Ultra-Wide Field of View Lens Using DSEARCH

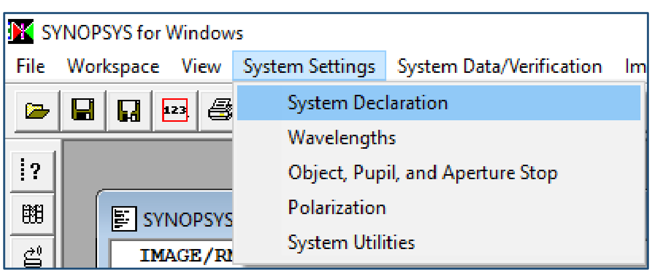
DSEARCH allows for the creation of several starting points for a system if given the initial design parameters. This can be done for a wide variety of systems and can even be used when designing systems with very large fields of view. This study will show you how to begin designing such a lens in SYNOPSYS™. These lenses are very popular with photographers for not only the wide field of view, but also the large depth of field, reduced camera shake, and ability to dramatically affect the perspective of objects within the image.

Front-End Design

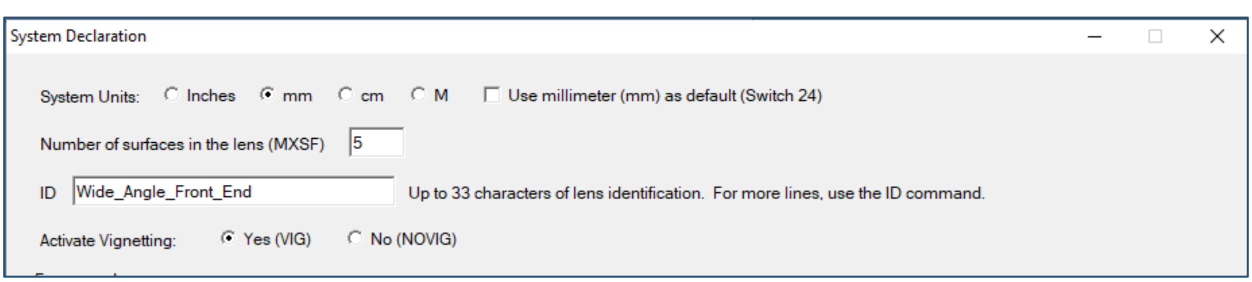
One limitation of DSEARCH is that it cannot generate new systems whose full FOV exceeds 180°. It can, however, work on existing system that do. So the simple workaround for this is to make a rough front-end for the lens, and then allow DSEARCH to work on that. To do this, create a new lens within SYNOPSYS™ and set up the system for wide-field imaging. In our case, we have a few design parameters we will be working towards:

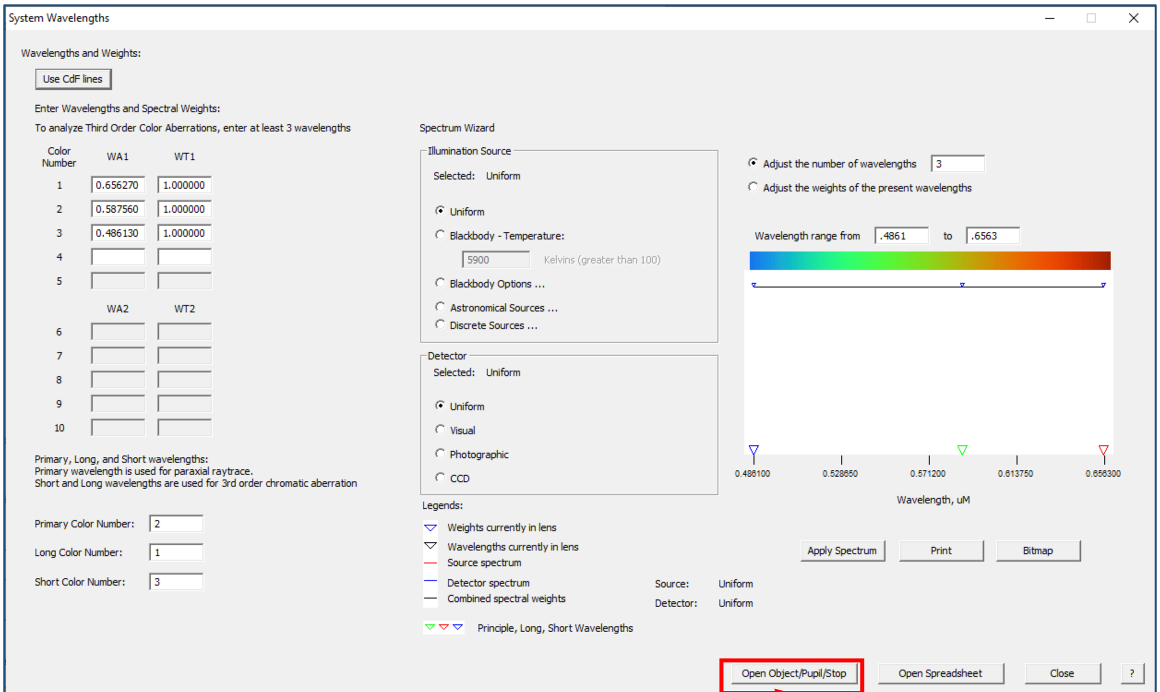
- f/4
- Back Focal Distance (BFD) = 5mm
- Total Track Length (TTL) = 35mm
- Full Field of View (FFOV) = 240°

Click on “System Setting > System Declaration” to begin:

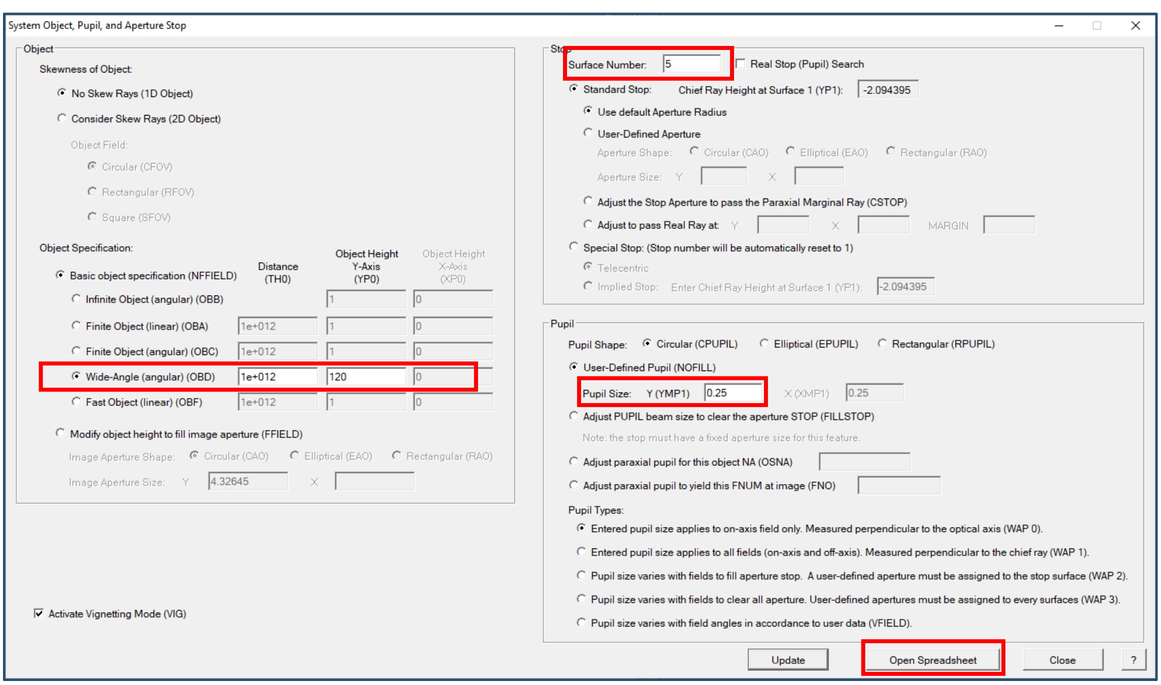


Make sure the following settings are the same, and then click the “Open Wavelengths” button at the bottom of this window.

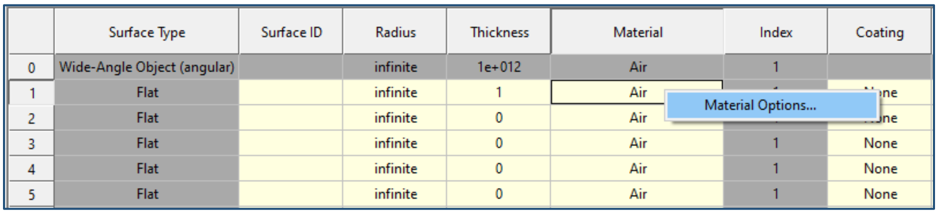


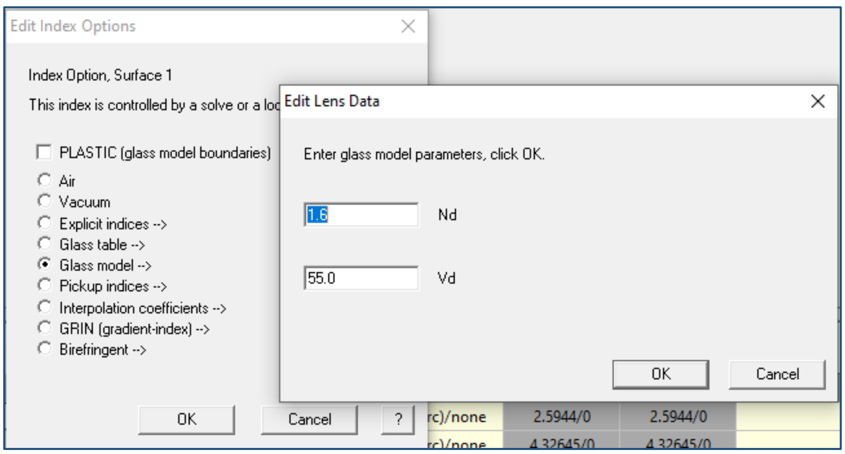


This window allows you to adjust the wavelength range and weights to your specific use case, but we will just use the default CdF lines. Next, click on the "Open Object/Pupil/Stop" button at the bottom of this window. Here, set our object to be a wide-angle object (OBD) with an angular extent of 120°. This is our Half Field of View (HFOV). Make sure our stop location is the last surface and set the pupil size to be roughly 0.5mm in diameter. Then, click the "Open Spreadsheet" button at the bottom of this window.



We want two elements to rough out our front-end design, so set surfaces 1 and 3 to glass models by right-clicking on the Material cell of each surface, select "Material Options…", and click on "Glass Model". The default values that come up are sufficient.

