Efficiently Manage Optical System Requirements with Specification-Guided Software

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Introduction

Optical design software helps engineers create virtual prototypes of optical systems more quickly and cost effectively than building physical prototypes. Once a virtual prototype is created, engineers can also use the software to analyze and adjust optical system designs. These software capabilities help companies get the best quality products to market faster. Additionally, that same software can help engineers meet project specifications, minimize costs and improve manufacturability.

Software that enables efficient management of optical design goals and objectives can substantially improve project outcomes. This can be done with specification-guided software, which provides an integrated, structured interface for defining project specifications and goals, followed by evaluation of the designs to determine if they are meeting the requirements, and if not, to easily identify the problem areas.

A specification-guided software methodology has been introduced in Synopsys' CODE V® software with the patented SpecBuilder™ and SpecEvaluator™ tools. The SpecBuilder and SpecEvaluator tools provide a streamlined approach to defining and evaluating optical specifications and requirements, and represent an important step forward in simplifying project monitoring and analysis.

Figure 1 provides a high-level view of how the CODE V SpecBuilder and SpecEvaluator tools fit into the optical design process.
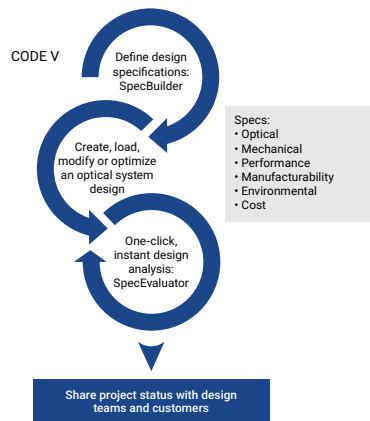

Figure 1: Optical designers can use the SpecBuilder tool to create a comprehensive table of specifications and goals tailored to their application. Then, at any point in the design cycle, designers can use the SpecEvaluator tool to instantly analyze the optical system and identify areas that do not meet performance requirements or other parameters.

This paper introduces the SpecBuilder and SpecEvaluator tools and provides an application example of how the tools can help you efficiently manage optical system requirements and performance evaluations.

CODE V SpecBuilder: Creating a Specifications and Goals Table

Optical system designers typically use a table of specifications and goals to describe the requirements and design objectives for an optical system. In CODE V, you can use SpecBuilder to create a Specifications and Goals Table. The table presentation makes it fast and simple to enter and evaluate optical system attributes and performance.

You can add different types of specifications to the table to evaluate wide-ranging aspects of your optical systems, such as optical, mechanical, performance, manufacturability, environmental and cost aspects. For each specification, you define evaluation parameters and performance targets. You can also create your own custom specifications using CODE V's Macro-PLUS™.

SpecBuilder allows working teams to evaluate designs based on a common set of well-defined and agreed-to specifications, reducing the likelihood of errors and miscommunication.

CODE V SpecEvaluator: Assessing the Optical Design

The CODE V SpecEvaluator works with SpecBuilder to provide one-click updates to show your progress against design requirements and project goals. SpecEvaluator sequentially performs each specification evaluation from the top to the bottom of the SpecBuilder table. If SpecEvaluator encounters an error during a specification evaluation, information about the cause of the error is provided, but the error does not prevent the evaluation of other specifications in the table. When SpecEvaluator is finished, the aspects of your optical design that do not meet specs and goals are highlighted, allowing you to see at a glance how actual system performance compares to your targets.

You can drill down, if desired, into individual specification results. You can then continue your design work and use SpecEvaluator to evaluate your design as often as you like to help you keep your design on target.

You can also selectively enable or disable which specifications are to be evaluated when running SpecEvaluator, such as computationally intensive specifications that you will only intermittently evaluate during the design process.

After SpecEvaluator is run, you can copy the entire table of results or selected results to other applications to create project documentation.

Application Example: Designing an Automotive Backup Camera with SpecBuilder and SpecEvaluator

As an example of how to use CODE V SpecBuilder and SpecEvaluator to manage the optical design and performance evaluation process, let's consider the design of a compact, wide-angle automotive backup camera objective.

The lens will operate at f/2.5 with a full field of view of 170°. For manufacturability, the number of aspheric surfaces should be minimized, lens elements should have reasonable center and edge thicknesses relative to their diameter (aspect ratios), and the design should be optimized to reduce sensitivity to tolerances. The project specifications and goals are summarized in Table 1.

