PUMA Quick Start Guide

Build a PUMA Microscope

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Contents

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Legal Information

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Limitations of Use

The PUMA microscope and its associated systems do not have any certifications or regulatory approvals in any country for use in clinical diagnostics or treatment (human or veterinary).

The PUMA microscope and its associated systems are released to be used for research and educational purposes only.

Disclaimer

All PUMA project information, including without limitation any CAD file or STL file and all documentation, advice and instruction (whether provided in video form, audible form, written form or otherwise) is provided 'as is' in good faith and is intended to be helpful but comes with no warranty whatsoever.

Anyone attempting to build or use a PUMA microscope or other PUMA-related material, accessory, module or derivative is hereby advised that there will be risk involved in 3D printing, post-print processing, assembly and usage of the resulting structures. This risk includes, without limitation, the risk of personal injury and loss of resources.

Dr Paul J. Tadrous, TadPath and OptArc cannot accept any liability for any such loss or damages that may occur. All those who attempt to build or use any aspect of the PUMA project or derivatives thereof do so at their own risk.

Safety Information

Throughout this manual please take heed of **warnings given in bold text and highlighted yellow** to avoid possible damage to equipment and/or harm to people.

PUMA microscopes and associated systems are not toys. They contain small parts which may come loose such as tiny metal screws and washers and glass components that may splinter or break or otherwise present a choking or sharp object hazard or chemical hazard (for batteries). **Please do not let babies or young children play with or use any aspect of a PUMA system without close appropriate adult supervision. Likewise keep PUMA systems away from pets**.

Abbreviations

Some common abbreviations used in this documentation

BoM	Bill of Materials (spreadsheet on the PUMA GitHub page)
OD	Outer diameter
ID	Inner diameter
RMS	Royal Microscopical Society

Introduction

The PUMA microscope is a portable compound light microscope designed to use professional standards of optics and to be relatively easy to build as a DIY project using 3D printed parts and standard inexpensive hardware.

One of its key features is that it is designed for direct vision through a lens and not restricted to camera imaging. It also has a wide range of illumination options.

The scope, its abilities, its limitations and comparisons to other 3D printed open source microscopes are described in detail on the GitHub site and links you can find there. See: https://github.com/TadPath/PUMA

However, because PUMA has so many options, it can be daunting for the newcomer to know where to begin when it comes to building their first PUMA microscope. This document was created to guide you through that process.

It is assumed the reader has basic DIY skills. No power tools are required to build a PUMA microscope with the possible exception of a hand held electronic drill (but only rarely if ever will this be needed, to maintain the stage mechanism as will be described).

Instead of repeating detailed construction information here I will link to the relevant videos and other resources that I have made to give you detailed instructions.

Note that any links to products for purchase are given in this document as specific examples and do not imply the seller is reliable or recommended. If you can find an equivalent spec product for sale somewhere else you are of course free to buy it from there.

Finally, you should be familiar with what it is that you are going to build. To that end I recommend you see the following videos and read the 'Foundation Scope User Manual' from the following links *before* you begin your build attempt:

Introduction to PUMA Microscopy

https://youtu.be/7UbkrZyNgpo

Unboxing (although you are building, not buying, a PUMA scope, this video will familiarise you with the parts that go into making a PUMA microscope)

https://youtu.be/EfecD0UGLDQ

Assembling a PUMA Microscope

https://youtu.be/C-2vRsHi46c

How to Field Strip a PUMA Microscope

https://youtu.be/6Yvc9X9xrKo

Foundation Scope User’s Manual

https://www.optarc.co.uk/wp-content/uploads/2021/08/UM_FoundationScope.pdf

3D Printing Guidance

It is assumed that the reader has familiarity with 3D printing or they will use a commercial 3D printing service to make the 3D printed parts for them. If you are doing your own printing take heed of the orientation of models on the print bed and the printer settings for supports, etc. that are detailed in the PUMA 3D printing guide found on the GitHub site here:
https://github.com/TadPath/PUMA/blob/main/3D_Printing/PUMA_3D_Printing_Guide.pdf

Cura slicer profiles for the prints are available here:

https://github.com/TadPath/PUMA/tree/main/3D_Printing/CE3_Cura

If you use a different printer (other than Creality Ender 3) or a different slicer program (other than Cura) then I strongly advise you print with equivalent settings to the ones specified in the above document (which you will need to study and translate into your preferred slicer).