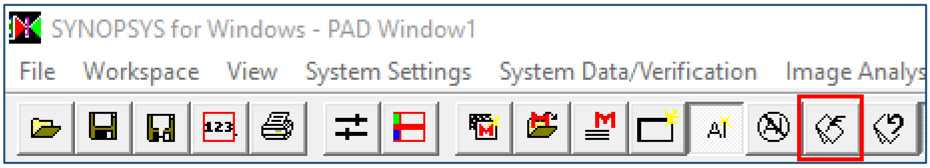




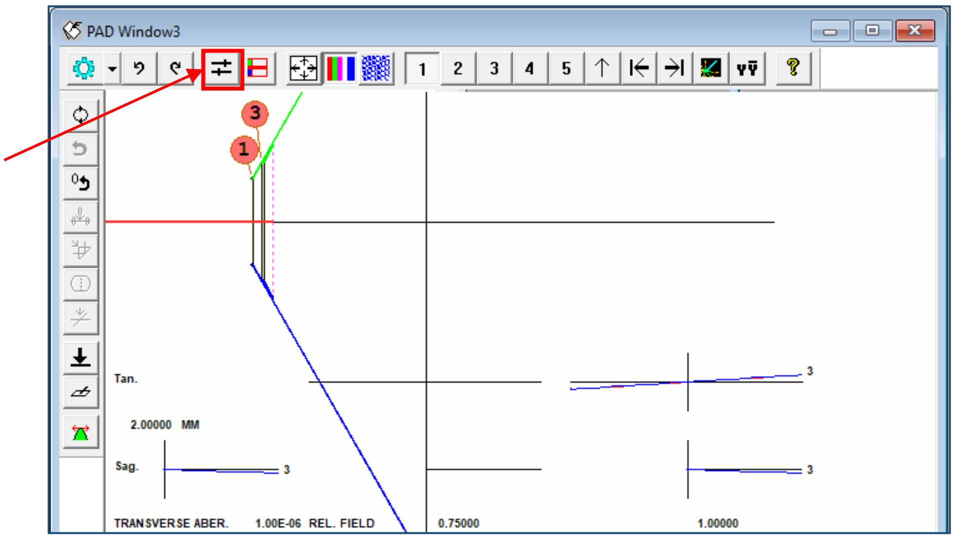
Set some reasonable thicknesses for the system to get started with, and then we're ready to begin roughing out a front-end. 1mm for any elements and 5mm for the spacings between elements is appropriate for this case.

	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating	Aperture Type (Outer/Inner)	Y Semi-Width (Outer/Inner)	X Semi-Width (Outer/Inner)
0	Wide-Angle Object (angular)		infinite	1e+012	Air	1		Def (Circ)/none	0/0	0/0
1	Flat		infinite	1	GLM	1.6	None	Def (Circ)/none	24.0619/0	24.0619/0
2	Flat		infinite	5	Air	1	None	Def (Circ)/none	24.7057/0	24.7057/0
3	Flat		infinite	1	GLM	1.6	None	Def (Circ)/none	33.3659/0	33.3659/0
4	Flat		infinite	5	Air	1	None	Def (Circ)/none	34.0096/0	34.0096/0
5	Flat		infinite	0	Air	1	None	Def (Circ)/none	42.6699/0	42.6699/0

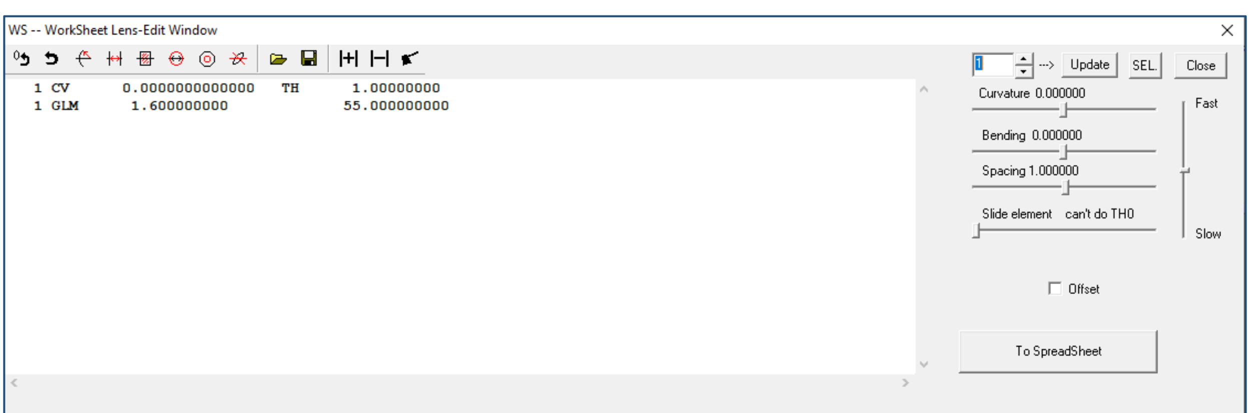
Now we can look at the system on the sketch pad:



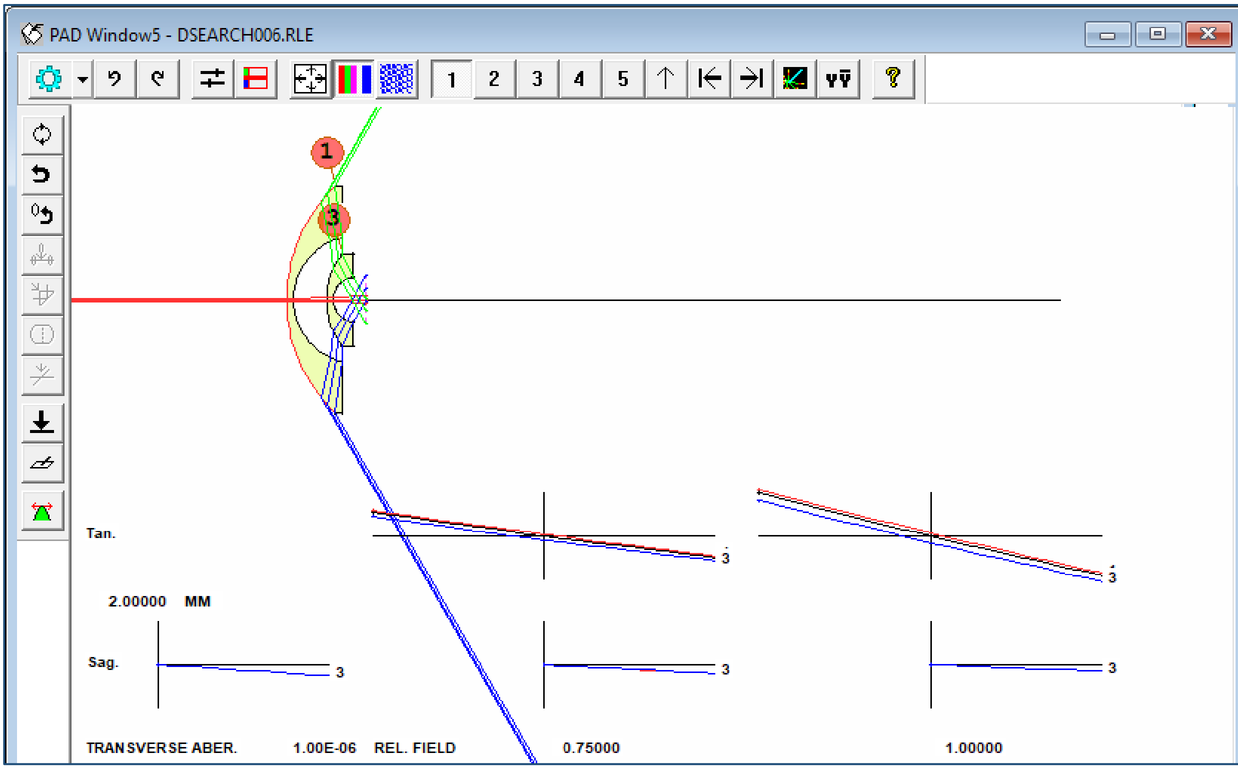
This doesn't look like much right now, but with some manipulation using the WorkSheet (WS) editor, we can create a system good enough to allow DSEARCH to generate several starting points for us to work with.