Parameter	Specification
Wavelengths	486.1– 656.3 nm
Focal length, number of elements, number of aspheres	Monitor
F-number	f/2.5
Image sensor full-diagonal	2.8 mm
Field-of-view, full-diagonal	170°
Overall length	< 15 mm
Lens diameters (with 2% overage added to beam size)	< 15 mm
Lens to sensor clearance (with 2% overage)	> 1.0 mm
Relative illumination	> 50%
As-built MTF at 75 cycles/mm for 0° & 90° azimuths over field, mean+2σ probability*	Minimum > 0.25, Average > 0.50
Aspect ratio: • Diameter/center thickness • Diameter/edge thickness	>2:1; <10:1 (goal) >2:1; <10:1 (goal)

Table 1: Specifications and goals for an automotive backup camera objective

* We assume a sensor having 840 pixels across the 2.8 mm diagonal, giving a limiting spatial frequency of ~150 cycles/mm. However, for navigation, detector-limited performance is not required.

Creating a Specifications and Goals Table with SpecBuilder

Within CODE V, we begin by opening a new SpecBuilder window; then, for each system requirement, we add a corresponding specification to the table. SpecBuilder includes a wide variety of built-in specification types, as well as a capability to create user-defined specifications.

Each specification includes controls for defining the parameters needed to evaluate results and, optionally, how those results should be compared to a target value or range of values. For example, a specification may include controls to specify:

- Which zoom, field, and defocus positions to use in evaluating results, for display or comparison to a target value or range of values
- Whether the maximum, minimum, average, or all individual results will be used for display or comparison
- Computational parameters required for the calculations
- The target mode, which can include a target value or allowable range of values for comparison

The calculations may produce a single result or a range of results, so the SpecBuilder will display either a single value or two values that represent the minimum and maximum calculated values. These values are then optionally compared to the target value(s), and a Value cell is highlighted in red in the table if the target value is not met, or if the specification has not yet been evaluated.

Figure 2 shows how the as-built MTF specification is defined. The individual values for as-built MTF (estimated for a mean + 2σ cumulative probability) are aggregated for all zoom positions and fields at a frequency of 75 cycles/mm for both 0° and 90° azimuths. The performance prediction at every defined field for each defined zoom position (configuration) must be greater than or equal to a target value of 0.25.
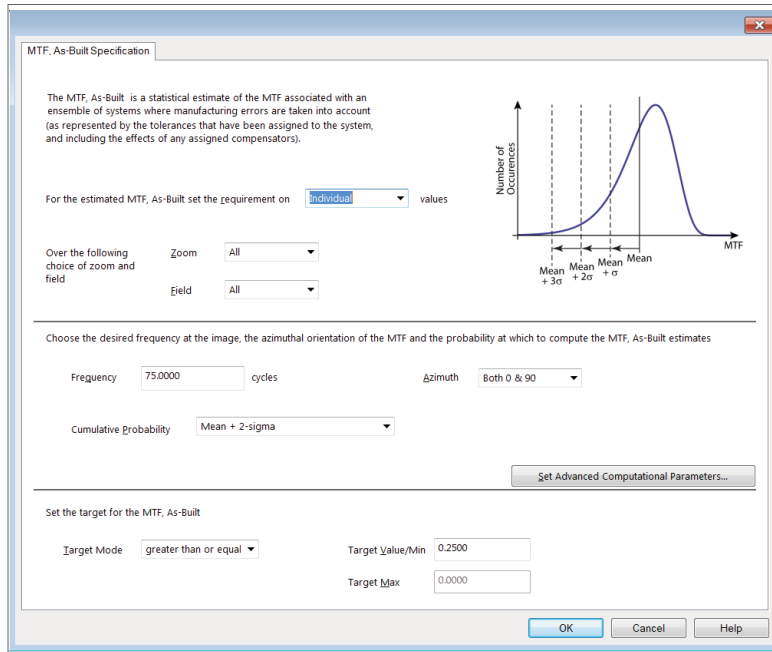
Figure 2: As-built MTF specification

In addition to the specifications shown in Table 1, we also include a few more specifications to track during the design process, including nominal MTF at 150 cycles/mm for 0 and 90° azimuths and lens model attribute specifications for the fields and system dimensions. For our example, we require five fields with object angles of 0, 25, 50, 75, and 85 degrees to ensure that average MTF over field is computed for these specific fields (which can be very important to monitor when comparing different lens models), and the custom image diameter specification requires millimeter system units for the lens model.