If you are using a third party service to print the parts for you then the print service should be made aware of the above documents and profiles for best chance of success.

The models that you will need to print are contained in the FreeCAD files that on the PUMA GitHub site. The procedure for printing any model is as follows:

1. Open the FreeCAD file that contains the model you want to print. To do this you will need to install the FreeCAD free software on your computer. You can get FreeCAD from the following link: https://www.freecadweb.org/downloads.php

2. Find the model you need from the pane on the left had side and save it in a format that will be put through your slicer software to generate the G-code for your printer. A step-by-step illustrated guide on how to do this is explained in the 3D Printing Guide document linked to above.

You will need to do this to generate each STL file for each model you want to print (or AMF file or OBJ file – whatever format you prefer for your slicer program) because the official PUMA reporitory does not store STL files – only the editable models in FreeCAD files.

If a particular model or STL file is mentioned in any of the build instructions or videos, you can find out which FreeCAD file contains that particular model by referring to the 3D Printing Guide document linked to above.

Finally, I recommend you only download and use the models from the FreeCAD files in the main branch of the GitHub repository – not the v1 release. The v1 release package, although it can be easily downloaded from GitHub as an ‘all in one’ zip download, is now quite out of date with older models that don’t work as well and some are not compatible any more with current video tutorials. The v1 release of PUMA should be viewed as a historical snapshot only.

What you will be Building

It helps to know what the goal is in any task before you start. This guide will show you how to go about building the most basic PUMA microscope configuration called the ‘Foundation scope’ (also known as the ‘Config 1’ scope or ‘Monocular mirror scope’), see figure 1.

