CAIRN MULTIPSLIT MANUAL

SETUP

General Principle of Cairn's Image Splitters

Setting up the Multisplit is necessarily a more complicated process than just a two or a three-way splitter that splits in one direction only, but it still shouldn't be too difficult if the correct procedure is followed. The procedure is best understood with respect to the twoway case as exemplified by the Optosplit (for comparison we just consider the basic Optosplit rather than the bypass version here). In the Optosplit, the two beam paths follow one or other pair of sides of a square, with the route being taken according to whether the mirror in the splitter cube at the input transmits the light or reflects it at 90 degrees. Both paths are then reflected by a further 90 degrees by a pair of mirrors that can be mutually rotated on a common carrier. Since this is in an infinity space, where the light has been collimated by a lens just before the mirror cube, the rotation shifts the position of the two refocussed images. The two beam paths converge at 90 degrees towards a further mirror shortly before the refocusing lens, but this mirror reflects only the light that has been transmitted by the mirror cube. It is offset so that the beam reflected by the mirror cube passes by it, the geometry being such that it is effectively (and from now on referred to) as a half-length, or combining mirror.

Although the Optosplit separates the images in only one direction, which we typically set up to horizontal, we nevertheless also need some "trim" controls to ensure that they are fully aligned in the other, hence typically vertical, one. Ideally this means that the light path should be confined to a single plane, which for a horizontal split should also be fully horizontal. If any mirror isn't fully vertical with respect to this plane, then the reflection will move it out of that plane, causing an additional rotation component that will move the focussed image up or down somewhat. However, this isn't a pure displacement! Instead, the movement will be along an arc of a circle, so the image will become progressively more twisted with respect to the one in the other pathway as it moves up or down.

Fortunately, we don't need every mirror to be completely vertical, as a vertical angle error in one mirror can be corrected by an opposite adjustment of another. This will leave a slight vertical displacement of the beam pathway within an overall horizontal plane, but since we are in an infinity space this has no effect on the position of the focussed images. We take advantage of this simplification in the Optosplit by having the vertical angles on the two rotating mirrors fixed to be as truly so as possible. Any small errors here can be compensated by a complementary vertical angle adjustment of the cube mirror and combining mirror respectively.

These adjustments necessarily allow the two separated images to be moved vertically independently, so even if they are at the same vertical position they could end up being twisted if they are above or below the plane that they should be on. The easiest way to complete the adjustment is to separate the two images so that their inner edges (which are the images of the rectangular diaphragm) just touch, and to mutually adjust their vertical positions so that these edges are fully parallel.

More generically, in preparation for considering the Multisplit, we can make a distinction between "in-plane" mirror adjustments that just shift the image positions, and "out-of-plane" mirror adjustments, that tend to twist the images as well. That's pretty straightforward for the Optosplit, as just described, but with the Multisplit things are potentially more complicated, as we are deliberately splitting in both the horizontal and vertical directions. Conceptually, one can think of a Multisplit as consisting of two Optosplits in series at right angles to each other, but without the benefit of being able to view the intermediate image. It's therefore potentially more difficult to distinguish between these two types of image movement, as what is “out-of-plane” with respect to one splitting direction is “in-plane” with respect to the other, but still with the same image twisting component. This requires the setup procedure to be correspondingly more rigorous.

While the Optosplit has just four mirrors, including the one in the cube, the Multisplit actually has twelve. This is because the additional (defined as vertical) separation system is actually two pathways in parallel after the first (horizontal) split. It is nested within the horizontal one so that it can operate within the same infinity space but with a minimum of extra path length. There are now three mirror cubes in the system. The first, referred to as cube 1, performs the initial horizontal split. The second, referred to as cube 2 and which is accessed from the same (“left”) side of the splitter as cube 1, performs the vertical split on the beam pathway transmitted by cube 1. The third, referred to as cube 3 and which is accessed from the opposite (“right”) side of the splitter, performs the vertical split on the beam pathway reflected by cube 2.

We now introduce the reference names for the four beam pathways, according to what happens at each cube. One pathway is transmitted by both cube 1 and cube 2, so is referred to as the TT pathway. A second pathway is transmitted by cube 1 and reflected by cube 2, so is referred to as the TR pathway. A third pathway is reflected by cube 1 and transmitted by cube 3, so is referred to as the RT pathway. The remaining, fourth pathway is reflected by both cube 1 and cube 3, so is referred to as the RR pathway.

