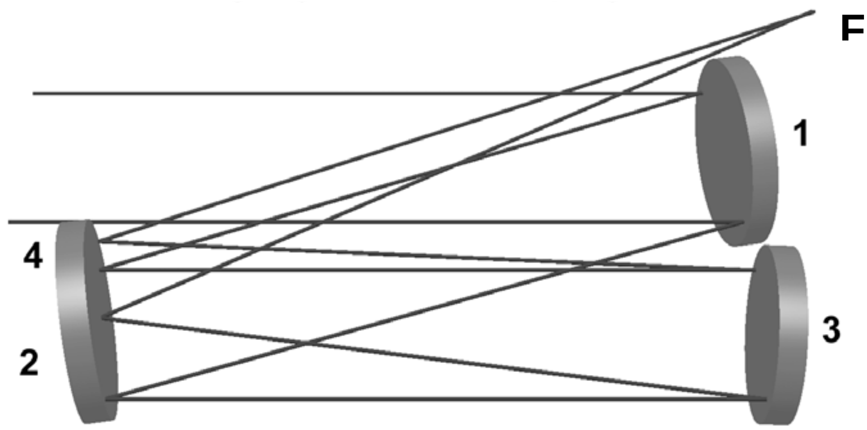
The small light power of the Schiefspiegler (typically f/18—f/30) restricts the observed objects practically to the sun, moon and planets. Furthermore the optical layout requires a long tube and therefore a stable mounting located on a fixed observation site.
The new type of a Schiefspiegler using 3 mirrors avoids these disadvantages almost completely and results in some new optical and mechanical features.

Optical layout of the Multi-Schiefspiegler

The optics of the Multi-Schiefspiegler uses three mirrors. One of them is used twice to realise a total of 4 reflections. The additional degrees of freedom in the optical design allow to compensate the image errors perfectly on axis. Even for 0.5° field of view a diffraction limited image quality is obtained. It is possible to construct compact Schiefspieglers with medium light power (up to f/10) which have rather large apertures. These telescopes can be used for almost all types of astronomical objects. The compactness of the tube allows to transport them to favourable observation sites.

The optical system of the Multi-Schiefspiegler uses the secondary mirror twice, it carries the second (2) and the fourth reflection (4). This mirror has to be about 6-20% larger in diameter than the primary mirror (1), depending on the optical layout. The concave primary (1) and the convex secondary mirror (2. and 4. reflection) use spherical surfaces and the third mirror (3) is parabolic. The image plane (F) is located sideways behind the primary mirror. The resulting image plane tilt amounts to 1.4° - 2° and can be neglected visually. The image distortion is less than 1.2%.

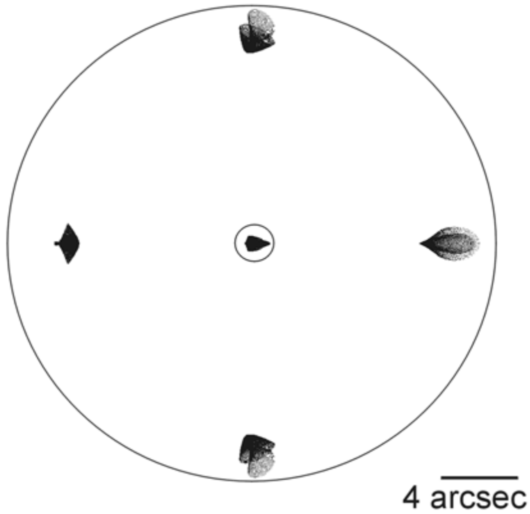
Optical path of the Multi-Schiefspiegler



The numbers in the Fig. above describe the sequence of reflections. Only the marginal light-rays within the telescope´s plane of symmetry (saggital plane) are shown. The centre of the fourth reflection (**4**) is shifted with respect to the second reflection (**2**) along the symmetry plane. This is necessary to make the final image plane accessible to the observer at position **F**.

