Thinking Outside the Barrel: What Really Matters in Modern Photographic Lens Design

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ABSTRACT

Because optical performance has increased so far with modern design software and aspherical manufacturing processes, optical performance is now the least important factor in modern photographic lens design. Far more important are ergonomic (usability) and systems-integration factors which determine a lens' acceptance by photographers, and ultimately, its commercial success. Common SLR cameras tend to have the most advanced systems and features, so they tend to be the focus of this paper simply because they offer the most to discuss. Inside-the-barrel optics and other design considerations have been covered in SPIE paper 7428-3.

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1. INTRODUCTION

As of 2009, photographic lenses are sharp enough. Lens sharpness is the least of any photographer's worries.

To quote one famous photographer when another photographer asked him to recommend a sharp lens, he replied:

"Any good modern lens is corrected for maximum definition at the larger stops. Using a small stop only increases depth..."

Who is this photographer? Ansel Adams, who wrote this on June 3, 1937![1]

Far more important to a lens' acceptance by photographers is how well it feels in-hand, how well it handles, and how well it integrates with his other cameras and lenses, both today, and for decades to come.

Good photographers are artists, not engineers. Just as musicians describe a good musical instrument as "getting out of the way," a good lens never gets in the way of a great photo. A lens' job is to get out of the way of making photographs.

Photographers usually own at least two lenses. It is critical that each lens works well as part of a system with the other lenses.

Photographers have careers, just like lens designers. A photographer doesn't simply buy a system of lenses and cameras and use it forever. Photographers need every lens, camera and accessory they buy, new or used, to integrate with their larger system today, tomorrow and yesterday. It is crucial that any lens design not only integrates as a system with other lenses today, but integrates as part of a system of cameras and lenses acquired both from the past, and in decades to come.

Professional photographers are the most sensitive to this because they buy cameras and lenses across the decades and expect them to work well together. People who use their equipment all day, every day are far more sensitive to lenses that work easily, or that get in their way. While professionals are only a small part of the market, their preferences drive the bulk of sales to everyone, and thus their preferences have driven various camera and optical companies to continued success for decades, or out of business.

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2. ERGONOMICS: OPERABILITY

Ergonomics, or human factors, are critical. If a lens is clumsy or difficult to use, it doesn't matter how great it might be optically.

2.1 Focusing

2.1.1 Manual Focusing

In the beginning, there was manual focus, and even that was difficult to do well.

A lens needed to be focussed fast, as well as precisely, with as little effort as possible.

The best lenses use brass-on-aluminum helicoids. Tight tolerances allow the use of a small amount of light lubrication, and brass slides with natural lubrication on aluminum. This provides for fast, easy turning of the focus ring and excellent alignment.

Cheaper lenses use sloppier tolerances and fill the slop with heavy grease. They will also economize on all-aluminum or plastic helicoids. This slows the focusing due to the heaver grease, and the sloppy tolerances give poorer potential alignment.

2.1.1.1 Manual Focus Direction

All focus rings must turn in the same direction, and thankfully this has never been a problem within one brand.

2.1.2 Automatic Focusing (Autofocus or AF)

AF lenses are designed with different mechanisms to allow a camera to focus them electrically or electronically.

The mechanics often provide less precision to allow faster speed with less power, but that's outside the scope of this paper.

Some of these systems are noisier than others. Nature and press photographers demand silent focusing, because even slight noises from AF cameras and lenses can disturb live subjects. Photographers can get kicked out of important events simply because their AF systems are too noisy. The photographer could switch to manual focus, but usually buys a better-designed lens that makes less noise.

2.1.3 Manual Switching Between Automatic and Manual Focusing

In the 1980s, cameras and lenses had focus mode switches labeled AUTO and MANUAL. This makes sense to camera designers, but gets in the way of making pictures.

In the Nikon AF camera system in the late 1980s and early 1990s, some combinations of cameras and lenses required photographers to move *two* switches to get from one focus mode to another: one on the lens and a second on the camera. Canon's camera system never required more than one switch, which was always on the lens. This is among the reasons that pro sports and news photographers switched from Nikon to Canon in the early 1990s. Little features like this are very important to the viability of lens and camera designs not just today, but for decades to come. Pro sports and news photographers stayed with Canon for at least a decade after Canon designed AF systems that worked faster and easier than Nikon's.