We refer to the TT pathway as the “master” one, since it is not affected by any of the cubes, and hence will also be the only one you will see if no cubes are fitted. Clearly we will need to start the setup procedure with respect to this pathway, and then align the other pathways with respect to it, with the RR pathway done last.

BASIC SETUP PROCEDURE

In order to minimise internal interference between the four imaging pathways, each one has a preferred (and in practice required) position within the final composite image which is going to be in the form of four equal quadrants. However, we immediately encounter a potential problem, in that the natural inclination is to view the images on a camera, and according to the camera’s orientation it may be difficult to ascertain which quadrant is which. Furthermore, the orientation of the “incoming” image from the microscope's camera port may be different from what is seen in the eyepieces, and also some cameras may “flip” the image as well! Since there is so much room for uncertainty, it is therefore recommended that images are first viewed by projecting onto a piece of paper instead. Use transmission illumination with a low magnification objective, preferably of relatively high NA for this magnification, in order to make them as bright as possible.

An important related issue is therefore what is “horizontal” and what is “vertical”. The various separation and trim controls are all specified as either horizontal (H) or vertical (V), and these are defined according to their directions of action within the splitter itself, so their operation will be exactly as specified when projecting images onto a piece of paper. If the opposite effect is preferred with respect to the composite camera image, then one merely has to rotate the camera by 90 degrees in either direction! However, the setup procedure is likely to be less confusing if the camera is oriented so that the H and V controls do operate in the directions they say – the camera can always be reoriented afterwards. But clearly there is much room for potential confusion here, which is why we define the individual images by how they are derived (TT, TR, RT or RR) rather than where they appear on the camera.

Start by removing all three cubes. This should leave just the single TT image, which should already be in its correct quadrant, but you can check this using the horizontal and vertical separation controls at the front of the unit. As you move them clockwise, the image should move towards the centre of the field, and as you move them anticlockwise, it should move out towards its "correct" quadrant (we define "clockwise" as the direction of rotation when you view the Multisplit in the direction towards the camera). For the above reasons its position in the camera image may be uncertain, but when projecting onto a piece of paper, this image will be in the TOP RIGHT quadrant. Again to make clear, the correct quadrant *as seen on the camera* is the one towards which the image moves when both the horizontal and vertical separation controls are moved anticlockwise.

For this image to be fully "square" with respect to the camera, it is of course important that the rectangular diaphragm (the openings of which can of course be adjusted to suit the size of the camera chip), the image splitter body and the camera are all themselves fully square with respect to the microscope, and that should be fully checked at this stage. Also check that the splitter is completely at right angles to the sideport of the microscope; if it isn't, this may cause a partial cutoff ("vignetting") of the images, as well as displacing them with respect to the centre of the camera.

The Multisplit has a variety of internal adjustments, which should have already been set and therefore need no further attention. However, if you can't see an evenly illuminated image in the above step, then it may be necessary to follow the more advanced procedure that we use when setting up a Multisplit for the first time, and which is described in the next section. But if there are problems, it will be best to refer back to us or your distributor (who can do all this for you if necessary) for assistance here, unless you have sufficient optical experience to carry out the procedure yourself.

If all is well here, you can now use the horizontal and vertical separation controls to position the TT image in its correct quadrant, and set the size of the diaphragm's opening to suit the camera chip. Now we can insert cube 1, which should cause a second image, the RT one, to appear alongside the first. This will be in the top left quadrant when projecting onto a piece of paper. A clockwise adjustment of the horizontal separation control should bring these two images closer together, or anticlockwise to move them further apart. We can use the horizontal and vertical adjustment controls of cube 1 to fine-tune its position relative to the TT image. These controls are at two diagonally opposite edges of the removable cover for this cube. These are screws that are adjusted by 1.5mm hex keys, but we can also provide appropriately terminated control knobs for fitting into them if preferred. The vertical control should be self-explanatory, as we just need to vertically align the two images, but the horizontal control will interact with the horizontal separation control, albeit in a helpful way. By appropriate mutual adjustment of these controls, we can ensure that the horizontal separation is fully symmetric with the camera chip.

Note that while the horizontal trim control for cube 1 produces a pure horizontal movement of the RT image, the vertical trim control for this cube is an "out-of-plane" type of adjustment. If it is deliberately misadjusted so as to cause a significant vertical misalignment of the RT image with respect to the TT one, then some twisting of the RT image should be observable. However, there should be no such twisting when these two images are fully vertically aligned. If there is, then some internal adjustments, as described in the more advanced setup procedure, will need to be made, but these are very unlikely to be necessary in normal use.