Click on the WS button to begin editing this system. This will allow the easy manipulation of lens parameters to begin making a rough version of a front-end to the system we want to end up designing. This step takes a little bit of time to get used to, so try adjusting some of the options here and get familiar with the effect that changing each parameter has. For our case I find that a rough 1:2 or 1:3 relationship between the first and second curvatures of each element tends to work well. The video component of this tutorial demonstrates how to use this feature.



Something along these lines is sufficient to begin using DSEARCH to work on. It doesn't need to be particularly exact because we will let DSEARCH handle the fine-tuning.



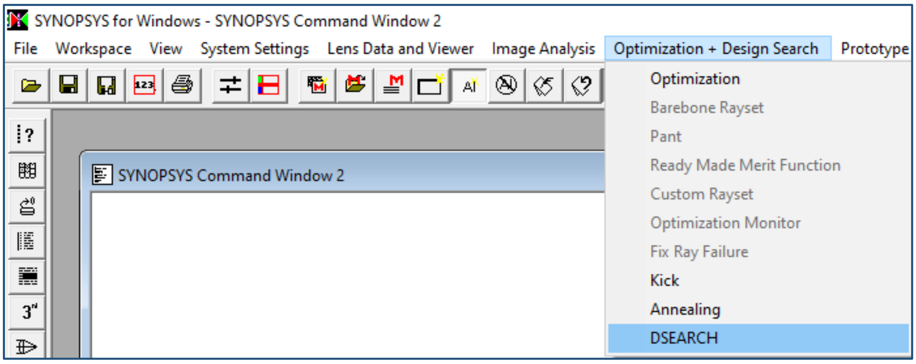
Below is a system that can be used as a starting point. You can use these numbers to follow along, or you can create your own front-end. Keep in mind that creating your own front-end may result in a final system that is different from the one demonstrated in this tutorial.

	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating	Aperture Type (Outer/Inner)	Y Semi-Width (Outer/Inner)	X Semi-Width (Outer/Inner)
0	Wide-Angle Object (angular)		infinite	1e+012	Air	1		Def (Circ)/none	0/0	0/0
1	Spherical		23.6205582	1	GLM	1.6	None	Def (Circ)/none	17.0952/0	17.0952/0
2	Spherical		9.58626504	5	Air	1	None	Def (Circ)/none	9.29698/0	9.29698/0
3	Spherical		11.4034451	1	GLM	1.6	None	Def (Circ)/none	6.92831/0	6.92831/0
4	Spherical		3.43274519	5	Air	1	None	Def (Circ)/none	3.39279/0	3.39279/0
5	Flat		infinite	0	Air	1	None	Def (Circ)/none	3.62751/0	3.62751/0

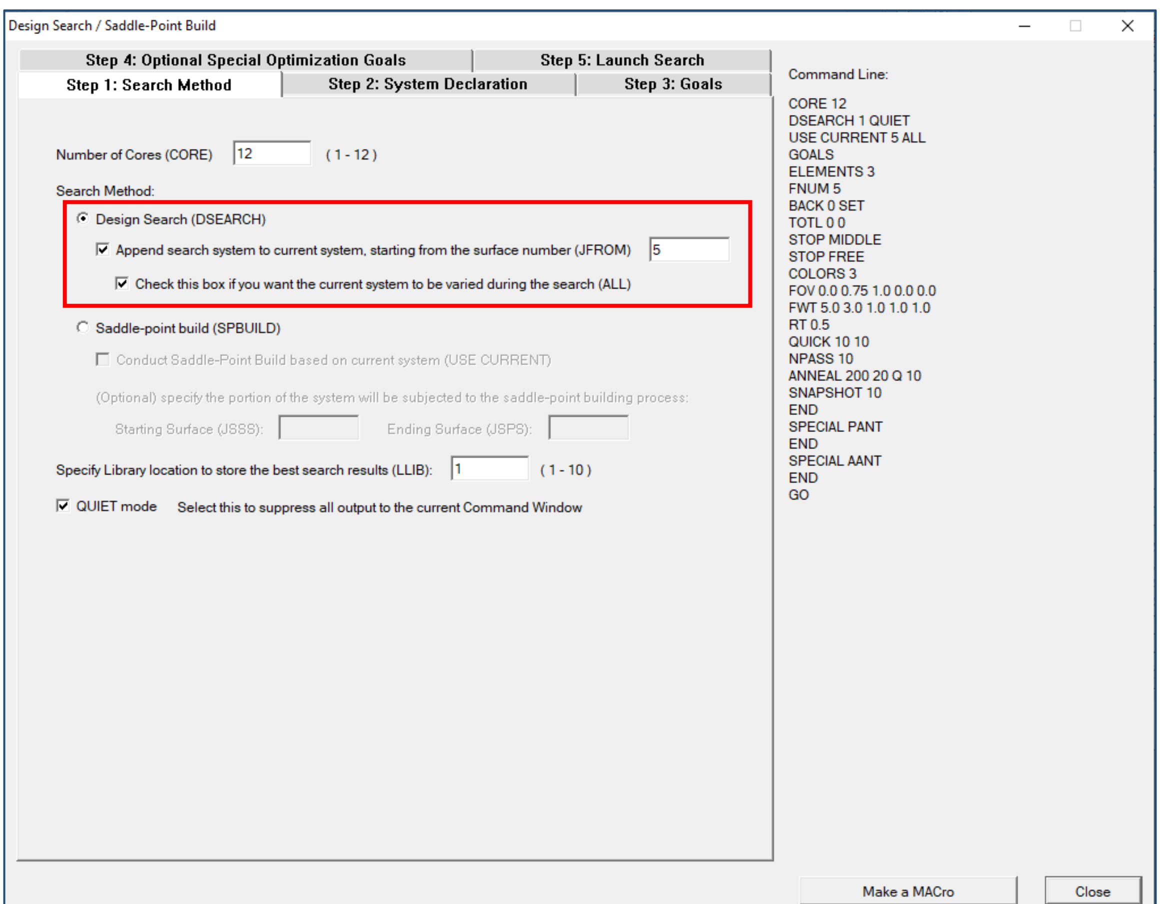
From here, we can begin setting up our DSEARCH parameters to get some starting points for this wide-angle lens.