It is critical that any AUTO/MANUAL switch be placed in the most convenient possible location for the photographer, not for the lens designer, and that this switch can be adjusted easily while the camera is held to the photographer's eye as he is shooting.

This switch must not move accidentally, and must not require any locks to be unlocked before moving. Some photographers have to tape-over switches or jam toothpicks in them so that they don't get knocked accidentally.

2.1.4 Automatic Switching Between Automatic and Manual Focusing

AUTO/MANUAL switches became obsolete in the 1990s.

Today, the best lenses are designed with logic and clutches so that the only thing a photographer needs to do to switch between AF and manual focus is to grab the focus ring (for manual) or tap the shutter button (for auto).

Once the photographer has made a manual focus correction, it is important that the lens not revert to AF unless the photographer wants it to. These things may seem silly, but are crucial to professional photographers whose subjects are always in motion.

Poorly designed lens systems have a habit of returning to AF when they shouldn't, which usually requires the photographer to move the focus mode switch back to Manual, which defeats the purpose of seamless manual-focus override.

The photographer should never have to move switches while photographing moving subjects.

2.1.5 Macro Focus Ranges

There should never be lockouts for various focus ranges.

Few things get in a photographers' way more than asking him to press a button to get into a macro range, or worse, to have to set a certain focal length range to be able to do it.

Thankfully designs like this haven't been around since the 1990s.

2.2 Aperture Setting

This is usually beyond the scope of the lens designer, but it is better to have a dedicated aperture ring on the lens instead of asking the photographer to hold a button and spin a dial on the camera while watching an LCD display.

Not only is a dedicated ring simpler and faster, a dedicated ring allows a photographer to make adjustments instantly by feel, while buttons and LCDs require him to stop looking at his picture and concentrate instead on a display in the viewfinder.

2.2.1 Aperture Setting Rings

The best design for aperture setting rings provide:

1. Clicks at full stops only (OK to have a click at the maximum aperture if it's an odd stop).
2. Easy to move with one fingertip while not looking at the lens.
3. All rings must rotate in the same direction on all lenses.

By doing this, the photographer can set any aperture instantly by feel in total darkness. Asking him to stop and look at a display, or to count half and other stops, will encourage him to buy a different lens.

Some lenses have had half-stop clicks. This historically was done as a marketing feature to impress innocent photographers that these lenses somehow had more precise mechanisms. Many photographers never realized that lenses could be set to any aperture value and thought only the click stops were valid settings.

The worst designs have used half-stop clicks at most apertures, and full-stop clicks between other apertures (try a Pentax or Tokina manual-focus lens from the 1980s or 1990s to see this). These designs make it nearly impossible for a photographer to count clicks to arrive at his desired aperture.

Remember, photographers usually are photographing things that move, and the difference between a photographer who stays employed is the one who got the shot instead of having missed it while fiddling with his settings.

2.3 Zooming

2.3.1 Zoom Ring Direction

All zoom rings must rotate in the same direction.

Photographers need to have their images zoom in or out in the same way every time they turn a zoom ring.

Within a brand, aperture and focus rings turn in the same direction, so it is incomprehensible how camera makers can introduce different lenses within the same brand with zoom rings that turn in different directions.

It is mandatory that all zoom rings rotate in the same direction because the zoom ring is part of a feedback control loop. The photographer instinctively needs to know in what direction to turn the zoom ring to get tighter or looser framing.

When changing between lenses whose zoom rings operate in different directions, it's as catastrophic to a photographer as reversing a sign in any other feedback control loop. Unlike automated control loops, the photographer usually figures it out, but possibly only after he's missed the shot that might have kept him his job or won him a Pulitzer prize.

2.3.2 Zoom Control Feel

As a goal, the zoom control should be adjustable with a single fingertip, and stay put when not touched.

Since so much glass needs to move around, this rarely happens, especially when zoom creep (section 2.3.4) is considered.

