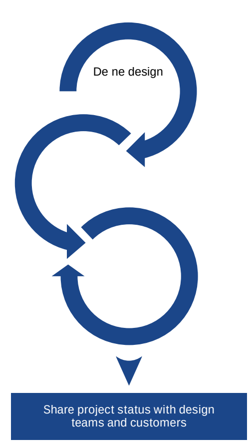
Optical design software helps engineers create virtual prototypes of optical systems more quickly and cost effectively than building physical prototypes. Once a virtual prototype is created, engineers can also use the software to analyze and adjust optical system designs. These software capabilities 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.



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.

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%
	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.

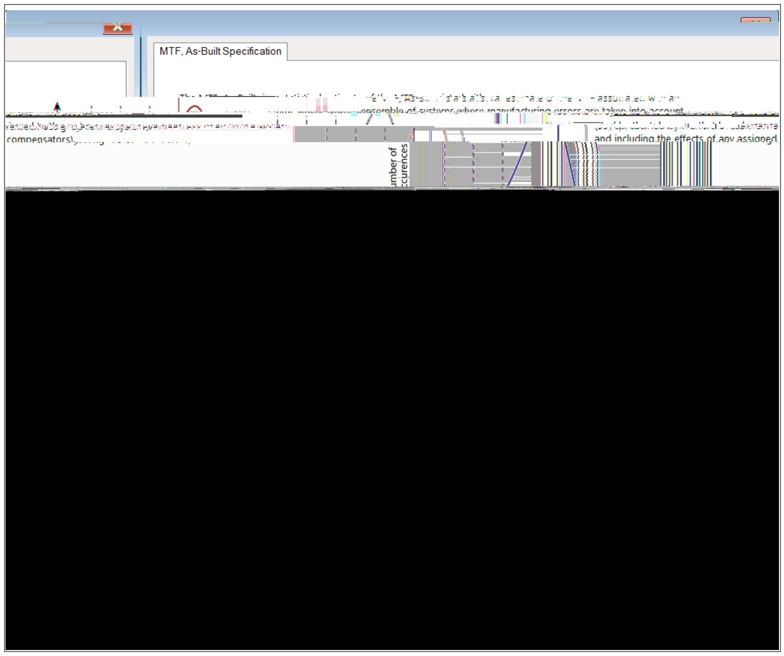


Figure 2: As-built MTF specification

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

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.

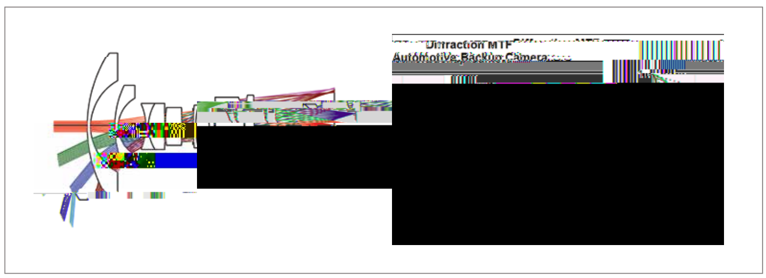


Figure 4: Starting point lens layout for an automotive backup camera objective (based on Japanese Patent 49_20535 740525)

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.

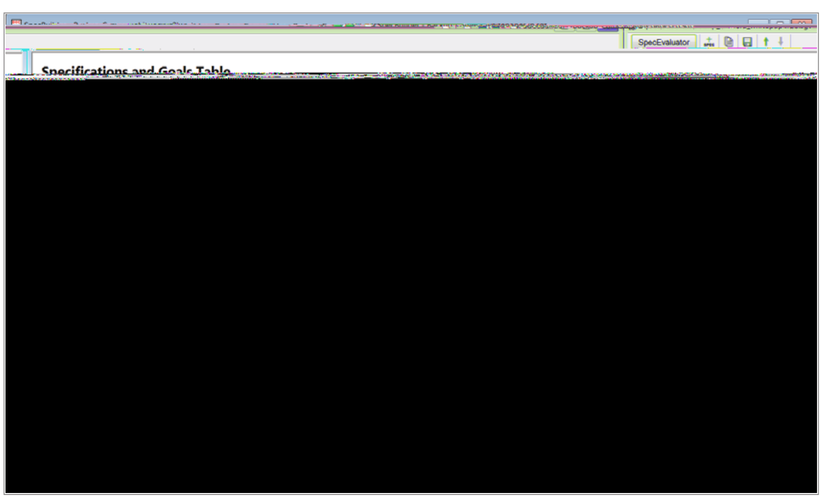


Figure 5: Specifications and goals for the starting point design (excerpt)

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.