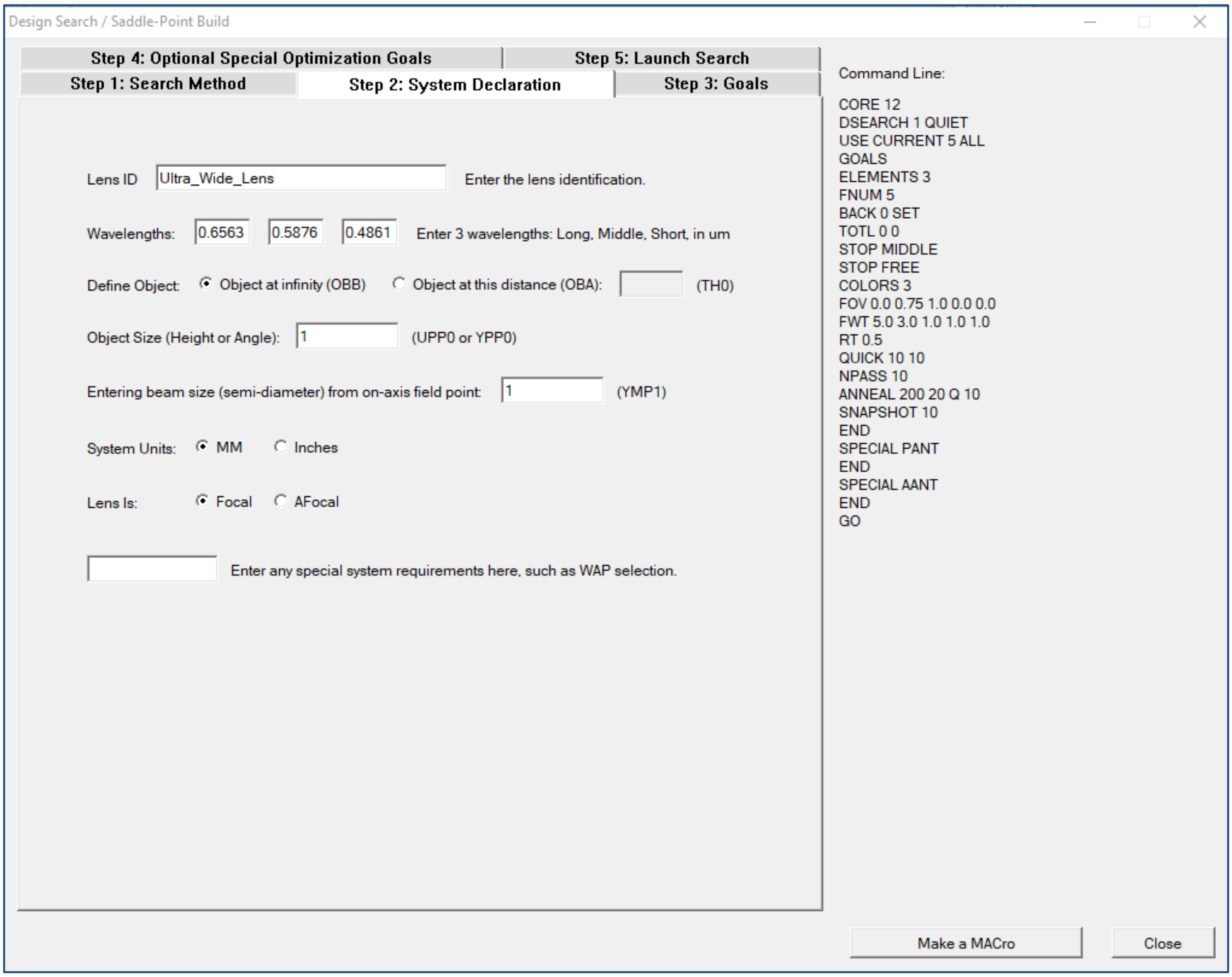
DSEARCH Script

To begin, click on “Optimization + Design Search > DSEARCH”