Next we can insert cube 2, which will cause the TR image to appear, vertically separated from the TT one, and below it when projected onto a paper screen. As previously noted, this cube is accessible from the same side as cube 1, but it fits into a carrier that reorients it to split vertically rather than horizontally, and the vertical and horizontal trim controls are in the form of adjustable knobs on the top plate. Alignment of this cube is similar to that of cube 1 after allowing for the difference in orientation. Thus we horizontally align the TR image with the TT one using the horizontal trim control, and then use the vertical trim control and the vertical separation control together to make the vertical separation fully symmetric with the camera chip. Note that the horizontal trim control is an "out-of-plane" adjustment, but if the internal adjustments have been set up correctly, then there will be no twisting of the TR image when it is fully horizontally aligned with the TT one.

Finally we can insert cube 3, which will cause the RR image to appear in the final quadrant (bottom right when projecting onto apaper screen). Cube 3 is the one on the opposite side to the other two, and is otherwise similar to cube 2 in that the cube is mounted into a carrier and its trim controls are also on the top plate. All we have to do here is to use this cube's trim controls to align its image vertically and horizontally with respect to the other three.

The important sequence for the alignment procedure is always to adjust the TT image first, and the RR image last, otherwise there will be a confusing degree of interaction. The positioning of the RT and TR images are equivalent operations, so could in fact be done in either sequence. In use, alignment should only be necessary when one or more cubes are interchanged, but these are precision machined items, so any necessary adjustments should only be small. Of course, if only one cube is interchanged at a time, then the adjustments need only to be made to that cube, but in that case you may notice that more than one image will move when you do so!

FULL ALIGNMENT PROCEDURE

The Multisplit has a total of twelve mirrors including those in the cubes, and they are effectively grouped as three sets of four, with each set being equivalent to the configuration in the Optosplit. Thus in each set we have the splitting mirror in the cube, a pair of diagonally opposite mirrors that rotate on a common carrier, and a half-length combining mirror to bring the two pathways parallel again for refocussing. The vertical separation system is nested within the horizontal one, being replicated within it as two parallel pathways. For the horizontal separation, this means that the first rotating mirror is at the same lower level as the first, horizontally-splitting, cube, and it makes the reflected pathway from this cube parallel to the transmitted one. The parallel vertical systems then follow, being equivalent to the Optosplit configuration as previously noted, and after their vertical separation and recombination they bring the four beams up to a higher horizontal plane, where they encounter the second rotating horizontal mirror and its half-length recombining one, before being refocussed by the output lens.

The same basic adjustment principles apply as for the Optosplit, but there are some practical differences. In the Optosplit, the rotating mirror pair can also be slid with respect to its axis of rotation. As explained elsewhere, this allows the beam locations within the splitter to be optimally located so that one beam is fully reflected by the recombining mirror while the other is fully transmitted past it. In the Optosplit the beam pathways are symmetrical, but in the Multisplit the distance between one of the rotating mirrors and the recombining one is now significantly greater than for the other distance (because of the intervening vertical separation system), so for optimising the beam separation at the horizontal pathway's combining mirror, the "sliding" distances now need to be different, rather than having the two mirrors move together as in the Optosplit. Since this is a more complicated situation, and yet it is possible to have settings that will cover a relatively wide range of microscopes, we have decided not to make these adjustments directly accessible to the user.

For the vertical separation pathways, the two rotating mirror pairs are on a common carrier, or "cradle" as we term it, so that they rotate together. In principle, and as in the Optosplit, this carrier could be slid as a unit to control the beam separations at the two combining points, but to simplify the mechanics here we have again provided separate sliding adjustments for each arm of the rotation, although in this case the two parallel mirrors on each arm can be and are adjusted together.

We therefore have a system in which the mirrors that rotate, of which there are six altogether, can all also be slid with respect to their axis of rotation, just as in the Optosplit, but the sliding adjustments are now all preset. Again as in the Optosplit, there are no individual “in-plane” rotation or “out-of-plane” tilting adjustments for any of these mirrors, but full correction is nevertheless possible by the equivalent adjustments in the corresponding one of the three cubes or the three combining mirrors. However, again because of possible confusion between vertical and horizontal adjustment errors, the combining mirror adjustments are now also internally preset. We do need to retain full adjustment on the cubes though, to trim for any alignment errors that may be introduced when they are interchanged, but again as previously noted, the precision nature of the cubes should mean that any such errors are small.