The f-ratio of the optical system is determined by the focal length of the parabolic mirror. A conic constant k = 0 defines a spherical curve of the mirror and k = -1 a parabolic curve (see table below).
The optical layout (Design 1) for a Multi-Schiefspiegler with an aperture of 150 mm and a corresponding f-ratio f/10.9 was calculated and the data were shown in the table. The corresponding spot-diagram for 0.5° field of view was displaced below.

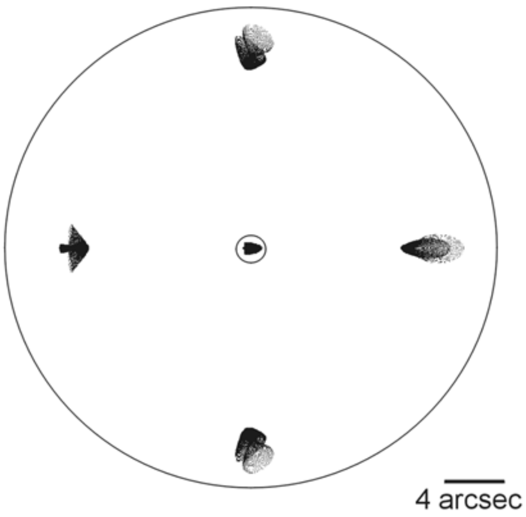
spot-diagram (design 1)



A spot - diagram describes the collimation of a parallel bundle of light within the image plane. In this case it is calculated for a bundle of light rays parallel to the optical axis and also for 4 tilted bundles (tilt angle 0.25° each) entering the aperture from 4 different directions. The circle around the central spot represents the diameter of the Airy-disc. All image errors, which result in a collimation of the rays located within this circle are not detectable. This layout results in an almost diffraction limited image quality for 0.5° field of view. The spot-diagrams have been produced by using the winspot-software of D. Stewick [4].

The corresponding geometrical and optical data for design 1 are shown in the table below.
Reflection No. 4 denotes the additional reflection on the secondary mirror. The mirror diameters in brackets are necessary to ensure an unvignetted field of view of 0.5°. Due to the extension of the illuminated areas and the separation of their centres (of the second and fourth reflection) a secondary mirror is needed, which is about 9% larger than the aperture. By using a standard sized secondary mirror of 150 mm in diameter the aperture has to be restricted to a diameter of 144 mm. Nevertheless the aperture can be extended to 150 mm resulting in more light and resolution of objects which are centred within the field of view (these central rays are unvignetted).
Since the optical system of the Multi-Schiefspiegler uses only spherical and parabolic mirrors they could be commercially produced without serious problems. Amateur telescope makers can produce their own optics and are encouraged in doing so. One has to take into account that the surface accuracy of each mirror should be doubled compared to that of a single mirror optic (Newton telescope) which fulfills the Rayleigh criteria [3]. Otherwise a higher amount of wavefront distortion might be the result, which limits the optical performance of the telescope.

spot-diagram (design 2)

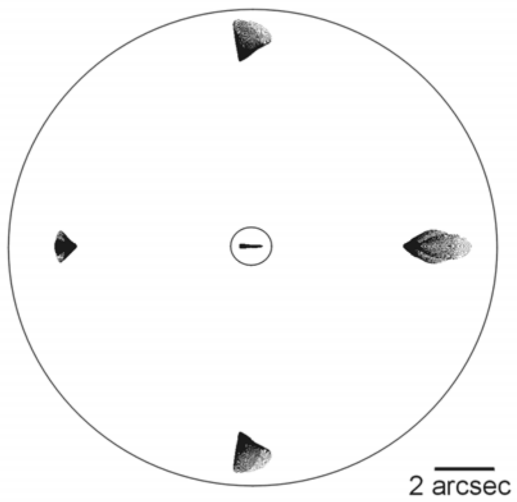


A second design with 150 mm aperture was calculated with a f-ratio of f/9.2. The corresponding spot-diagram is displayed on the left side. A diffraction limited image quality is obtained near the field centre. Due to the higher f-ratio the off-axis image errors are slightly larger than that of design 1.