An example of a lens which does this perfectly is the Nikon AF NIKKOR 70-210mm f/4 of 1986-1987. Most other lenses require more force.

2.3.3 Logarithmic Zoom Control Calibration

This is the area in which the individual lens designer can have the greatest positive impact in creating a practical lens.

Zoom controls (usually rings or push-pull) should alter the focal length logarithmically. Equal movement of the zoom control should result in an equal percentage change in focal length everywhere in the zoom range.

Sadly, too many lenses are designed with arbitrary or linear relationships between zoom control position and the focal length.

With larger zoom ratios, making this mistake usually results in a lens on which it is difficult to set a precise magnification at the short end, and requires far too much zoom ring rotation at the long end to change much.

As an example, a well designed zoom lens with a hypothetical 12.5mm - 200mm range will have equal spacing between 12.5mm and 25mm, between 25mm and 50mm, between 50mm and 100mm and between 100mm and 200mm. A one-octave [1:2] ratio in focal length will always take up the same spacing on the zoom ring, allowing easy setting anyplace in the lens' range. The middle of its zoom ring will be the 50mm setting, making any focal length easy to set fast and precisely.

A poorly designed lens covering 12.5mm to 200mm often has equal spacing per millimeter of focal length. It will be very difficult to set precise focal lengths, and thus photographic compositions, between 12.5mm and 25mm because these settings will be too close together, while the spacing between 100mm and 200mm will be too spread out to allow fast setting. This poorly designed (at least for photography) lens will have 105mm in the middle of the zoom range , with all the shorter settings crammed into very little space, and the longer settings spread out way too far.

This defect is all too common today. Some lenses' zoom spacing is so poorly designed that they have to use index lines to mark the positions of the shorter focal lengths on the zoom ring!

This problem becomes worse as the overall zoom ratio increases, since the importance of log versus linear spacing becomes more apparent.

2.3.4 Zoom Creep

Longer-ratio zooms often creep to longer focal lengths when pointed down.

Every time the photographer brings the lens to his eye, he has to pull it back to the shorter settings, since while pointing straight down while carried around his neck, the lens zoomed itself out to its longest focal length.

Zoom ring locks have not been effective, because although they prevent creeping, activating and deactivating the locks is as annoying as the original problem.

2.4 Control Ring Locations

Focus, zoom and aperture rings need to be located where they can be controlled by the photographer's fingers as they naturally fall when holding the lens on a camera.

They should be in the same place on every lens from the same manufacturer. When shooting, a photographer shouldn't have to guess which lens is on his camera.

Bad positions result in uncomfortable usage, or worse, inadvertent unintended operation. If a ring is always accepting input, as most modern AF/MF focus rings do, then they need to be placed just outside of where fingers naturally fall. The Nikon AF-S NIKKOR 24-70mm f/2.8 G ED (2007-today) places its always-on focus ring where fingers often fall, which does result in unintended focus shifts.

Good lens designs go out of their way to determine exactly where the rings should go, and then go out of their way to put the controls where the photographer finds them most convenient, not necessarily where the lens' design finds it most convenient.

2.5 Exterior Materials and Finishes

Lenses are often used outdoors in all temperatures.

It is more elegant when bare fingers won't freeze to cold lens barrels, or get burnt from hot barrels left out in the sun.

Lenses are always being handled. It is important that they not slip out of hands and fall on the ground as they are attached and removed from cameras.

2.6 Size and Weight

Smaller and lighter are always better, but to a point.

Lighter lenses can become more susceptible to the effects of hand tremor, but this is rare.

A lens today can never be too small, too light or too inexpensive.

Sadly, as manufacturing techniques have freed lens designers to use larger elements and make bigger, better lenses for the same price, lenses are starting to get too big for comfort.

When designing a lens, know when to stop.

Lens sizes today for professional SLR lenses are continuing to spiral out of control. A reasonably sized lens with reasonable performance is better for photography than a much larger lens with slightly better performance. Remember: photographers have to carry all this with them all day, even if they're not using it; they don't simply take it out of the box and stick it on their camera in one spot.