The Actual Procedure

We now describe the full alignment procedure. This should be carried out with the top plate removed and bright illumination transmission (use a low magnification but relatively high NA objective) so that the internal beam pathways and any obstructions of them can clearly be seen. Note that at least to begin with it is also much easier to project images onto a paper screen rather than viewing with a camera. This will also allow the camera coupling to be removed from the refocussing lens tube, so that a much wider field of view is potentially available, and is particularly useful in the early stages of the procedure. But a camera will of course be useful or even necessary when it comes to getting the alignments to their final precision.

There are two aspects to the alignment procedure, as the rotatable mirrors must start by being at more less their correct angles, and the fixed mirrors must start by being in more or less their correct positions, otherwise no light will get through. This is why visual internal inspection with bright transmission illumination is recommended, as this will clearly show how each mirror needs to be at least approximately adjusted. For purposes of explanation, we describe the angular mirror adjustments first, and then the positional ones, but in practice the two will needed to be carried out in parallel, so the entire procedure should be carefully read before making any sort of start.

Angular Mirror Adjustments

As a prelude to this, we may need, especially if setting up for the first time, to adjust the operating range of the image separation controls. For the vertical separation control this is quite easy, as it can be done at the vertical mirror cradle end of the connecting rod to the control. By temporarily releasing an M3 grubscrew on the part that links the rod to the cradle, the rod can be slid relative to this part in order to achieve the required control range.

For the horizontal separation system, the angular position of one or other lever arms on their common rotating rod can be adjusted, but this is a bit more fiddly as each lever is secured by two grubscrews because the transmitted forces are quite high. The upper lever is likely to be the easier one to adjust, but in order to access one of the screws the front plate will need to be removed. With care this can be done without disturbing the linking rod to the vertical separation system, as the front plate only needs to be moved to the extent of disengaging the lower lever from its contact point on the horizontal cradle. The levers can then be rotated to access the grubscrew on the upper lever that was previously inaccessible. This can be temporarily released, and the front plate replaced, now setting the required orientation of the upper lever by adjusting the other grubscrew. Once that screw has been locked off, the front plate can be temporarily removed again for accessing and locking off the second one.

For the angular mirror adjustments, we start with no cubes, so we'll just be looking at the TT image at this stage. It can be roughly aligned as described in the basic procedure, but here we can be somewhat more precise. The issue we are trying to address here is that we want to discriminate between a horizontal image displacement caused by an out-of-plane error in the vertical separation system (which will twist the image around to some extent as well) and one generated within the horizontal separation system itself. But at the same time, there may be an out-of-plane error in the following horizontal separation system, which in addition to a vertical displacement would also twist the image somewhat, so we can't tell the source just by looking at the image itself.

More to the point, equal and opposite out-of-plane errors in the horizontal and vertical image separation systems would also give an untwisted image! In this case, we suspect that aligning the other images with respect to this one would still end up with all four images being correctly oriented, but with corresponding out-of-plane components in the horizontal and vertical separation pathways of all of them. That would still be fine in practice for small errors at least, but clearly it would be nice to get this exactly right, which the following procedure will achieve.

The procedure is to remove the splitter's rear plate, the lower pair of vertical cradle mirrors and the second (higher) mirror on the horizontal cradle, and to shine a laser pen through the splitter's input. With careful adjustment of the horizontal separation control, the laser beam should be able to pass through through the narrow gap between two of the support legs for the second mirror on the horizontal cradle. The beam should be projected onto a reference surface some feet away and its position marked. The lower pair of mirrors on the vertical cradle should be now replaced at a position that will now reflect the laser beam upwards to the half-length combining mirror on that side. The vertical separation control should now be adjusted so that the the laser is now doubly reflected to be at the same or similar vertical position on the reference surface (it may be necessary to slide the lower vertical cradle mirrors to a position such that the reflected beam still strikes the combining mirror as the vertical separation control is adjusted; this adjustment can be repeated later in the setup procedure if necessary). We now adjust the horizontal trim control on the vertical combining mirror (marked as TTH) so that the beam is in the same horizontal position on the reference surface as before. *That control should never be touched again!* To indicate this, the adjustment screw will have been painted red.