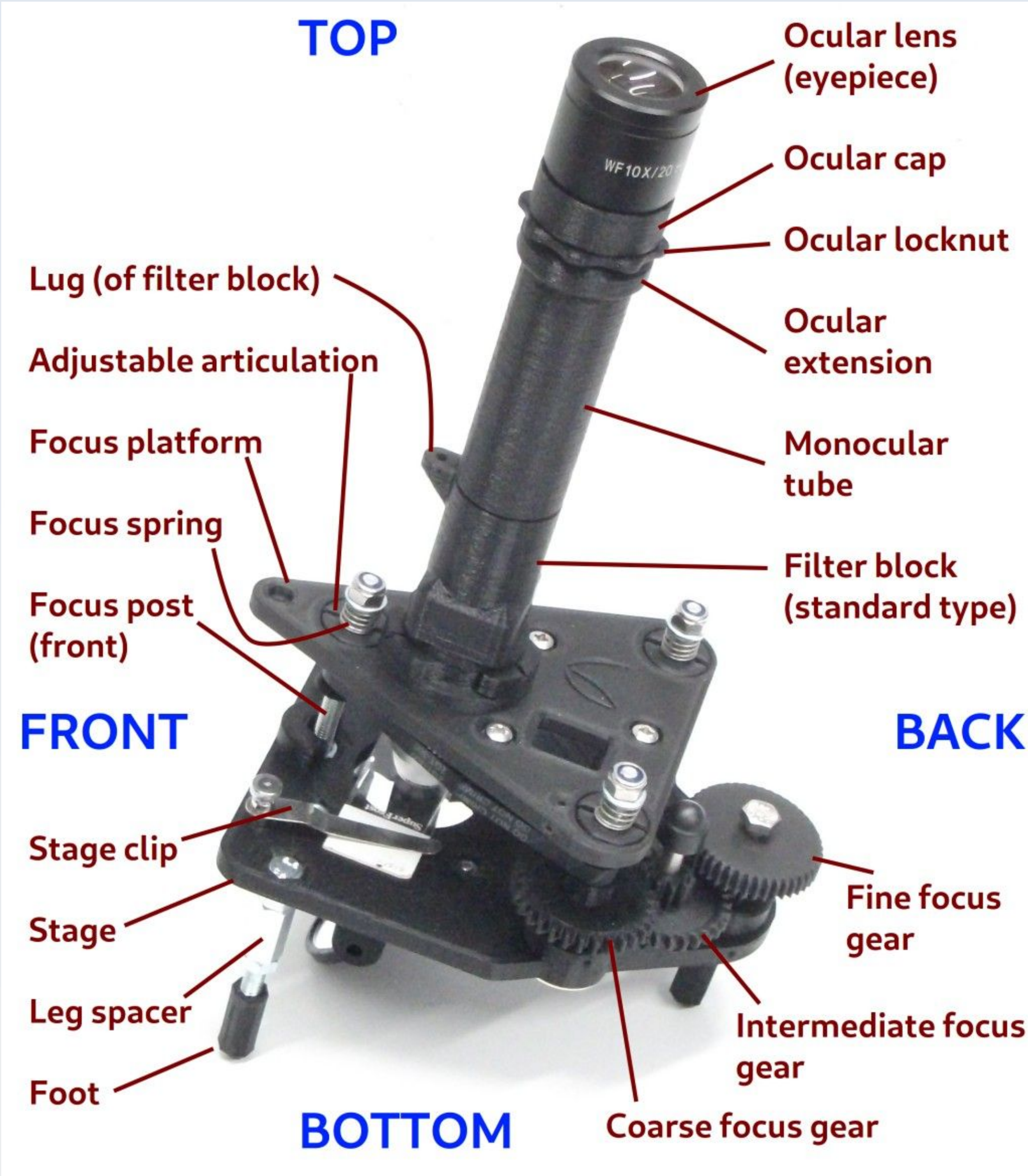

Figure 1. The Foundation scope with some component parts labelled.

PUMA microscopes are modular and take many forms. A complete, ready-to-use, microscope is called a '***configuration***' and each configuration is made up of a series of functional parts called '***modules***'. Each module consists in any number of parts, 3D printed and/or non-printed parts.

The Foundation scope configuration consists in the following 8 modules:

1. Stage
2. Legs_short
3. Stage_clips
4. Mirror_Simple
5. Objective_x4
6. Filterblock_simple
7. Monocular_head
8. Ocular

So, to make a Foundation scope you will need to build or acquire each of the above modules. Some of these modules don't include any 3D printed parts.

To find out what exactly is required for each module use the Bill of Materials (BoM) spreadheet on the GitHub page found here:

https://github.com/TadPath/PUMA/tree/main/Bill_of_Materials

This sheet has many worksheets in it. The module worksheets are all prefixed with 'MD_' so, to find out what parts are needed for the 'Stage' module, look at the 'MD_Stage' worksheet. To see what is required for the 'Legs_short' module look at the 'MD_Legs_short' worksheet, etc.

The BoM spreadsheet also has a worksheet called 'Non_Printed_Parts' which gives you the specs of any non-printed parts that you need such as screws, washers and optics – together with example URLs where you can purchase the parts.

Step 1. Making the Stage

A logical place to start is to attempt to build a working Z-stage[1] before making a complete microscope because this is the single most complicated part. If you succeed in doing this, then making the rest of the scope will be relatively quick and easy.

So you know what you are building, figure 2 shows the main components of the Z-stage labelled.

