EF Lens Technology

1 Constantly Pursuing the Best: Canon's Lens Design Concept

The primary task of a photographic lens is to reproduce an image of a subject as clearly and accurately as possible on film or via digital capture. This is not, however, an easy task, because lens elements invariably have properties and imperfections which prevent them from accurately converging light rays into a single point and which tend to disperse light near the edges. These properties, which prevent a group of light rays from a single subject point from reconverging at the ideal image point or cause dispersion when the light rays pass through the lens, are called aberrations.

Put simply, the main objective of lens design is "to determine lens construction data for minimising aberrations." However, although there is no single ideal solution for the design of a certain type of lens, there are countless solutions which approach the ideal. The problem becomes which solution to select, and how that selection is made greatly determines the performance of the lens.

A method of lens design used since the 19th century is a method of calculation called ray tracing. Although this method makes it possible to determine aberrations, it only allows calculations in one direction (i.e., the calculation of aberrations for a predetermined lens design) and thus does not allow lens construction data to be determined from aberration specifications.

In the mid-1960's, Canon became the first company to successfully develop practical computer software for analytically determining detailed lens construction data of near-optimum lens configurations achieving minimal aberrations (target values), together with computer software for automatically directing the analysis procedure.

Since then, Canon has continued to develop many other original computer programs for use in lens design. At present, use of this software enables Canon to consistently produce precision lenses with the original product concept virtually unchanged in the final product. Equating the act of designing a lens to climbing a mountain at night, Canon's advancement from conventional lens design techniques to its current computerised lens design methods is equivalent to leaping from a state where a flashlight illuminates only the feet in pitch black darkness and nothing can be done except to keep walking, to a state where not only the road but also the objective point can be clearly seen, allowing sure and steady progress to the desired goal.

Canon's idea of an ideal lens

There are three general image formation requirements of an ideal photographic lens:

① The light rays from a single subject point should converge at a single point after passing through the lens.

② The image of a flat subject perpendicular to the optical axis should be contained in a plane behind the lens,

③ The shape of a flat subject perpendicular to the optical axis should be accurately reproduced without distortion in the image. In addition to these three general requirements, Canon adds one more:

④ The colours in the subject should be accurately reproduced in the image.

Although the above four requirements are "ideal" and can therefore never be perfectly satisfied, it is always possible to make improvements which come closer to those ideals. Canon's constant goal is to produce lenses which are in the market's top class in terms of every facet of performance and quality. To accomplish this, lofty objectives are set. The latest technology combined with years of accumulated experience and knowledge are used to realise lenses having the best possible picture quality with the simplest possible lens construction.