Figure 3 shows the completed SpecBuilder table. Note that the Value column is highlighted in red to indicate that the specifications have not yet been evaluated. The SpecEvaluator button at the top of the SpecBuilder will be used to evaluate the specifications once a lens model is loaded.

Figure 3: Specifications and goals for an automotive backup camera objective

The SpecBuilder window gives you flexibility to move specifications or groups of specifications up or down, add labels and notes in the columns provided, resize rows and columns, copy and paste the table or portions of the table to other applications, modify goal modes and target values, and temporarily enable or disable individual calculations.

The SpecBuilder table can be saved to a file for reuse. The table file is independent of the file for your resident CODE V optical model, so you can use it to evaluate different optical systems against the same requirements. You can also have multiple files open simultaneously. For example, one file can contain specifications that need to be listed in a report, while another file can contain additional specifications that are important to monitor during the design process.

Starting Point Design

For our starting point, we use CODE V's Patent Lens Search feature and filter the results to find candidate designs with F-number < 2.5, a semi-field-of-view between 80° and 100°, and a ratio of overall length to effective focal length within < 15 mm. We select a result and make a few modifications to define the required F-number, wavelengths, object field angles and system units, and scale the system length to give the required image height. The result is shown in Figure 4.
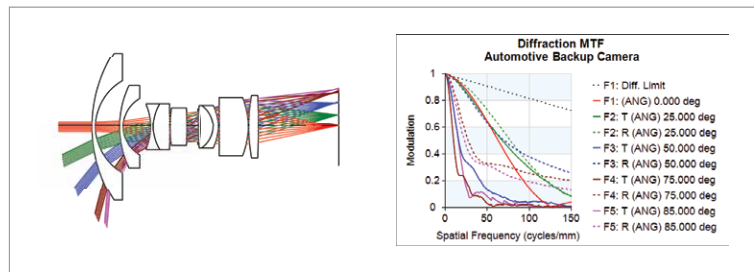
Figure 4: Starting point lens layout for an automotive backup camera objective (based on Japanese Patent 49_20535 740525)

Now that we have a starting point design, each specification is evaluated. The results are shown in Figure 5. The system-level and mechanical specifications are generally being held, except for the element aspect ratios. The nominal system performance is quite poor, and no tolerances are defined so we cannot evaluate the as-built MTF.

Figure 5: Specifications and goals for the starting point design (excerpt)

Each of the specifications now includes an information icon and may also include an alert icon in the two columns to the right of the Value column. Clicking the information icon provides a detailed listing that includes all data used to compute the values listed and provides useful tabulated output. The alert icon provides a listing of warning and error messages produced during evaluation; for example, the MTF, As-Built specifications indicate that we need to specify tolerances before evaluating these specifications.

Preliminary All-Spherical Design

For our initial optimization, radii of curvature, thicknesses and glass data are used as variables. We remove the cemented components, since they are impractical for small, molded elements. We optimize the design using constraints for image size, overall length, image clearance, front element semi-diameter, element aspect ratios, general sensitivity, and constraints to prevent the back surfaces of the front two elements from optimizing to hemispheres. Tolerance sensitivity is controlled using CODE V's built-in General Sensitivity constraint, which significantly improves as-built performance with minimal impact on optimization speed. To evaluate the as-built MTF performance, we specify premium-class tolerances along with a focus compensator. The tolerances are listed in Table 2.

Parameter	Value
Power (fringes @ 632.8 nm)	± 0.2
Irregularity (fringes @ 632.8 nm)	± 0.05
Thickness (µm)	± 25
Refractive index	± 0.0003
Abbe number (%)	± 0.3
Wedge (µm, Total Indicated Runout)	± 6.5
Element Tilt (arcsec)	± 5
Element Decenter (µm)	± 6.5

Table 2: Premium-class tolerances used for the case study designs

The optimized, preliminary all-spherical lens layout and nominal MTF versus field are shown in Figure 6, and the SpecBuilder table with SpecEvaluator results is shown in Figure 7. The system-level and mechanical specifications are being held, including the element aspect ratios; however, the as-built MTF performance is not meeting the specification.
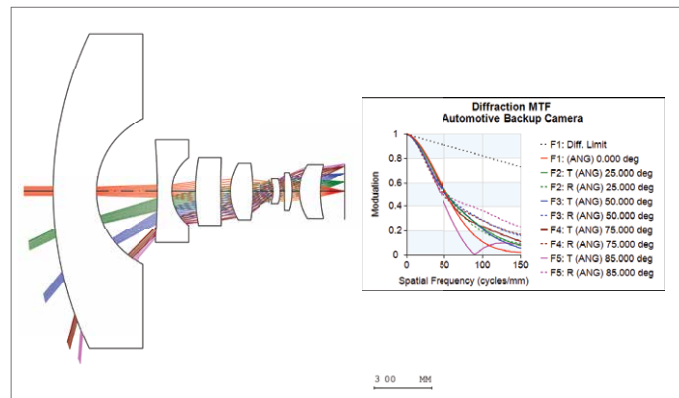