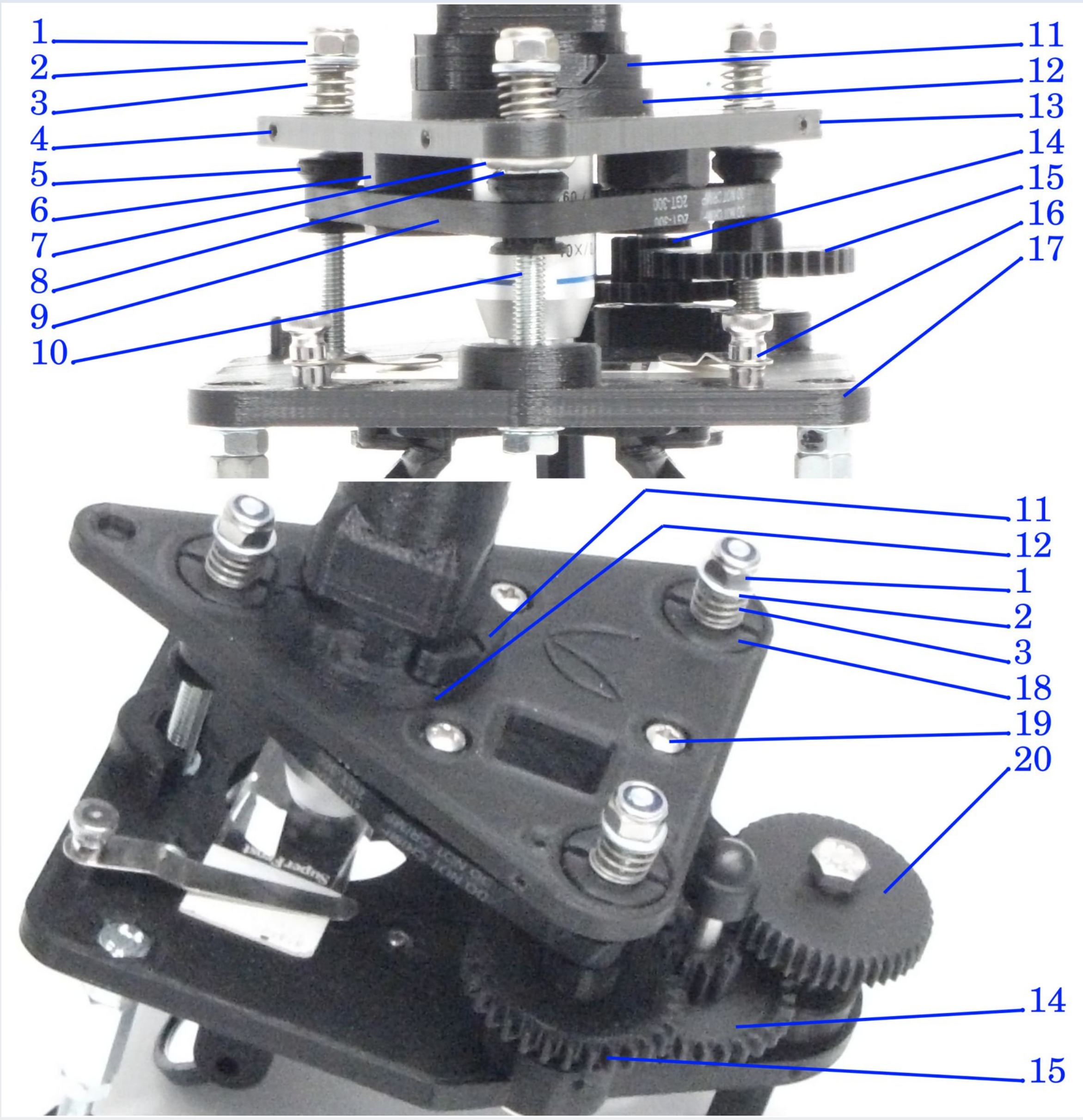

Figure 2. Main components of the Z-stage focussing assembly. See text for labels.

1 I use the terms 'Z-Stage' and 'Stage' a bit loosely in my documentation. The Z-Stage means the combination of focus plate (also called the focus platform) and base plate together with timing-belt-driven focus mechanism which includes the screws, springs, washers, etc. and focus gears. Sometimes the term 'Stage' refers to the complete Z-stage assembly just described but at other times it refers to the top part of the base plate (where the specimen is placed). Context should make it clear what I mean by 'Stage' in each case. This chapter is about building the whole Z-stage focussing assembly.

The labelled parts shown in figure 2 are as follows (a further description will be given later):

1. M6 ‘Nyloc’ Lock nut
2. M6 flat ‘Form A’ washer
3. Compression spring, 0.8 guage, 10 mm diameter, 20 mm long
4. Hole for M3 grub screw to lock the adjustable articulations (18) in place
5. GT2 Pulley (model FG_Pulley.stl)
6. Adjustable belt tensioner GT2 pulley (each one is made from 3 models: FG_Eccentric_Tensioner_Top.stl, FG_Eccentric_Tensioner_Bottom.stl, FG_Eccentric_Tensioner_Pulley_c_adhesin.stl)
7. Countersunk screw cup (size No. 12)
8. Exposed top of M6 nut in front pulley
9. GT2 Timing belt, 300 mm long closed loop
10. M6 hex head bolt focus post (70 mm long, fully threaded type)
11. Quick release aspect of above-stage optical tube (this, and the rest of the optical tube are not part of the Z-stage, you will build those later)
12. Quick release receptacle built into focus platform
13. Focus platform (model ST_FocusPlate.stl)
14. Intermediate focus gear (model FG_Intermedius.stl)
15. Coarse focus gear with its integral GT2 pulley (model FG_Pulley_coarse.stl)
16. Stage clip (each 5.5 mm long with a 4 mm diameter post)
17. Base plate of stage (model ST_BasePlate.stl)
18. Adjustable articulation (model ST_Articulation.stl)
19. M4 screw that holds one of the 3 adjustable belt tensioner pulleys (M4 Pozi Pan head machine screw of type DIN7985, 16mm long)
20. Fine focus gear (model FG_Fine_gear.stl)