The geometrical and optical data for design 2 are given in the table below. In contrast to design 1 the focal length of the 3. mirror has been reduced from a parabolic f/8 mirror to a parabolic f/7 mirror, which results in a higher f-ratio of the telescope. The radii of the first and second mirror remain unchanged.

This design allows for a rather compact telescope tube with a total length of about 620 mm (see table, technical data of the telescopes).

spot-diagram (design 3)



Design No. 3 describes the optical layout of a Multi-Schiefpiegler with 200 mm aperture and f-ratio of f/12.5. The spot-diagram (left side) demonstrates the high image quality within 0.5° field of view. This design uses a parabolic tertiary mirror with f/ratio of f/9.

This construction has not been realised up to now, but the tube length should be less than 1m as indicated by the geometrical data in the table below.

Data of the Multi-Schiefspiegler designs (No. 1 - 3)

Design No. aperture f-ratio focal length	No. of reflection	mirror diameter	radius of mirror	Distance to the next surface	mirror tilt	conic constant
1	1	150(144)	-7205	533	-9°	0
150	2	150(132)	7205	503	+8.5°	0
f/10.9	3	150(132)	-2400	513	+2.8°	-1
1637 mm	4	(81)	7205	749	-14.5°	0
2	1	150(145)	-7205	462	-10.3°	0
150	2	150(135)	7205	437	+9.6°	0
f/9.2	3	135	-2100	447	+2.85°	-1
1383 mm	4	(81)	7205	662	-15.7°	0
3	1	200 (189)	- 10000	800	-8.0°	0
200	2	200 (175)	10000	785	+7.8°	0
f/12.5	3	200 (175)	- 3600	799	+2.6°	-1
2493 mm	4	(104)	10000	1071	-13.5°	0

The designs given above are only examples of optical layouts. Other layouts may result in a more optimised design.
All lengths are given in mm.
(diameter) describes the diameter of the illuminated area of the corresponding mirror which is necessary for an unvignetted field of view of 0.5°
The f-ratios belong to the free aperture of the primary mirror and are only valid for images near the field centre. This value is slightly reduced off-centre.
Negative radii describe concave mirrors, positive values denote convex mirrors.
The angle of reflection is twice the mirror tilt.
The conic constant k describes the surace figure of the mirror and is defined as $k = -(\text{eccentricity})^2$.
k = 0 describes a spherical and k = -1 a parabolic mirror.

Realisation of the Multi-Schiefspiegler

Two prototypes of the Multi-Schiefspiegler design with 150 mm aperture and f-ratios of f/10.9 and f/9.2 have been realised and were tested at the stars and interferometrically (they correspond to design No. 1 and No. 2). The optics consists of commercially produced mirrors of 150 mm diameter each, made from Duran or Pyrex glass. The image below shows a prototype with f/10.9 on a simple mounting. The tube is adapted to a fork made of aluminium and placed above the declination shaft of the mounting. The centre of gravity of the tube should be balanced above the declination axis. This special adapter avoids the counterweight of the German type mounting. This construction is sometimes used for Schiefspieglers. The disadvantage of this adaptation is, however, that not all regions of the sky could be reached. Alternatively, the tube can be attached by the usual way at the front end of the declination axis. Therefore an aluminium plate is attached at the underside of the tube which can be attached individually to different types of mountings. The mounting should be stable enough to carry the weight of the telescope tube which amounts to 10 –12 kg for design No. 1 and No. 2.