We now perform the corresponding adjustment of the horizontal separation system. To do this, we now replace the second mirror on the horizontal cradle. The horizontal image separation control should now be adjusted so that the laser is reflected both by this mirror and by the halflength horizontal combining mirror that would normally be in front of the (currently removed) refocussing lens. The combining mirror has a "rocking" type of adjustment control, which should be made so that the height of the beam at some distant point is exactly the same as before we replaced the second horizontal cradle mirror. *That control should also never be touched again!* To indicate this too, the adjustment screw will also have been painted red.

To repeat and summarise, these two adjustments should ensure that both the vertical and horizontal separation systems for the TT beam pathway are fully "in plane", so all the other adjustments can reliably be made with reference to what will now be a precisely oriented image, which is now affected *only* by the vertical and horizontal image separation controls. However, it should be noted that if one starts with a purely visual adjustment of those two "don't touch again" mirrors, so that they are observed to be as horizontally and vertically oriented as possible, they will require little if any further adjustment during this procedure.

We can now vertically position the TR image relative to the TT one. When projecting onto a paper screen its correct position will be below rather than above the TT image. It can be aligned horizontally with respect to the TT image by the horizontal trim control for cube 2, and although this is an out-of-plane type of adjustment, there can be no twisting of the TR image when the two are exactly aligned, so this should be straightforward. For vertical placement of both these images, we want to arrange that they are symmetrical with respect to the camera chip. As a prelude to this, we want to centralise the vertical trim control for cube 2, which we can do to a sufficient extent by checking that the cube is visually level within its adjustment system. We can now use the vertical trim adjustment on the vertical combining mirror on this side (marked as TTV) to move the TT image with respect to the TR one, while moving them in equal and opposite directions by the vertical separation control, so as to vertically centre this pair with respect to the camera. The vertical trim adjustment on the vertical halfmirror on this side won't need to be touched again, as any future vertical alignment errors will be due to interchanging cube 2, and which can now be corrected by its own vertical trim control.

Apart from the adjustments on the cubes themselves, this just leaves those on the vertical half-length combining mirror on the other (cube 1 reflected) side, and which affects the RT beam pathway, to concern ourselves with. The same as for the TT beam pathway, the horizontal adjustment (marked as RTH) is to correct for out-of-plane errors in this vertical section that would otherwise cause twisting of the RT image, but here we need a vertical adjustment (RTV) too. This is because the vertical trim adjustment on cube 1 is an out-of-plane one, so it can't be used to reliably vertically align the RT image with respect to the TT one (and it affects the RR image too), whereas the vertical trim adjustment on this combining mirror is an in-plane one just for RT and hence safe. We'll come to how to set the vertical trim on cube 1 in a moment.

The horizontal trim adjustment for cube 1 is an in-plane one that affects both the RT and RR images. We can therefore use this in conjunction with the horizontal image separation control to centralise the horizontal separation system with respect to the camera chip, and we'll also come back to this in a moment. The controls for cube 3 affect the RR image only, with the vertical trim being another in-plane one that just adds a local offset to the movement produced by the vertical separation control.

However, we have two controls that independently affect the horizontal positions of the RT and RR images, namely the horizontal trim control (RTH) on the vertical combining mirror on this side, and the horizontal trim control on cube 3. Although it sounds as if they could be used to move these two images by the same amount in order to maintain their horizontal alignment with respect to each other, they are both out-of-plane adjustments, so the images would both be progressively twisted with respect to the TT and TR ones as they are moved in this way. Therefore the correct settings for these controls are such that the two images are horizontally aligned but neither is twisted. This is easy enough to do by using the diaphragm edges at the junctions between the individual images as references.

Once we have correctly trimmed the individual horizontal positions of the RT and RR images in this way, we can now use the cube 1 horizontal trim control as described above, to jointly adjust the horizontal positions of the RT and RR images relative to the TT and TR ones, so that they are symmetrically disposed with respect to the camera chip.

Finally we come to the correct setting of the cube 1 vertical trim control. If this is incorrect, the RT and RR images will both be twisted with respect to the TT and TR ones, so the procedure here is to find the vertical position for this image pair where there is no observable twist. Again the diaphragm edges provide useful reference points. The correct setting here is going to affect any previous vertical alignment of the RT and RR images with respect to the TT and TR ones, but the RT image can be realigned with respect to the TT one by the vertical trim control (RTV) on the vertical combining mirror on this side, and the RR image can be similarly realigned with the TR one by the vertical trim control on cube 3.