3. SURVIVABILITY

Photographers use lenses in the field, not the lab. Not only does nature take its toll, but so does the photographer. News photographers show their bosses that they were out working by the amount of physical abuse they can wreak on a lens. Since newspapers own the equipment, the photographer looks better the worse he can make the gear look.

3.1 Mechanical Design

3.1.1 Barrel Design

Lenses whose barrels fully extend beyond and enclose any zoom or focus groups are toughest. When hit on the front, the force is transmitted around the focus and zoom mechanics directly to the lens mount.

Most lenses have exposed front zoom or focus groups. Any shock to the front of the lens is transmitted to the focus system or directly to the delicate zoom mechanism. I good hit on the front of most lenses can break a zoom cam follower.

Even if the front of the lens is a live focus or zoom group, the mounting for a hood can be put on the barrel itself. In these cases, with a hood attached, blows to the hood are transmitted directly to the barrel, saving the delicate focus and zoom mechanics from impacts while those groups move inside the protective hood.

It's a bad idea to attach the hood directly to the front group if they move with lens operation.

3.1.2 Focus and Zoom System Design

Lenses that use internal focus and zooming don't require the front to move as the lens adjusts.

This makes for a tougher external design, with any hits to the barrel transmitted around the focus and zoom systems.

3.1.3 Airflow

Air is pumped in and out of a lens and camera as the lens is adjusted.

The worst case is with zoom lenses that zoom by moving the front group. Untold amounts of dirt and dust are continuously pumped in and out of the camera and lens as the lens is used.

Air not only comes in and out through the lens; it is also pumped in and out through every orifice of the camera, including the eyepiece and viewfinder assembly of an SLR.

Often the easiest zoom to design results in dirt in viewfinders, and worse today, dirt in the camera and ultimately on the sensor, which results in black dots in every image.

Better designs use fixed barrels inside of which the optical groups move. In these lenses, air filters can be installed, and if a filter is used over the front, dirt ingress can be greatly reduced.

The best designs use fixed, sealed external elements with internal or rear-element focusing. Now little to no air and dirt is drawn from, or pumped out to, the environment as the lens is used.

3.1.4 Materials

Interview a news photographer, and you'll learn that metal or plastic are different, but neither is necessarily better for use on the exterior of a lens.

When dropped, metal dents, while plastic bounces.

Either is OK when done well.

3.1.5 Markings

Please engrave all markings.

Paint alone wears off, so in enough years, no one will recognize your design anymore.

Filter designers, please engrave your markings clearly on the edges of screw-in filters. After a few years of use, painted markings wear off, so photographers have to guess which filter is which.

Painted markings can be preserved by putting them inside the filter ring as B+W of Germany does, but unfortunately those markings can't be read when filters are stored and carried as stacks.

4. FILTERS

Filters are a critical issue for serious photographers. It is not unusual to use three filters at the same time. For instance, two colored filters (one deep-colored filter for coarse color-conversion and a lighter-colored fine-tuning color-correction filter) and a gradiated filter might be used to turn a dull sunset into a wild one.

Cinematographers are at least as crazy about filters. It is quite common for two to four filters to be used at once over a motion-picture camera lens when shooting feature films.[2] Separate filters for colors, gradations and diffusion all have to be used simultaneously.

Most lenses are designed with a thread to accept one filter, but any additional filters, especially with wide lenses, often cause vignetting. Photographers have to become junior mechanical engineers to figure out how to get enough filters on the front and back of a lens without vignetting or extra ghosts.

Ideally, some lenses are designed to accept deeper or multiple stacked filters. Schneider's 47mm f/5.6 Super Angulon XL lens with a 120 degree field of view for 4x5" film has a clever design where the front filter threads recede back into

the lens. This allows filters to get closer to the front elements, allowing the use of more or deeper conventional screw-in filters.

No one will complain about a clever lens barrel design that allows more than one filter size to be used. This could save the problem of vignetting when using stepping rings.

Please be generous with the size of the filter thread so lens users don't have vignetting when using more than one filter.

5. INTEROPERABILITY

Lenses need to work with every camera used by a photographer, and all his lenses need to work well with each other.

5.1 Uniform Filter Sizes

Uniform filter sizes among lenses, and throughout the decades, are mandatory for long-term commercial success.