The table below gives a technical description of the telescopes realised so far, which correspond to design No. 1 and No. 2 :

Characteristics	**Design 1**	**Design 2**
Aperture/ f-ratio/focal length	150 mm / 10.9 / 1673 mm	150 mm / 9.2 / 1384 mm
Dimensions of the tube (L x B1/B2 x T) (mm)	700 x 380/480 x 200	620 x 370/450 x 200
Weight of tube assembly	Approx. 12 kg	Approx. 10 kg
Composition of the tube frame	Steal profile combined with front plates made of aluminium	steal profile combined with front plates made of aluminium
Outer tube material	aluminium plates, 1 mm thickness	aluminium plates, 1 mm thickness
Mirror cells	3 aluminium cells, fully adjustable	3 aluminium cells, fully adjustable
Focuser	2” Precision focuser with 1.25“ adapter tube, about 100 mm way of travel	2” Precision focuser with 1.25“ adapter tube, about 100 mm way of travel
Mirror optics	2 spherical and 1 parabolic mirror of 150 mm diameter made of Duran or Pyrex glass	2 spherical and 1 parabolic mirror of 150 mm diameter made of Duran or Pyrex glass
Reflective coating of mirrors	enhanced aluminium coating with 94 % reflection	enhanced aluminium coating with 94 % reflection
Reduction of stray-light	system of baffles and rough black inner coating	system of baffles and rough black inner coating
Finder	Finderscope or Telrad to be mounted at the topside	Finderscope or Telrad to be mounted on the topside.

B1 describes the width of the tube on the front side and B2 on the back side.

Adjustment of mirrors

The fully description of adjustment is given in a separate adjustment manual. The following part describes only the general procedure to give an overview.
New mirror cells have been developed to allow a final adjustment during observations or on the optical bench. The final compensation of image errors is achieved by small mirror tilts within the telescope´s plane of symmetry (saggital plane) and the direction perpendicular to it (meridional plane). The mirror cells allow a pre-adjustment at 3 points by turning corresponding nuts on bolts. The pre-adjustment can be performed by the help of a laser pointer which is located at the center of the aperture. For this purpose the tube is opened to have acess to all mirrors.. This procedure and final adjustments by using a bright star are described in the adjustment manual. Optical calculations [4] show that remaining image errors can be compensated perfectly by small tilt changes of the first, second and third mirror within the saggital and meridional plane. This is realised by attaching the cells to a hinge type fork mounted to the frame. Two adjustment screws for each mirror allow for small tilts and can be reached from the outside of the tube (2 at the frontside and 4 at the backside).

Pre-adjustment of the mirrors is performed by mounting the laser pointer centred within the aperture stop. The laser beam should reach the primary, secondary and tertiary mirror at their centres. The primary mirror is tilted a little bit further within the saggital plane and should reach the secondary a distance of 10mm (design 1) or 8 mm (design 2) apart from the centre. This avoids vignetting of the two illuminated areas on the secondary mirror.
The beam is reflected from the secondary to the centre of the tertiary mirror. Afterwards, it is reflected back to the secondary, where two laserspots appear, which are a distant apart. This additional spot should be a distance of d = sin 5.6° x 513 mm = **50 mm** (**design 1**) and d = sin 5.7° x 447 mm = **44 mm** (**design 2**) apart from the second reflection spot but aligned within the saggital plane in a direction towards the aperture stop. The distances and tilt angles are taken from the table. The latter condition is achieved by turning the meridional nut of the cell of the tertiary mirror. After the light passes the last reflection (reflection No. 4 on the secondary mirror) the beam is directed towards the centre of the focusser. With some experience this procedure takes only some minutes and allows a nearly perfect adjustment of the telescope.

A final adjustment to compensate the residual astigmatic image error can be performed during observations of a bright star (or by an optical test at the optical bench using a plane reference mirror). The star should be observed inside and outside of the focus. The defocused star should appear like an evenly illuminated disk with a circular shape. If an elliptical disk of the defocused star is observed, the axis of which rotates by 90° by changing from the infocal to the extrafocal image position (or vice versa), astigmatism is present. This is compensated by changing the tilt of the first and secondary mirror by small amounts in a defined procedure. This procedure is describted in the quick adjustment manual, which shows the necessary movement of screws on a single page.
In principle the star test can also be used to elucidate the optical quality of the optics, but in practice the atmospheric seeing is often not perfect enough fo this tests. The following image shows the elliptical shape of the defocused star for an infocal and extrafocal postion of the focuser. The ellipse indicates astigmatism which can be corrected by doing 2 adjustment steps and is transformed into a circular disk.