That's it!

POSITIONAL MIRROR ADJUSTMENTS

We now come to the positional adjustments for the six rotating mirrors. On the horizontal cradle, the two mirrors can be individually moved at 90 degrees with respect to their reflecting surfaces. On the vertical cradle there is a similar adjustment, but here the corresponding mirrors on the cube 2 and cube 3 side are moved together as pairs, so there are four rather than six adjustments overall. Also, two of the other mirrors have been mounted on their carriers to give a fixed displacement compared with their expected positions. Most notable is the vertical halflength combining mirror on the cube 3 side, which has been displaced inwards by approximately 6mm, but the horizontal halflength combining mirror has also been displaced outwards slightly, so that it now "covers" rather less than half of the aperture of the refocussing lens. As explained elsewhere, this is because the interposition of the vertical separation system makes the horizontal one asymmetric with respect to the distances between the two horizontal cradle mirrors and their combining one.

For adjusting the mirror positions, it is very strongly recommended that this is done in conjunction with visual inspection of the individual beam pathways under conditions of bright transmission illumination. Any "overspill" of a beam beyond the edges of a *particular* mirror, which is the most likely cause of vignetting, is easily noticeable this way. The camera will also show the loss of course, but it doesn't directly show where in the light path it actually occurred. All you need to do for this visual inspection is to remove the top plate and switch on the microscope's transmission light source.

The internal beam sizes vary as they go through the splitter, and depend on a combination of three factors, which are the size of the diaphragm opening, the magnification and NA of the objective, and the point where the rear focal plane (effectively the "pupil" and hereafter referred to as such) of the objective is brought to a focus within the splitter. The dependence on the objective is particularly strong, and in any case is instructive to observe. Low magnification objectives of relatively high NA tend to produce the largest internal beam sizes, and also the brightest beams, so provide the most stringent (and hence recommended) tests. In all cases the beam size is at a minimum where the objective pupil is brought to a focus, and although that depends on the microscope optics, the position doesn't vary very much (see the section on multiplane imaging for further discussion). It tends to be near the second auxiliary filter position in the TT and TR pathways, and near the first auxiliary filter position in the RT and RR pathways, with the possibility of these positions being made exact for multiplane imaging and related applications.

With regard to diaphragm opening, a fully open diaphragm of 16x16mm with a standard (and recommended) Multisplit of 1:1 magnification would require a 32x32mm camera sensor to accommodate all four images, so in practice it is likely to be set to something smaller. However for these setup adjustments there is no harm in using it at full aperture, although the internal beam sizes from low magnification high NA objectives will be particularly challenging, which will therefore provide the best tests.

The actual setup procedure for the mirror positions should be pretty self-explanatory. It should be followed with the horizontal and vertical image separation controls set as required, and with the other mirror adjustments at least approximately correct, so this is likely to be an iterative process if starting from "cold". The horizontal pathways are likely to be the more critical, since as previously noted one of them is quite long. This is the one reflected by cube 1 and then again by the first (lower) mirror on the horizontal cradle. The position of that mirror should be adjusted so that the beam fully clears, and hence goes past, the half-length horizontal combining mirror, which is just before the refocussing lens. In practice this beam is going to be deviating slightly towards the midline of the splitter because of the effect of the horizontal separation control on the beam angle, and that causes a significant displacement of the beam by the time it reaches the horizontal recombination point, on account of the relatively long path length here. This is why the positions of the horizontal recombining mirror and its vertical equivalent on this side have both been offset from their nominal positions as described above.

A the same time we must ensure that the the beam reflected from the second (upper) rotating horizontal cradle mirror is further fully reflected by the horizontal combining one. The relatively short distance here means that the position of this beam at the recombination point changes far less with the required horizontal separation of the images, so this adjustment is less critical. However to provide more “room” for the other beam, this mirror needs to be set back towards that corner of the splitter with respect to its nominal position. In this respect, note that the diagonally opposite holes on the platform on which it sits are asymmetrically placed. The platform is (or should be!) oriented so that the hole nearer the platform corner is oriented towards this corner of the Multisplit, as this will allow the mirror to be moved further back.