3D Printed Parts

To build the stage you will need the following 3D printed parts in the quantities shown (this is taken from the BoM spreadsheet 'MD_Stage' worksheet – you should consult that for the most up-to-date information but currently it is as follows):

Model	***In FreeCAD file***	***Quantity***
ST_BasePlate.stl	Stage.FCStd	1
ST_FocusPlate.stl	Stage.FCStd	1
ST_Articulation.stl	Stage.FCStd	3
FG_Fine_gear.stl	Focus_Gears.FCStd	1
FG_Focus_spacer.stl	Focus_Gears.FCStd	2
FG_Intermedius.stl	Focus_Gears.FCStd	1
FG_Pulley_coarse.stl	Focus_Gears.FCStd	1
FG_Pulley.stl	Focus_Gears.FCStd	2
FG_Eccentric_Tensioner_Top.stl	Focus_Gears.FCStd	3
FG_Eccentric_Tensioner_Bottom.stl	Focus_Gears.FCStd	3
FG_Eccentric_Tensioner_Pulley_c_adhesin.stl	Focus_Gears.FCStd	3

Non-Printed Parts

To build the stage you will need the following non-printed parts in the quantities shown (apart from the last item 'Stage clips', this is taken from the BoM spreadsheet 'MD_Stage' worksheet – you should consult that for the most up-to-date information but currently it is as follows):

Non-Printed Parts	***Quantity***
PTFE_Ferrule_8mmOD_6mmID_5mmLong	3
Spring_StainlessSteel_Compression_0.8guage_x10diam_x20long	3
M6_nyloc_locking_nut	3
Timing_belt_GT2_300mm_long_closed_loop_6mm_wide	1
M6_Full_Nut	9
M6_Washer_Flat_FormA_DIN125	10
M6_Washer_Penny_Repair 1.5 mm thick by 25 mm diameter	2
M6_Hex_Head_Bolt_Fully_Threaded_16mm_long	2
M6_Hex_Head_Bolt_Fully_Threaded_70mm_long	3
M4_Full_Nut	8
M4_Washer_Flat_FormA_DIN125	4
M4_Pozi_Pan_Head_Machine_Screw_DIN7985_16mm_long	3
M3_Grub_Screw_Cup_point_Hex_socket_DIN916_5mm_long	3
M6_Hex_Head_Bolt_Part_Threaded_DIN931_50mm_long	2
No.12_M6_Cup_washer	3
Optional: Stage clips 5.5 mm long with 4 mm diameter peg for attachment	Pair

For the PTFE ferrules you will usually buy tubing of (e.g.) 1 metre long and then you will need to cut 5 mm segments off it. This is best done with a jig or guide of some kind so you can get flat perpendicular edges. If you use a mini pipe cutter this can cause the edges of the cut segments to turn inwards. You should correct that somehow (for example by passing a plastic pen lid into the ferrule to upen it up a bit and counteract the in-turning). An example link to purchase this tubing is:

https://www.aliexpress.com/item/33064459360.html

For the compression springs: https://www.aliexpress.com/item/1005001408406253.html

For the M6 Nyloc nuts: https://www.aliexpress.com/item/1005001839539218.html

For the GT2 timing belt: https://www.aliexpress.com/item/32950422029.html

The M6 full nuts can be got from any hardware store but you need ones that are 5 mm long.

Likewise for the M4 full nuts but these must be 3 mm long.

The standard flat washers should be available from your local hardware store but if you have difficulty getting the penny washers then try this:

https://www.aliexpress.com/item/1005001862513193.html

The other 'unusual' washer is the 'No. 12 Cup washer' which you can find here:

https://www.aliexpress.com/item/1005002446881842.html

or in the UK from here:

https://www.ebay.co.uk/itm/111304110685

or in the US from here:

https://www.ebay.com/itm/403381716746?hash=item5deb6c870a:g:j~QAAOSwf-5gUKxV

NOTE: You need to get the hollow pressed type – not the solid machine-turned type. The ones you need are illustrated in the above links.