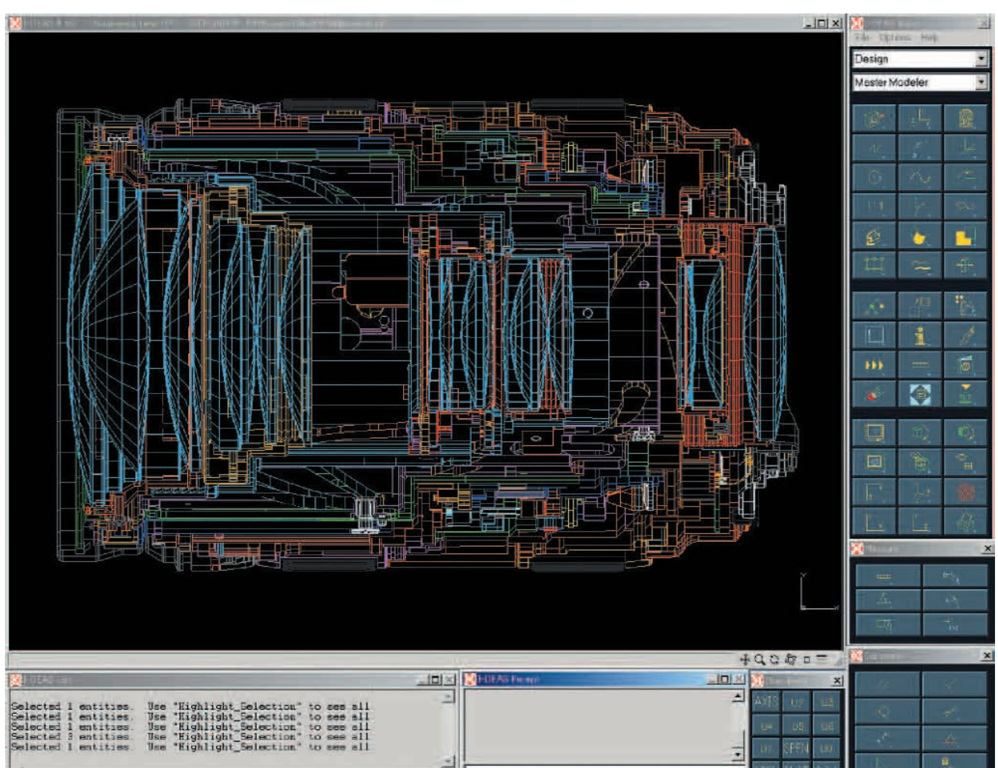


Photo-1 CAD-facilitated lens design

Canon EF lens design fundamentals

To be able to offer EF lenses which satisfy the needs of all kinds of users, Canon has set the six basic design goals described below. For Canon EF lenses, all of these conditions are of absolute importance and must be satisfied before lenses can be approved for production.

High picture quality over the entire image area

A lens cannot be said to have high picture quality if it provides only high resolution or high contrast. It must provide both. However, depending on the lens type, resolution and contrast generally have a mutually opposing relationship where improvement of one results in degradation of the other. To achieve both of these goals simultaneously, Canon makes liberal use of materials such as aspherical lenses, fluorite, UD glass, super UD glass, and high-refraction glass, which have outstanding optical characteristics, delivering sharpness, clarity, and unrivaled imaging performance (high picture quality).

True colour reproduction characteristics uniform among all lenses

Colour reproduction (colour balance) is a Canon tradition and one of the most important features of EF lenses. Not only is each lens designed for optimum colour balance, but colour balance must be made uniform among all interchangeable lenses. Canon established many highly reliable single and special multi-coating techniques early on, and has undertaken scrupulous control of colour balance ever since development of the FD lens series. For the EF lens series, the latest computer simulation techniques are used to determine the optimum type of coating for each lens element in order to both eliminate ghost images and achieve superior colour reproduction, as well as ensuring true colour balance uniform among all lenses.

Natural blur effect

While photographic lenses record three-dimensional subjects as a flat image on film or image sensor, in order to achieve a three-dimensional effect, not only must the image which is in focus appear sharp, but the out-of-focus, or "blurred," image in front of and behind the focused image must be natural. While it is of top priority to maximise the picture quality of the in-focus image plane, Canon also analyses the effects of aberration correction and other considerations in the lens design stage to ensure that the out of focus portion of the image appears natural and pleasing to the eye. Attention is also paid to factors unrelated to optical design in the pursuit of a natural blur effect, including development of a circular diaphragm which achieves apertures with a high degree of roundness.

Superior operability

No matter how great a lens's optical performance is, it must always be kept in mind that a lens is a tool used for taking pictures and it must therefore exhibit good operability. All EF lenses are designed to deliver sensitive manual focus, smooth zooming, and outstanding operability in general. From the optical lens design stage, Canon lens designers are actively involved in the development of optical systems (such as rear and inner focusing systems) for achieving faster autofocusing, better manual focusing performance, quieter operation, and multi-group zoom systems for more compact lenses.

Silent operation

Cameras and lenses have become increasingly noisy in recent years, influencing the photographic subject and often causing the photographer to miss valuable picture-taking opportunities. In EF lenses, Canon has worked actively from the start to develop new technologies to minimise the AF drive sound with the goal of producing lenses similar in silence and performance to manual focus lenses. Since then, Canon has independently developed two types and four models of Ultrasonic motors (USM), and is quickly nearing its goal of incorporating quiet-operation USM in all EF lenses.

