Musings, Ramblings, and Ruminations on Optical Specifications

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DO THE BEST YOU CAN

How many times have you heard the phrase, "Do the best you can!"? If you are old and experienced (i.e., wary), you will probably snap back with "What does *that* mean?" "Oh, diffraction limited will do," your customer will reply with a condescending air, and hurry off. It is sad, but so often true, that the optical designer (or project engineer) finds himself/herself with back firmly affixed against the proverbial wall as a result of this simple, preliminary, and often only specification. The odds are that "the best" is usually too good (i.e., costs too much and/or takes too long) or is not good enough (i.e., functions poorly).

However, it sometimes happens that an old, experienced, and cantankerous engineer will not accept only one verbal specification and insists on the various performance characteristics' being specified in numbers. Such individuals have even been known, on occasion, to demand these numbers in writing!

Should you be one of this difficult breed, you will know further that the real winner in the specification game is the engineer who not only demands, and receives, written numerical parameters but uses these values to: (1) guide the initial design and (2) generate an error budget for manufacturing and assembly.

For those who aspire to win the specification game, the following ramblings and painfully acquired wisdoms are offered.

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THE DESIGN PROCESS, OR, "HOW TO GET THERE FROM HERE"

Historically, the optical design process has been cloaked in mystical significance and shrouded with an air of complexity. Undeniably, design can be a complex process. However, its truly complex and difficult aspects (i.e., designing a manufacturable item) are typically given cursory attention and often ignored completely. Figure 1 is my simplified conception of the steps involved in the optical design process.

Note that the performance specification is the first (and, I feel, the most important) step in the process. It represents the objective of the design, or "the place you're trying to get to from here." (If you don't know where you're supposed to be going, it's very hard to get there!) Detailed optical design (i.e., optimization, evaluation, etc.) is what is generally thought of when optical design is mentioned, and the remaining blocks are the engineering steps that must be taken to ensure that the final fabricated and assembled system meets the performance specification.

PERFORMANCE SPECIFICATIONS

The performance specification is a document that determines what a given optical system is supposed to do. Heed the deliberate reference to the word "document," because it must, indeed, be written. The written aspect is extremely important, even if specifications are in a state of flux for extended periods of time. As long as a written specification exists, and is circulated periodically, everyone knows who was thinking about what, when.

If, as an optical designer or optical engineer, you have found yourself in the unfortunate position of having to write your own specifications, it is a good idea to have your customer's written concurrence. Note the use of "customer" in the broadest sense of the word, for customers may also be systems and project personnel within your own organization or company.

Parameters that may be included in the performance specification include:

1. Image quality, which may be expressed in terms of:
   a. MTF (square wave or sine wave)
   b. Resolution
   c. Energy distribution in the image
   d. Beam divergence
   e. Geometrical aberrations, etc.
2. System transmittance
3. Wavelength region of interest
4. Field of view
5. Entrance aperture
6. Detector type and configuration
7. Effective focal length
8. Back focal length
9. Magnification
10. Boresight accuracy
11. Distortion
12. Vignetting
13. Tilt and displacement of final image
14. Thermal, shock and vibration environment
15. Mechanical constraints
16. Miscellaneous items such as shutters and filters that everyone overlooks until the first unit appears and has to be hastily (and usually clumsily) retrofitted.

In addition, there are several factors peculiar to infrared systems that may be important:

1. Scanning mechanisms
2. Amplitude and extent of Narcissus image
3. Scan noise
4. Cold stops and other gremlins that hide in detector bottles (Dewars).

All of the above parameters should be specified as maximum, minimum, nominal, or toleranced values. These designations become extremely important during the sensitivity and tolerancing phases of the design.