The partially threaded DIN931 M6 bolts can be purchased from here:

https://www.aliexpress.com/item/1005002658617697.html

Stage clips

Stage clips are actually part of a separate module to the stage because they are optional but I recommend you get them if you are starting out. The other alternative is a mechanical XY Vernier slide holder (or nothing at all if you don't need to hold a slide on the stage e.g. if you are content to just hold the slide with your fingers or you are using a small Petri dish or something other than a slide as your specimen).

The type of stage clip used are the ones that have 5.5 cm long flat clips made of springy stainless steel mounted on a 7 mm long peg (the peg being 4 mm in diameter). These can be purchased, for example from this link:

https://www.aliexpress.com/item/32979312478.html

Tools

You will need the correct type of spanner / Allen key / screwdriver for the nuts and screws (e.g. 10 mm spanner for the M6 nuts, Posidrive screwdriver for your M4 screw and 1.5 mm Allen key for the M3 grub screws.

A wire brush and craft knife may be useful for cleaning up the prints.

You will also need some thick gell-like lubricant such as axle grease or petroleum jelly to lubricate the focus articulations.

Construction

The following two videos will show you how to do it, step-by-step.

You should watch them both, all the way through, before you begin to put things together.

HowTo Stage

https://youtu.be/XZ7KlyTD7dg

Z-Stage II - Troubleshooting and maintenance

https://youtu.be/ffLx28N85uE

After following these instructions you should have a functional Z-stage. At this point you can consider progressing to turning it into a microscope as explained in the following sections.

Step 2: Making the Below-Stage Components

The below-stage components comprise the short legs stand and the mirror illuminator. The module worksheets containing the details for the parts you need in the BoM spreadsheet are: ‘MD_Legs_short’ and ‘MD_Mirror_Simple’.

3D Printed Parts

To build the below-stage components you will need the following 3D printed parts in the quantities shown (this is taken from the BoM spreadsheet ‘MD_Legs_short’ and ‘MD_Mirror_Simple’ worksheets – you should consult the BoM for the most up-to-date information but currently it is as follows):

Model	***In FreeCAD file***	***Quantity***
LG_Short_leg.stl	Legs.FCStd.	3
DI_Cnd_Adj_thumbwheel.stl	Dominus_part2.FCStd	4
DI_Mirror_holder_plain.stl	Dominus_part1.FCStd	1
DI_Mirror_suspend_plain.stl	Dominus_part1.FCStd	1
DI_Mirror_to_baseplate.stl	Dominus_part1.FCStd	1

Note: The ‘DI_Cnd_Adj_thumbwheel’ models is found in the ‘Abbe_Condenser’ folder of file Dominus_part2.FCStd

Non-Printed Parts

The non-printed parts, taken from the same worksheets of the current BoM are as follows):

Non-Printed Parts	***Quantity***
M6_20mm_Hex_Steel_Spacer_20mm_long	3
M6_Washer_Flat_FormA_DIN125	3
M4_Pozi_Pan_Head_Machine_Screw_DIN7985_6mm_long	2
M4_Hex_Head_Set_Screw_12mm_long	2
M4_Washer_Flat_FormA_DIN125	2
Oval Mirror (“Small 5.5x4x0.1 cm” if buying from the example link)	1

The hex head steel spacers must have 20 mm of spacer (with female thread) connected to 20 mm of male threaded rod. The don’t have to be ‘hex’ (round bodied spacers of similar spacing dimensions can be used instead). An example buying link with illustrations is:

https://uk.rs-online.com/web/p/enclosure-accessories/0603536

If you can't find this specification you could make up something similar using M6 spacer ferrules and M6 threaded rod.

An example supplier of the oval glass mirror is here:

https://www.aliexpress.com/item/4000522518566.html

You want the 'Small' type which they label as 3.6 cm x 5.5 cm.

WARNING: These are rough cut glass mirrors and can cut you if not handled with care. Use of gloves is recommented when handling.

If you can't get this mirror or you would rather not use them for now, it may be sufficient to use reflective foil such as aluminium foil cut to side but this should be quite flat without obvious wrinkles or these can show up as irregular shadows in your microscope image.

Acrylic mirrors can also be used if you can find the right size (if you don;t want to use glass).

There is no need to use an expensive optical first surface mirror for this purpose.

If you are considering upgrading to a Kohler illuminator then aluminium foil will not be good enough and use of the above glass mirror is recommended.

The M4 hex head set screws can be purches from here:

https://www.aliexpress.com/item/1005004018299401.html

The thickness of the hex head shoul be between 2.8 and 3 mm max.