Reliability

To ensure total reliability — quality, precision, strength, shock resistance, vibration resistance, weather resistance and operation durability — of every lens in each EF lens group, the various operating conditions each lens is likely to be subjected to are surmised and consideration of these operating conditions is made during the design stage. Not only this, but each successive prototype is subjected to strict tests until a final product is generated. Thorough quality control based on original Canon standards is carried out during production. Further, new autofocus and digital factors are constantly being added to the list of considerations for the Canon standards, based on Canon's highly reputed FD lens standards.

These six design fundamentals are the backbone of modern EF lens development. Supporting them is the "Canon spirit" which has produced a constant stream of new technologies since the company's founding, and which continues to pulsate in Canon's never-ending effort to realise unrivaled lens quality approaching the ideal.

2 Development of High-Performance EF Lenses

1 Challenge to Create the Ideal Lens:
— Development of High-Performance EF lenses —

The development of an EF lens starts with careful listening to the opinions and requests of actual EF lens users.
While the requests of professional users are very important, the types of users that Canon designs its products for also include amateurs, advanced amateurs and semi-professionals of all ages, sexes and walks of life. In short, Canon products are designed for "people who love photography." Thus, requests from all types of users are gathered through various routes and collected at Canon headquarters. The product planning division and development division cooperate to closely analyze the requests and carefully study the marketability of the desired lenses. If sufficient demand is deemed to exist for a particular lens, a clear concept of a product which will appeal to a wide variety of users is determined. This concept is then carefully studied from both the standpoint of the user-i.e., focal length, zoom range, aperture ratio, closest shooting distance, required imaging performance, size, weight, cost, etc.-and the standpoint of the developer and manufacturer, and thus further refined into a concrete plan. Once this stage is completed, design of the actual lens optics begins. Since EF lenses combine optical, mechanical and electronic technologies, designers in charge of various areas such as lens barrel design, lens drive design, electronic control circuit design and industrial design work closely together from the initial design stage through the entire development process to produce an optimum lens based on the initial design concept.

(Actual EF lens design and development processes)

Optical lens design

Figure-1 shows the lens optical design process used by Canon. Once basic specifications such as focal length and maximum aperture are set, the "lens type" is determined. This is where the so-called structure of the lens is decided. The structure selected here is for all intents and purposes a general conjecture of what structure the lens will likely have, but since it has a large influence on the subsequent process flow, special software is used to search every possible lens type with an original evaluation algorithm used to select the optimum solution. Next, the process proceeds to the initial design stage where the optimum solution is analyzed based on Canon's own near-axis theory and aberration algorithms, and the initial shape of each lens element is determined. Since this initial design stage is the most important part of the design process flow, Canon utilises analytic solutions based on theory, a rich databank of accumulated data and years of accumulated design experience to establish a system which can determine the ideal final configuration in a short amount of time.
Once the initial lens configuration is determined, a super-high-speed large scale computer is used to repeatedly perform the following design cycle: ray tracing → evaluation → automated design → type/shape change → ray tracing. In this process, as shown in Figure-2, the computer methodically varies each parameter such as the curvature of each lens surface, the surface interval (thickness) of each lens, each lens interval, and the material characteristics of each lens to

Figure-1 Lens Design Process Flow (general design procedure)