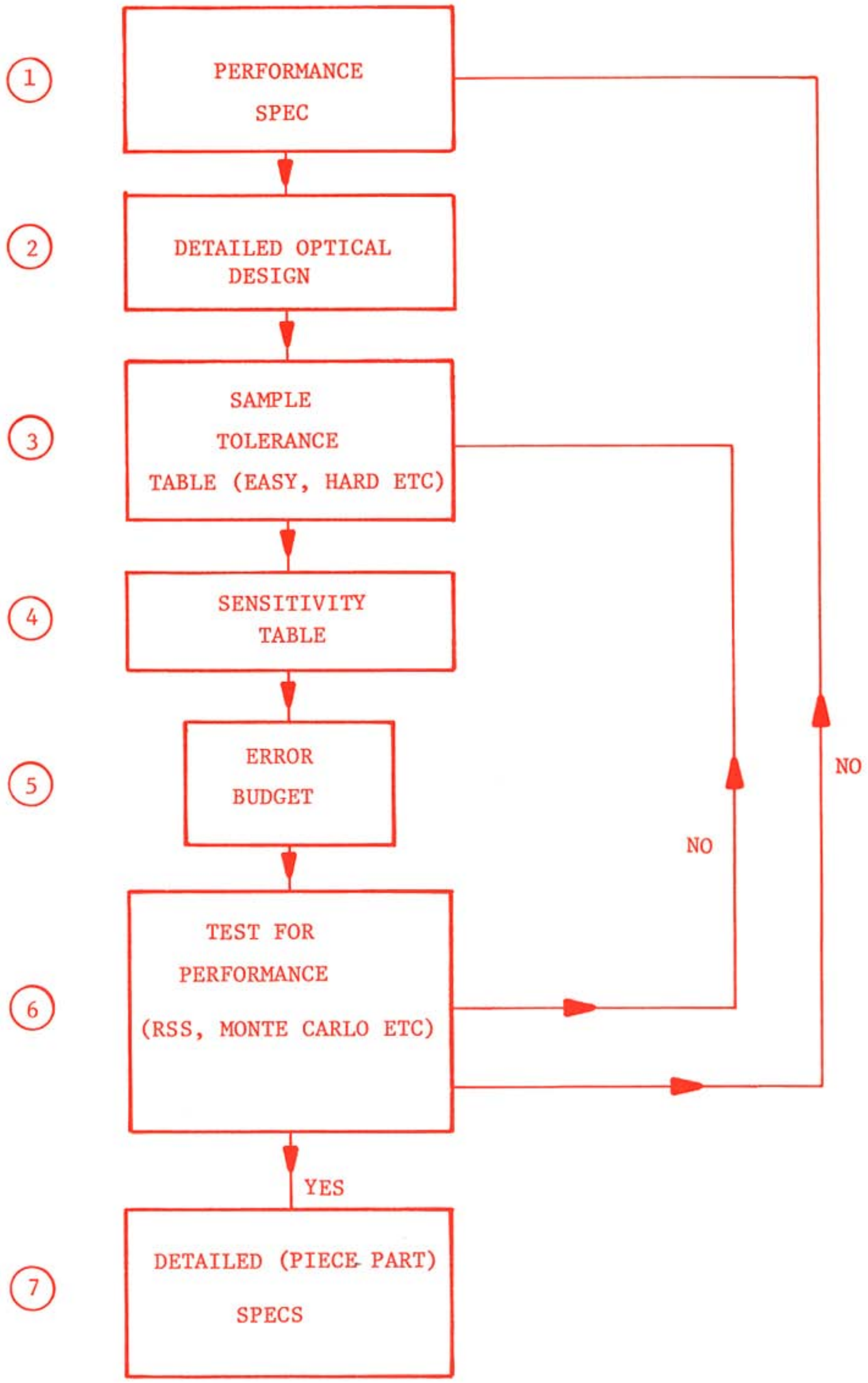

Figure 1. The optical design process, or, How to get there from here.

DETAILED OPTICAL DESIGN

Once the optical designer is in possession of the performance specification, a paper design may be attempted. It is well known that the paper design is concerned not only with residual aberrations but also with the wave nature of light. However, it is not so well known that thermal and mechanical constraints must also be considered as integral parts of the detailed optical design. Unhappily, these aspects are often treated as afterthoughts, and their impact results in a mad scramble of bandaid fixes and unnecessary compromises with other performance characteristics.