Construction

The following video will show you how to do it, step-by-step.

You should watch it all the way through before you begin to put things together.

How To Build the Foundation Scope

https://youtu.be/_5T8KuMbnq0

Step 3: Making the Above-Stage Optics

You now have a working stage and functional illumination system. The final step is to make the optical tube that holds the lenses and any optional filters.

The optical tube consists in the combination of an eyepiece (ocular) holder, a filter block and a quick-release objective holder to hold the objective lens and to attach and detach the whole optical tube assembly from the stage. These parts are covered in the following module worksheets in the BoM spreadsheet: MD_Filterblock_simple, MD_Monocular_head and MD_Ocular. I'll discuss the actual lenses (ocular and objective) separately so I won't put them in the following lists even though they are included in the BoM spreadsheet.

3D Printed Parts

To build the above-stage optical tube you will need the following 3D printed parts in the quantities shown (this is taken from the BoM spreadsheet 'MD_Filterblock_simple', 'MD_Monocular_head' and 'MD_Ocular' worksheets – you should consult the BoM for the most up-to-date information but currently it is as follows):

Model	*In FreeCAD file*	*Quantity*
FB_Filter_block_simple.stl		1
FB_Filter_slot_bottom.stl		2
FB_Filter_collar.stl		2
FB_Filter_slider.stl		2
QR_Base_thread.stl		1
QR_C-RMS_Thread.stl		1
QR_Male_C_extn_1mm.stl		1
MN_Monocular_tube_c_adhesin.stl		1
MN_Ocular_extension_c_adhesin.stl		1
MN_Ocular_cap.stl		1
MN_Ocular_lock_nut.stl		1
MN_Ocular_tube_protective_cap.stl		1

Note: You may choose to use the metal C-RMS adapter instead of the 'QR_C-RMS_Thread' 3D printed verion if you wish – you don't need both.

Non-Printed Parts

The non-printed parts, taken from the same worksheets of the current BoM are as follows):

Non-Printed Parts	*Quantity*
M3_Grub_Screw_Cup_point_Hex_socket_DIN916_5mm_long	3
M3_Allen_Bolt_Socket_Cap_DIN912_14mm_long	4
M3_Full_Nut	1

The M3 full nut must be 2.5 mm long. It is used in the top front lug of the filter block to attach the binocular head to should you ever upgrade to a binocular head (so you can omit this if you never intend to do that).

An example of the DIN912 Socket Cap Allen Bolt screws can be seen here in this example purchase link: https://www.aliexpress.com/item/32864780772.html

Optional Metal RMS Thread

If you prefer to use a metal thread to attach the objectives you can get one like this:

https://www.aliexpress.com/item/32972220978.html

Note that there other 'similar' styles that have extra metal rims and such – you cannot use those types. A metal thread will make it easier to attach and remove objectives and be more durable but the 3D printed version will work just fine if you take care in printing it and in post print processing as described in the construction video.

Eyepiece (Ocular Lens)

I don't specify specific eyepeices because there are so many types and you can buy good ones second hand, *etc.* However you need to get one that has a 20 mm field number and ideally this should also be of wide field type and with high eye reliefe (sutable for spectacle wearers). The barrel of the eyepeice must fit a standard 23.2 mm (sometimes just specified as 23 mm) tube. An example of a suitable type is shown in figure 3.

Figure 3 Example eyepiece (ocular) lens suitable for use with PUMA.

Objective Lens

For similar reasons I do not specify particular objectives. However the type of objective required should have the following characteristics (see figure 4).

It must have an RMS thread to connect it to the scope. It must have a conjugate focal distance of 195 mm and a parfocal length of 45 mm. It must be made to work with a finite mechanical tube length of 160 mm (infinity objectives will not work with the configuration of PUMA you are building here).

As for magnification, x4 or x10 is recommended for this Foundation scope because it does not have an Abbe condenser. If you want to use higher magnification objectives then you will need to upgrade your scope with the PUMA Abbe condenser module (which you can build by following this video tutorial: https://youtu.be/2wpsvA2cQgQ).

For best image quality use a 'Plan' objective as opposed to a simple achromat. Plan objectives will give an image that is in focus all the way across the field of view from the centre to the periphery while 'semi-plan' or simple achromats will show either the centre or the periphery in focus at any one time but not both. Of course, 'Plan' objective ar more expensive due to the extra corrective optics they employ.