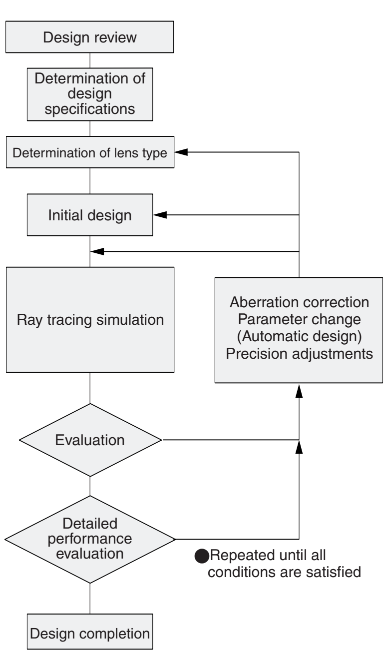


Figure-2 Automated Lens Design Process Flow

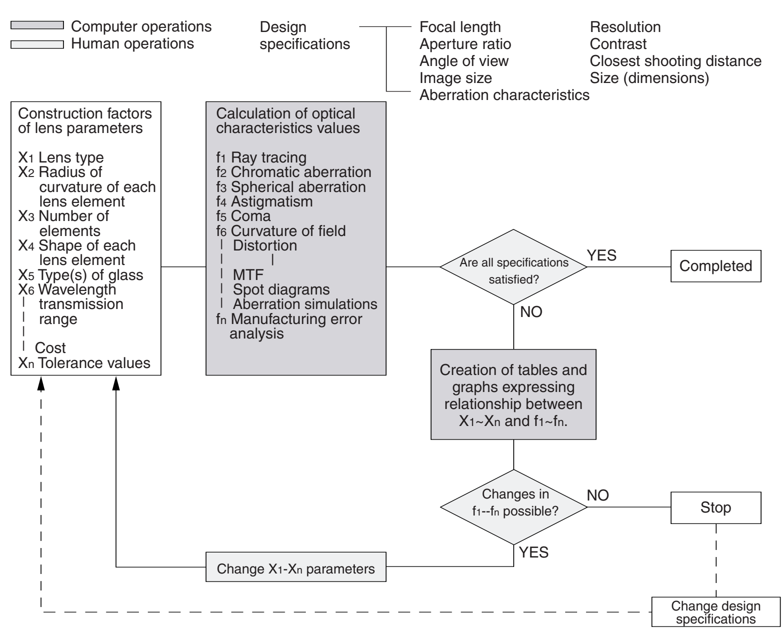
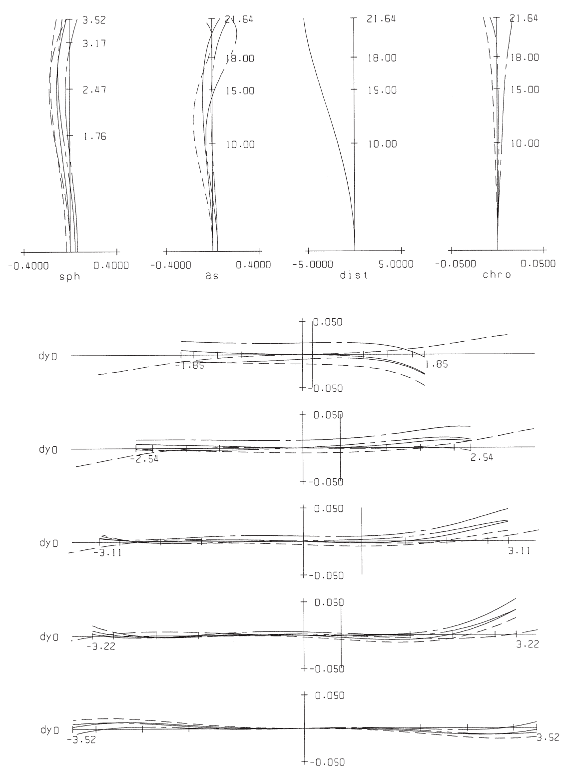


Figure-3 Computer Simulation of Aberration Characteristics



gradually progress toward the optimum design configuration in which every type of aberration is reduced to a minimum. This part of the process requires the most complicated and largest volume of calculations in the entire design process. With Canon's original optical design software, however, an environment is available in which design procedures can be carried out interactively and with great efficiency.

The automated design software used in this process was developed independently by Canon based on Canon's own automated design theories. By simply inputting the target values, the optimum solution for those values can be obtained in a short period of time.

Without having their train of thought constantly interrupted by mundane procedures, our designers can smoothly pursue the optimum final design values by setting the starting data and target values for input to the automatic design system, evaluating the simulation results, and setting the optimum re-input values for minimising aberrations. In this way, our designers interact with the computer to repeatedly make accurate judgments which eventually lead to near-ideal design values. The effect of using aspherical lenses or special material such as fluorite or UD glass can also be thoroughly considered during this process, enabling designers to determine whether their use is necessary or not.

Next, taking an ultra-compact 28-105mm zoom lens as an example, we will describe the actual design process flow.