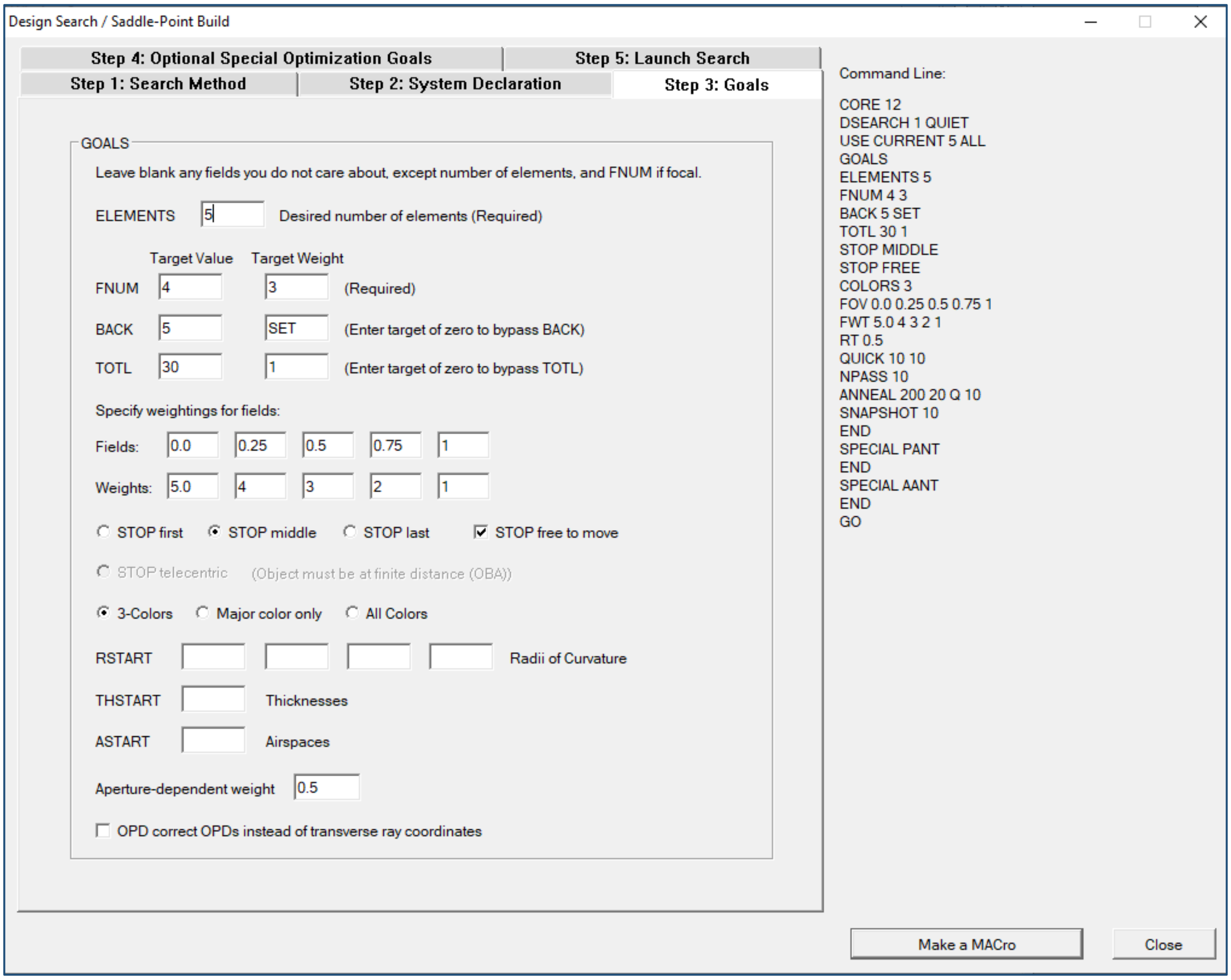


When the DSEARCH dialog opens, make sure to check the boxes shown below and set the starting surface number to the last surface in the system (5). Since the front-end we made was just a rough estimate, we want DSEARCH to optimize these elements as well. You’ll notice the MACro being generated on the right as we adjust settings within this dialog.