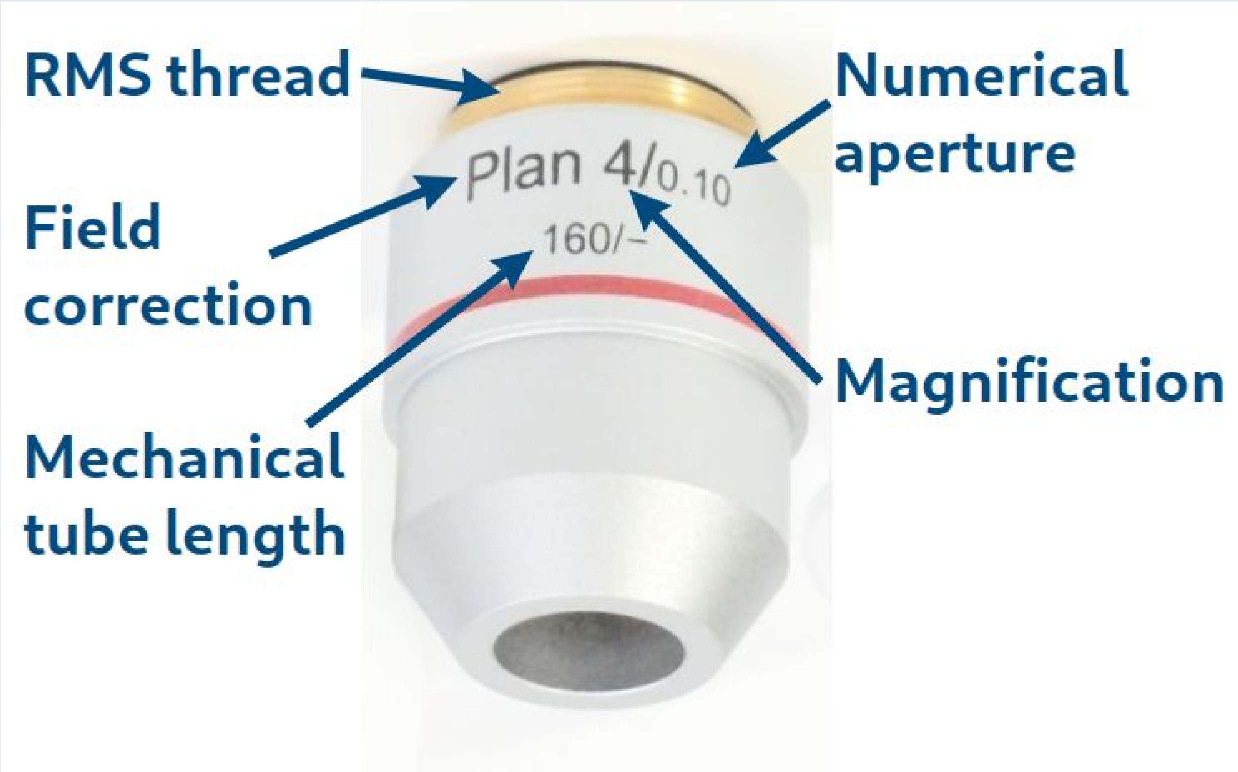

Figure 4. A type of objective that is suitable for use with the PUMA Foundation scope. The position occupied by the minus sign ('-') after the tube length is the coverslip thickness indicator. A '-' indicates it can be used with any coverslip type or none at all. For some high magnification objectives this is replaced with a number (e.g. '0.17') to indicate that the objective is designed to be used with that type of coverslip.

Construction

The following video will show you how to do it, step-by-step.

You should watch it all the way through before you begin to put things together.

How To Build the Foundation Scope

https://youtu.be/_5T8KuMbnq0

Concluding Remarks

If you have got this far then you have successfully built your PUMA Foundation scope. The User Manual linked to in the Introduction section of this document will help you get started using it and you can see the other videos on the PUMA microscope channel for instructions on how to extend its abilities with various add-ons and upgrades.

If you have successfully followed this guide then you will also have acquired the knowledge and skills you need to follow the instructions shown those videos (for example, how to use the BoM spreadsheet to find out exactly what you need to print and what non-printed parts to get).

Consider subscribing to the PUMA microscope YouTube channel to keep up to date with the various modules and useage notes for different types of microscopy you can perform with the PUMA system.