During the night using the telescope for observations, it is not necessary to change the adjustment. Only after strong mechanical shaking, after strong temperature changes (from winter to summer conditions) or after removing the mirrors for recoating them, a fully adjustment procedure will be necessary. You should not remove the mirrors for cleaning purposes.

Cleaning of mirrors

Cleaning of the mirrors requires great care. The reflective coatings and even the protective coating is not very stable and mechanical cleaning by using clothes almost always induces small scratches. This should be entirely avoided. Dust can be removed by using compressed air. Layers of grease are solved by spirits and more rigid dust can be removed by distilled water. For cleaning the mirrors it is not necessary to remount them. The surfaces should be spilled over entirely by pressing on a small plastic bottle filled with distilled water or spirits. The mirrors will easily dry. Only the top aluminium plates of the housing has to be removed. This procedure also avoids to damage the mirrors. You can remove the top plate of the tube by unscrewing the 8 small screws on top (make only some turns- it is not necessary to take the screws completely out) and take away the two rubber bands. Thereafter you can move the plate to the focussers end and take it out. The mirrors are now acessible for cleaning. Locate some softpaper or clothes at the botom, directly below the mirror cells to remove the liquid after cleaning.
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Storage of and observations with the telescope

This is similar to the storage of chocolate – keep the telescope dry and cool.
All openings of the telescope should be closed to prevent the optics from dust. The telescope should be stored in a closed bag or package . The telescope needs about 1/2 h for adaptation to the ambient temperature at the observation side (open all closings). After you have finished observations, the telescope should be stored in a warm room and not be closed immediately. This allows humidity to dry out.

Observing the sun

Daylight observations of nature and surroundings are also possible with this telescope. But observations of the sun or even of surrounding clouds are very dangerous and might result in an irreversible damage of your eyes. Therefore all people using this and other telescopes and especially all children should be warned. A telescope should not be used like a toy – as far as daylight is concerned. To observe the sun it is necessary to mount a special solar filter (glass filter or a special aluminised foil with partial reflective coating, less than 0.1% of the light is transmitted) in front of the aperture of the telescope. Using a dark filter in front of the eyepiece is also very dangerous, because the small glass is extensively heated and can explode. In this case your eye will not be protected further. Additionally, the heat inside of the telescope will cause turbulence which strongly affects the image quality. Therefore the best method is to use an aperture filter. Make shure that the aluminium coating of your filter (glass or foil) looks uniform and is not damaged. Take care to attach the solar filter in such a way that it can not fall down or is blown away by the wind.

astrophotography

This telescope can also be used to make astronomical images or even images of the nature during daylight. For astrophotogaphy you will need a stable mounting with a motor drive for both axes. A precise motor drive and its adjustment is only necessary if you want to make long exposures on chemical films. By using an adapter you can attach a photocamera to the focusser and obtain images on the 24x36 mm film size without vignetting. You can also attach a webcam to produce videos of moon, sun and planets or special CCD-cameras to image faint deep sky objects. For photography with webcams or CCD cameras it is sufficient, if your mounting can follow the star for a few minutes (using an eyepiece of medium power) Several examples obtained with a simple webcam or a CCD-camera can be found at the fotogallery of our website : http://www.wolterscope.de

Final remarks

The principles of the design of the Multi-Schiefspiegler and that of several modifications have been protected against commercial use by patents [6]. A detailed description of the optical and mechanical construction of the Multi-Schiefspiegler has been published in [7, 8].

References

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