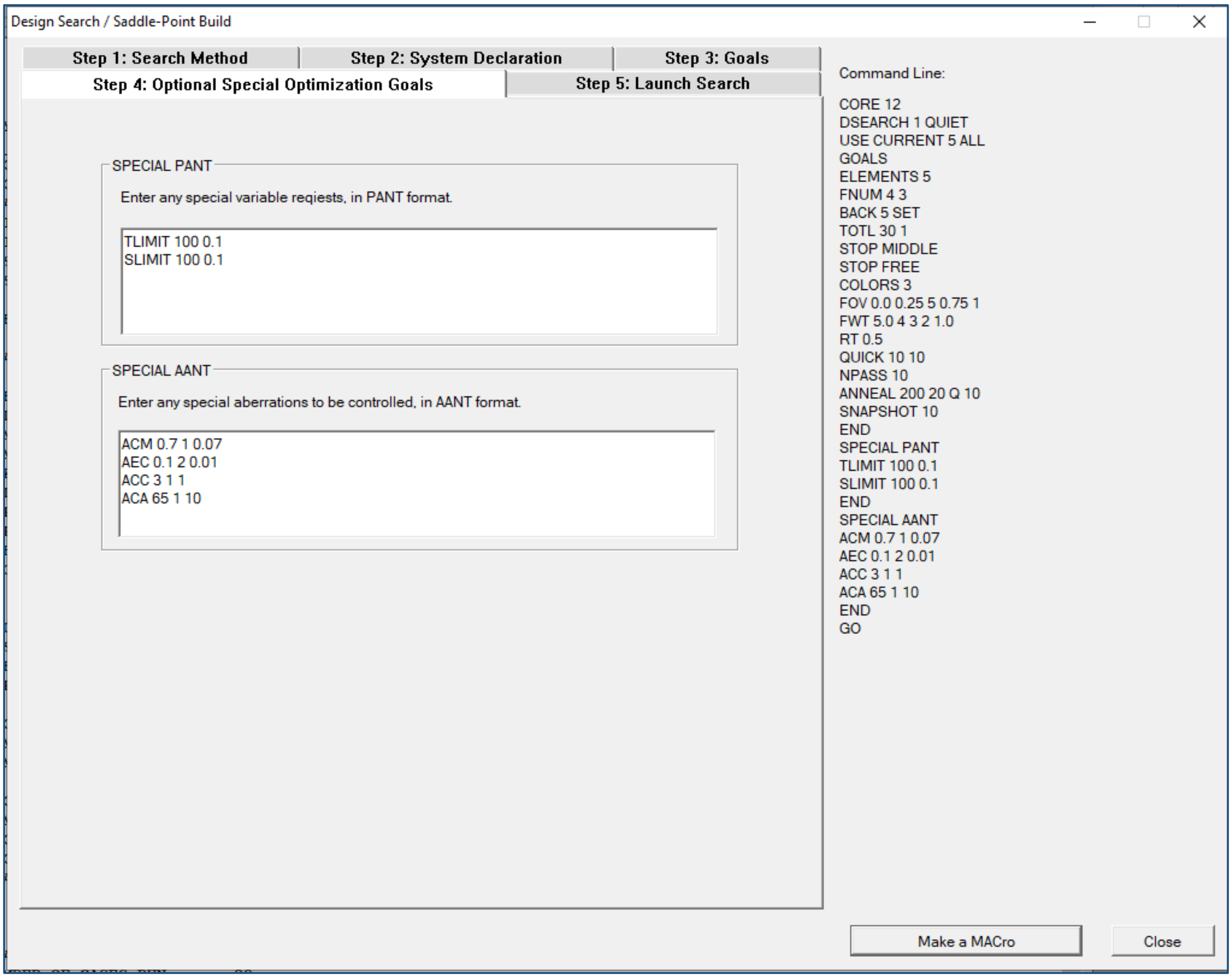




Because we are appending the search to the current system, the settings on this page are overwritten by the parameters we defined when first setting up the system. You'll notice that none of these options don't make their way over to the generated MACro, so there's no need to worry here.



Here we set the main parameters of the system we want to find. The ELEMENTS cell near the top is the number of elements generated *after* the front-end we've already designed. This means our full system will consist of 7 elements. Changing this number will result in different potential solutions that could be helpful to look at in some instances. We want the FNUM to be very close to 4, so we give this value a large weighting to make DSEARCH prioritize this. Our track length must be 35mm, but the TOTL value is only the distance from the first surface to the last surface of the last element and does not include the BFD. Because of this, we set TOTL to be 30 to give us a track length of 35mm.

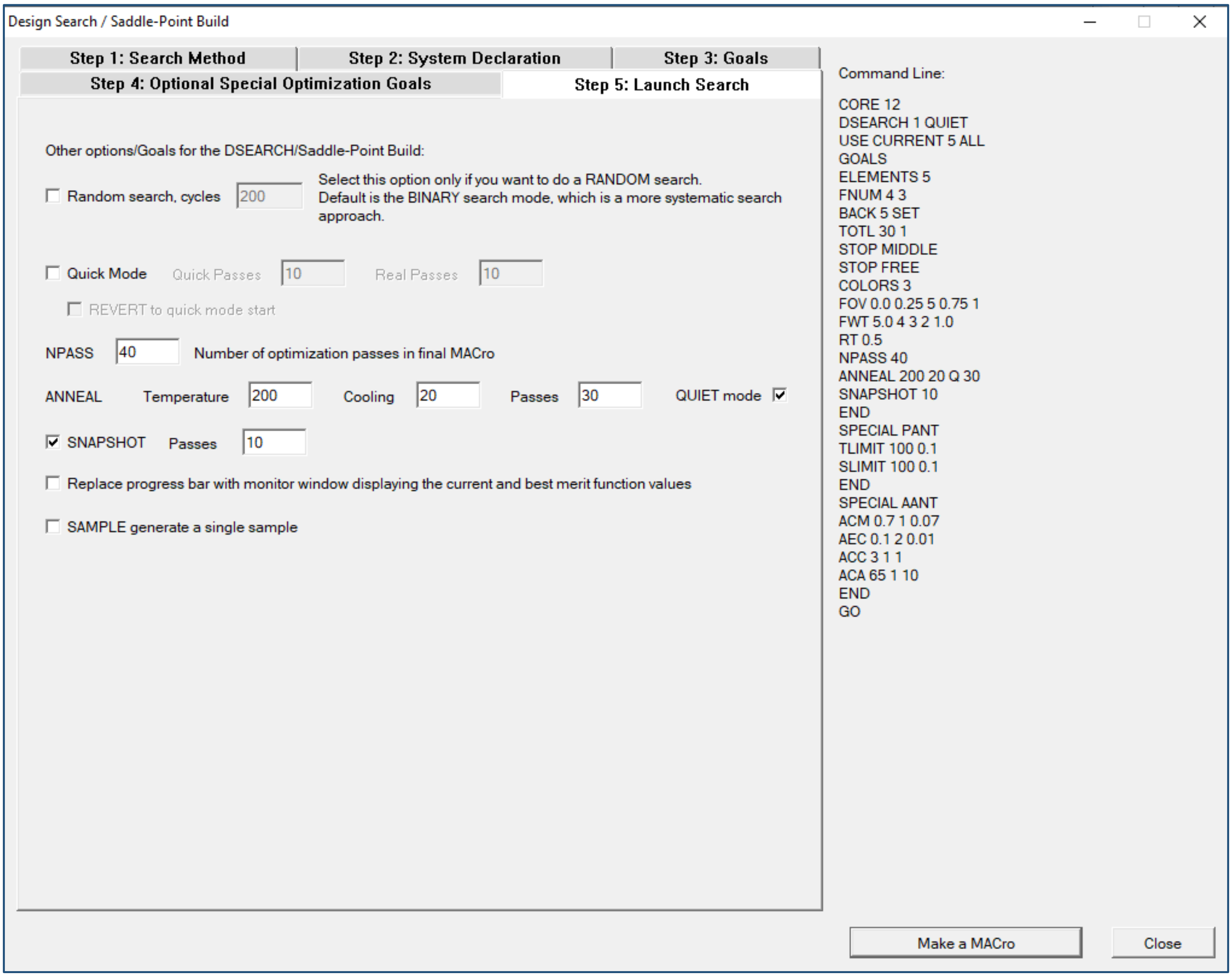


Here, special variables and constraints can be defined that are not present in the DSEARCH dialog to fine-tune your search. These extra commands are necessary due to the nature of our system. The **TLIMIT** and **SLIMIT** commands change the limits of the element thickness and airspace thickness respectively. Because our system must lie within 35mm, some of our elements will get quite thin and need to get smaller than the default minimum thickness of 1mm.