The corresponding vertical mirror adjustments should be less critical. Each mirror pair on the vertical cradle can be slid in and out with respect to its axis of rotation by loosening the M3 socket head fixing screw on that side. Movement is restricted to a pure distance one by locator pegs that slide along slots in the cradle body. With the vertical separation control (roughly) set to the required image separation, the upper mirror pair should be slid so that the TR and RR beams pass fully below the halflength vertical combining mirrors, but not significantly more than necessary. The lower mirror pair should be slid so that the TT and RT beams are fully reflected by these mirrors instead of any element passing upwards by them on the refocussing lens side, but again not significantly more than necessary. The TT and TR beams will then be reflected again by the second horizontal cradle mirror, and then further by the horizontal half-length recombining mirror. The optimum positioning of the two mirror pairs on the vertical cradle should result in the height of the TT and TR beams being roughly symmetrically displaced with respect to the centre of the refocussing lens, with the TT beam being the one above.

BEAMSPLITTERS, FILTERS AND OTHER ACCESSORIES

The Multisplit accepts our standard mirror cubes and accessory (“filter”) holders, as used in so many of our other products, but the relatively high complexity of this product means that there is a correspondingly wider choice of possibilities. This is also a good point at which to mention a variant of our mirror cube, which may be a useful choice for the cube 1 position in more “demanding” applications.

The issue here concerns the diameters of the individual beams as they pass through the splitter. These are well defined at two types of location, namely at the rectangular diaphragm and its images, and at the rear aperture (“pupil”) of the objective and its images. The beam that passes through the rectangular diaphragm tends to expand until it reaches the collimating lens at the input to the body of the splitter, after which the beams are separated by the cubes, progressively reducing in size to form images of the objective pupil part way through the splitter (there will be much more about this later!) After that they expand again until they reach the refocussing lens to generate the focussed images.

In practice this means that the beam diameter is greatest at the collimating lens. There is plenty of available aperture here, as this “lens” (actually a multi element one of our own design) has a nominal aperture of 40mm, giving a clear optical aperture of something over 36mm. The beam then begins to converge as it approaches cube 1, but this has a clear aperture of just 22mm, which is still usually sufficient but not necessarily always. We can therefore offer an alternative “cube” for use here, of much more open construction, with a clear diameter of 28mm. Standard “25mm” optical filters also have a clear diameter of around 22mm, so this alternative component therefore has no provision for these. (For the record, we also have a bigger cube design, which takes 32mm filters and has a clear aperture of 30mm, but we don't need to go to quite those lengths here.) In any case cube 1 is generally not such a convenient point for filters or other components because the optical pathway is only partially separated here.

The two beams separated by cube 1 are then further separated by cubes 2 and 3 respectively. As the beam diameters are steadily converging towards the pupil images, they will be significantly smaller at cubes 2 and 3 than at cube 1, so clear diameters of 22mm are certainly sufficient. We can therefore safely use standard 25mm optical filters here, so these are the logical places to further define the optical bandwidths after the beams have been separated on the basis of the properties of the mirrors. The separation is usually on the basis of wavelength of course, but it can also be by polarisation or by a neutral beamsplitting as in the case of the multidepth imaging application.

However there are two other locations in each pathway where filters or other optical accessories can be incorporated. The first location is immediately after the transmitted and reflected outputs from cubes 2 and 3 respectively, and the second is somewhat further along at 90 degrees to the first, after reflection from one or other mirrors on the vertical cradle for each side. We have played a neat trick here! Cube 2 immediately follows cube 1 on the transmitted side, whereas cube 3 is optically further away from cube 1 on the reflected side, as this pathway has a lateral component before it is reflected by the first mirror on the horizontal cradle. This means that the first accessory position in the cube 1 reflected pathway is 55mm beyond the corresponding one in the cube 1 transmitted pathway, but it just so happens (because we designed things this way!) that the second accessory position in each pathway is 55mm beyond the first. *Therefore the second positions in the cube 1 transmitted pathways are in optically equivalent locations to the first positions in the cube 1 reflected pathways.*

Not only that, but this particular point of coincidence is close to where the image of the objective pupil comes into focus, and for most microscopes it can be made exactly so by adding a relatively short extender to the input coupling, in order to correspondingly increase the distance between the input lens and this point. Direct access to the pupil image plane is useful for a variety of reasons, but a particularly useful one is that if corrector lenses are added at these points, the plane of best focus within the sample can be varied without any change in magnification. You can read more about this in the section on multiplane imaging.