Figure 6: All-spherical preliminary lens layout and nominal MTF performance versus field

Figure 7: Specifications and Goals results for the all-spherical preliminary design (excerpt)

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Final Design

For our final design, we use two powerful CODE V features: Asphere Expert and Glass Expert.

- **Asphere Expert** uses an extremely efficient computation to determine the best locations within the lens to introduce non-spherical surfaces. It ranks the relative benefit of aspherizing each spherical surface in the lens. Constraints can be applied, such as limits on aspheric slope departure and maximum permitted aspheric order. In this example, we add two aspheres without aspheric slope constraints. Asphere Expert recommends aspheres on Surfaces 10 and 5
- **Glass Expert** automates the process of traditional glass selection. It selects the element optical materials from a user-specified list of candidates to improve performance, while meeting optional cost, weight, transmission and manufacturability goals. All fictitious glasses in the backup camera lens are replaced with real glasses from the RPO Molded Glass Catalog

Note that, for this case study, we only use local optimization, but improved results are likely to be found if global optimization is done using CODE V's Global Synthesis® feature, particularly if optimization controls on tolerance sensitivity are included (e.g., using CODE V's built-in features for reducing tolerance sensitivity or optimization using an error function that includes the estimated effects of tolerances).

The final lens layout and nominal MTF versus field are shown in Figure 8, and the specification table with SpecEvaluator results is given in Figure 9; as shown, the design meets all specifications and goals.

For reporting results, the SpecBuilder table (as well as output listings and warnings/errors for individual spec evaluations provided by clicking the information and alert icons) can be copied directly to a project report. In this case study, for example, we may wish to include the table of estimated as-built MTF versus field and azimuth provided by the information icon for the as-built MTF specification. Also, although the MTF specification has been met by the final design, an alert icon warning is given that the MTF loss was significant, which might be important to report.
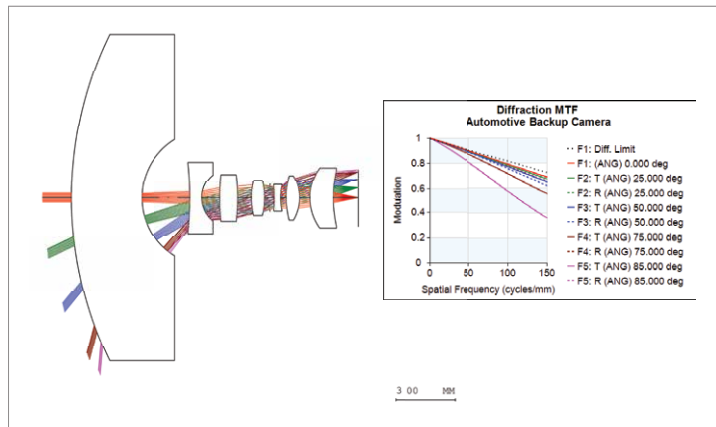

Figure 8: Final aspheric lens layout and nominal MTF performance versus field

Figure 9: Specifications and goals for the aspheric final design (excerpt)

Conclusion

The CODE V SpecBuilder and SpecEvaluator tools offer optical engineers a novel and efficient interface for defining the specifications and goals for an optical system and for quickly evaluating, comparing and reporting actual parameters and performance for a resident design. These benefits are demonstrated using an automotive backup camera example.

The tools:

- Allow design progress against specifications and goals to be monitored actively throughout the project, greatly minimizing the likelihood that a detail will be missed at project completion
- Provide a common, agreed-to set of specifications and goals for team environments to avoid miscommunication or misinterpretation of project requirements
- Support easy and efficient comparison of different candidate design forms against the project requirements
- Greatly improve designer efficiency and communication with management and customers

To Learn More

For more information about CODE V, visit synopsys.com/optical-solutions or send an email to optics@synopsys.com.