Each item in the AANT section for this case is defined as:

Item Target Weighting Window

ACM controls the minimum center thickness. We've set that to 0.7mm with a weighting of 1, and an allowed window of ±0.07mm
AEC controls edge thickness to be a minimum of 0.1mm
ACC controls the maximum allowed center thickness of each element to be no more than 3mm. This prevents unreasonably large lenses to be used
ACA prevents solutions being found where rays enter/exit elements at extreme angles to prevent ray failing. In this case, we want to try to limit the entering/exiting angle to be less than 65 degrees measured from the surface normal.



Here we input the final search parameters. We won't be using quick mode during this search because we want SYNOPSYS™ to spend extra time searching/optimizing solutions, and the quick search is unlikely to help us find better solutions in our case.

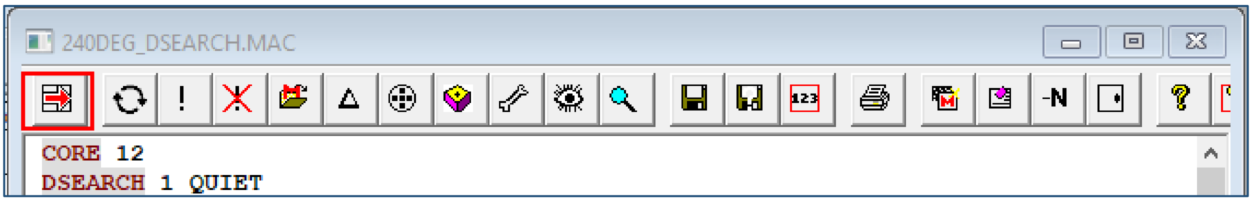
NPASS allows for 40 optimization passes made for each case it searches for.
ANNEAL allows DSEARCH to try to jump out of any potential local minima, to further drive the merit function lower. Higher "temperatures" allow for greater variety in potential solutions, while cooling affects the run speed. Passes defines the number of passes for this process.
SNAPSHOT defines how often the Sketchpad window updates. Larger numbers here mean faster runtime, but it can be useful to watch this as solutions are found.

With this done, we're ready to click on the "Make a MACro" button and begin searching for solutions!

A DSEARCH MACro will pop up on the screen with all the options we've previously set. We just need to add one thing and then we're ready to go. Since we're dealing with such an extreme lens, it can be helpful to vary the conic constant in DSEARCH to allow it to search for potentially better cases. Add this line to the DSEARCH MACro:

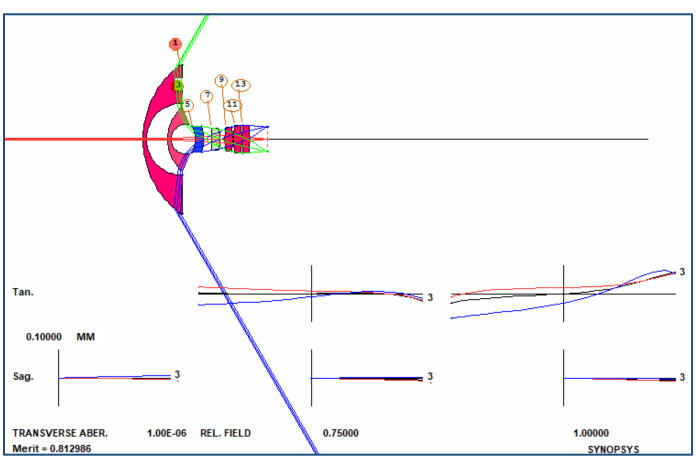
```
TOTL 30 1
STOP MIDDLE
STOP FREE
ASPHERIC 1 3 5 6 7 8 9 10 11 12 13 14
COLORS 3
```

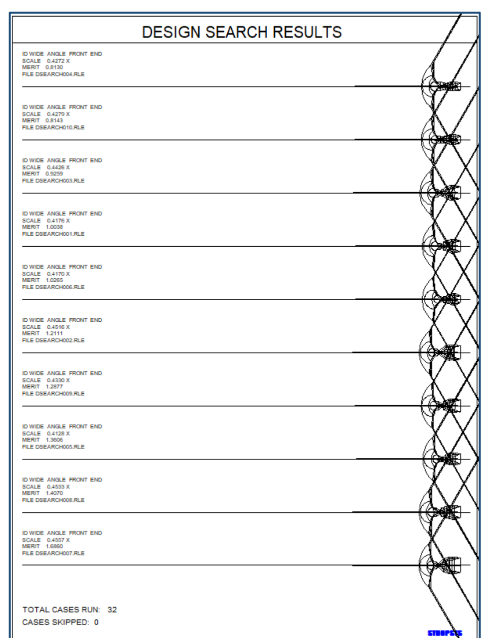
Then, click the Run icon on the top left and watch as SYNOPSYS™ searches for lenses that fit our specifications.



The solution that has the lowest merit function will be loaded in, but ten of the other best fitting solutions will also appear in a graphics window. The system loaded in automatically may not actually be the best, so it can be useful to peruse the other options and see if there's a form you would prefer to work with. In my example, the default works fine. Loading in a different result is as simple as typing in "FETCH DSEARCH___" and filling in the blank with the appropriate number.

Due to the random nature of DSEARCH, you will not see the exact same systems shown in this guide, but they likely will have a similar form.





As we can see from the ray fans, this lens is a good starting point for this application. It still requires work to bring to a point worth manufacturing. SYNOPSYS™ has a powerful optimization algorithm that will allow us to greatly improve the lens. Optimization itself is a huge topic that we will explore in the following tutorial. There we will discuss good strategies to tackle this issue and demonstrate the tools that SYNOPSYS™ has to offer. For right now, you should have a better understanding of how to use DSEARCH to quickly generate starting points for your design and allow the computer to use its resources to do a lot of the basic work for you. This tool is unique to SYNOPSYS™ and I hope you can get great use out of it.

References

[1] Dilworth, D. (2018). *Lens design: Automatic and quasi-autonomous computational methods and techniques*. Bristol: IOP Publishing.