TOLERANCING, SENSITIVITY TABLE, AND ERROR BUDGET

No optical design can be considered complete until it has been determined that the system can be built, i.e., implemented with reasonable tolerances. In order to make this assessment, it is necessary to follow steps 3, 4, and 5 as outlined in Fig. 1. The heart of this procedure is the sensitivity table, whose main purpose is to help determine a tolerance for each parameter of an optical system. Tolerances can then be set to provide acceptable performance of the completed system at the lowest cost in money and time.

However, before generating a sensitivity table, it is necessary to assign some realistic tolerances to the various parameters of interest. These parameters might include:

1. Material (i.e., index of refraction
2. Surface shape (radius, irregularity)
3. Surface or element location (thickness, air space, decenter, tilt, wedge)

After the sensitivity table has been formulated, a realistic error budget can be established. The budgeted system is then root-sum squared or subjected to a Monte Carlo analysis to determine if the performance specifications have been met. Note that if the specification has not been satisfied, there are two paths open: try some new tolerances or change the specification. Trying new tolerances is a path that may be iterated many times; changing the specification is usually so painful, it is done only once.

DETAILED (PIECE-PART) SPECIFICATION

Now that you presumably have specifications and tolerances on all piece parts, subassemblies, and assemblies, how do you ensure that the parts are fabricated the way you want them? The first thing to recognize is that there is no industry standard for detailing optical components; different suppliers use different callouts; different customers use different callouts; in fact, different divisions of the same company use different callouts! A good place to start, if you are brand new at the specification game, is *Modern Optical Engineering* by Warren Smith (McGraw-Hill, New York, 1966).

In general, when dealing with fabricators (even those in your own department or company) it is imperative to:

1. Find out what they can do very early (preferably before the design is "set in concrete"). Note that this may be different from finding out what they say they can do.
2. Make sure that they perceive the prints the same way you do (i.e., do you both interpret the specs identically?).

Attention to these areas will ensure that something unbuildable is not designed and also that there will not be a protracted finger-pointing contest when a given part or subsystem does not meet specifications.

Some other cautions are appropriate with regard to piece-part specifications.

1. Beware of over-specification of scratches and digs. For example, there is generally no earthly reason for requiring better than 80–50 on infrared glasses (which are very forgiving on this type of requirement).
2. When dealing with coated substrates, attention should be paid to potential coating buildup. For example, many layers of dielectric may cause center thickness to be out of tolerance after coating. Should the suspicion exist that buildup may occur, always insist that *all physical dimensions be met after coating.*
3. Don't specify anything that you can't measure (or, at a minimum, be aware that you can't measure it). You will notice a tremendous increase in the mutual respect between you and your vendor when he is aware that you are spot checking incoming parts. Over time, you will also note a tremendous increase in the number of acceptable parts. However, the bad news is that you may also notice a tremendous increase in the prices of parts. Spot- or one-hundred-percent checking provides an excellent system of checks and balances for you as well as for your vendor. If checking should uncover a component that is not within its specification, you are faced with two unpleasant choices:

   a. Reject the part. Not only does this option make you a "bad guy," but, especially in a large organization, the act of rejection can cost a fortune in time and money.

   b. Begrudgingly accept the part. This option makes you look very silly, since it usually means you didn't need that tight a tolerance anyway. Even if you accept a reject part because of schedule press, the vendor will assume you didn't do your tolerance homework properly and you lose credibility.

One last ramble: The design and specification of a bond joint is part of the optical design task as much as is the determination of radii and thicknesses of lenses. Many a fine and expensive component (lenses, windows, and especially domes) has been cracked during curing or thermal cycling because of cavalier attitudes toward the design of bond joints.

From the above it is evident that the optical design task is a complex one. It must begin with a well-written performance specification, address itself to tolerancing by means of a sensitivity table and error budget, and provide manufacturing and assembly personnel with sufficient data to produce an optical system that meets the performance specification and is not inordinately expensive. It should also be evident that I have merely scratched the surface of the subject.

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