If different lenses use different filter sizes, a photographer can go mad trying either to buy and carry duplicate sets of the same filters in different sizes, or trying to find adapter rings to step-up every lens to a common, larger, size.

Step-up rings are a poor solution because a step-up ring takes up a critical couple of millimeters which could either cause mechanical vignetting, or rob the photographer of his options of what kind, how deep or how many filters will fit on the front of his lens.

Lens makers Nikon and Leica have done the best job of maintaining uniform filter sizes. Leica rangefinder lenses have often used 39mm x 0.5mm pitch screw-in filters from about the 1930s through the present day. Since Leica rangefinder cameras today still use all these lenses, a photographer can use almost any combination of lenses from any eras and use the same set of filters.

Starting in 1959, almost all of Nikon's 35mm SLR lenses have taken 52mm x 0.75mm pitch screw-in filters, and has maintained this reasonably well even as lens sizes have grown to this very day. Many of Nikon's newest smaller lenses still use the same 52mm filter size.

The use of uniform filter sizes throughout the lens line and throughout the decades are a strong factor in why Nikon and Leica still dominate their respective markets.

Among the reasons other brands have gone out of business is because they used different filter sizes within their lens line, and then made cosmetic changes from year to year that changed filter sizes for the same lens!

Minolta used to have lenses that used 49mm, 52mm and 55mm filter sizes, and then every other year their marketing departments changed everything around again.

Pro photographers cannot accept different filter sizes among similar lenses they are shooting at the same time. Even as a 12-year-old-kid I was frustrated trying to swap different sized filters, adapters and accessories as I did aerial photography from an open airplane. This was among the strong reasons I stopped using Minolta in 1984 and converted to Nikon, and have been using Nikon ever since.

I'm not alone; this is very important to photographers. Photographers don't just buy a camera and go away; they add to their systems over periods of decades and everything has to be compatible, or they shift to a different brand that is.

If one looks at Nikon's lenses, one will see that Nikon's designers have gone out of their way to retain the 52mm filter size. Lenses with larger front elements will have those elements held in place with 52mm retaining rings and the lens' identities engraved on the outside of their barrels. Smaller lenses will have the lens' identity on the usual ring inside the filter thread.

Nikon has made SLR camera lenses in focal lengths from 20mm through 200mm available with the 52mm filter size since the 1970s, as Leica has made rangefinder camera lenses that take 39mm filters in focal lengths from 21mm through 135mm since the 1950s.

For larger lenses, pick one larger size and stick to it. In 2009, the most popular filter size for professional lenses from Nikon and Canon is 77mm.

The scary news (to photographers) is that as clever manufacturing allows larger elements to be made economically, lenses size keeps creeping up, and now Canon has some common professional lenses that require 82mm filters. No one wants to rebuy the same set of filters in a new, larger size.

Photographers typically own far more equipment than they ever tale with them at one time. Typically when a photographer picks what lenses to take, he'll be sure to pick a set that uses the same size filters. For instance, Leica's larger lenses take 46mm x 0.75mm pitch screw-in filters, and Nikon and Canon's current pro zoom SLR lenses almost all use 77mm filters.

5.2 Long-Term Interoperability

While consumers might buy a camera and a couple of lenses all at one time, the professional photographers who drive the preferences of consumers buy equipment as their careers progress over decades. They need gear bought today to work with their older gear, and the gear bought today needs to work with gear that won't be bought until 10 years or more from today.

Pay attention to backwards and forwards compatibility. If your design won't work with cameras made 10 years from today, those potential customers just might change brands, and not come back.

Do not change filter sizes. Your customers already own your older lenses and filters in one size, and they expect that new lenses will drop right into their existing system of filters and accessories.

Would you want to have to buy all new cups, saucers and plates for your kitchen just because you bought a new oven? Of course not, so be mindful of the fact that photographers invest almost as much in filters as they do in lenses.

6. REFERENCES

[1] Alinder, Mary Street, "Ansel Adams: an Autobiography," Little, Brown & Co. 1985, page 244.

[2] Personal conversation with Ryan Avery of B+W Filters, Hollywood, CA, 07 July 2009.