Figure-4 shows the zoom type structure of this lens. The lens has a 4-group convex-concave-convex-convex construction, with the movement of all groups linked to the zooming action and the 2nd group used for focusing. The optimum lens type and power distribution for an ultra-compact zoom lens are determined by the software which determines power distribution. At this stage it is possible to estimate various specifications such as the track of the zoom cam, the focus extension amount, the total length of the lens, the diameter of the front lens element and the back focus distance.

The next diagram, Figure-5, shows a minimum-element construction using thick lenses. The shape of each lens was selected from the optimum solution determined from the specified conditions. At this stage, a simulation of light passing through the lens is performed and the minimum number of elements required for each group is estimated from the way the light rays bend and from the various aberration algorithms.

Ray tracing by computer

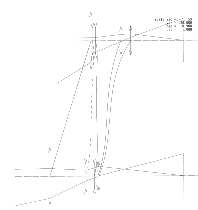


Figure-4

Spot diagram

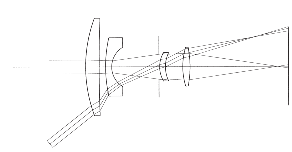


Figure-5

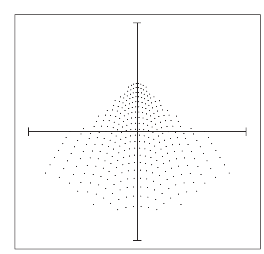


Figure-8

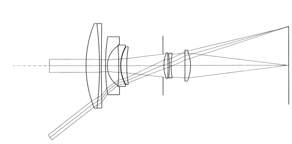


Figure-6

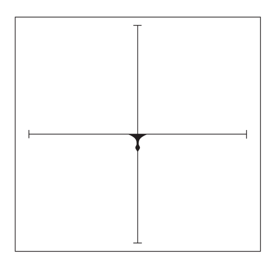


Figure-9

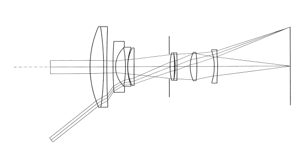


Figure-7

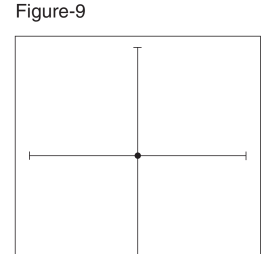
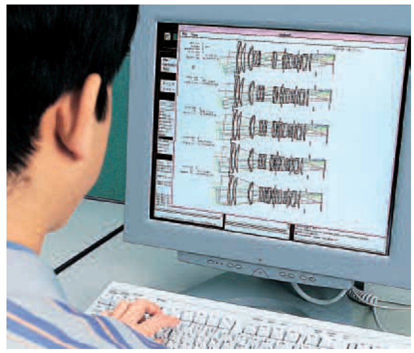


Figure-10

Photo-2 Actual Lens Barrel Design Example (Structure)

Photo-3 Actual Computer-aided Lens Design Example (Optical)



Next, with this lens it is necessary to eliminate the aberration fluctuations caused by the focusing movement of the 1st group. To do this, one element is added to the 1st group. Since the 2nd group shoulders most of the burden of magnification, it must be powerful and since it is also the focusing group, aberration fluctuation caused by zooming and focusing must be thoroughly eliminated. Two elements – one positive, one negative – are added to make it a three-element group. The 3rd group absorbs the dispersed light from the 2nd group, so a negative lens is added to correct axial colour aberration and spherical aberration, making it a 2-element group. In this manner, the minimum number of lens elements is determined and the result of several repeated automated design cycles can be seen in Figure-6. From this it can be seen that the convergence of the light rays has improved greatly. Finally, to better correct the comatic astigmatic aberration at wide angles, an aspherical element is added to the imaging surface side of the 4th group, where the light ray groups are relatively far outside the light axis.

Once the final lens construction is determined, all desired specifications such as shooting distance, aperture and focal length are added into the equation and the automated design cycle is repeated many times while slightly varying design factors such as glass material and power distribution. Looking at the final result in Figure-7 and Figure-10, it can be seen that the light ray groups converge extremely well.

Lens barrel design

Now that design of the optical system is completed, the process moves to the design of the lens barrel which must hold the lens elements in precise position according to the optical design values and must move the various lens groups with high precision during zooming and focusing. Several basic conditions are required of a lens barrel, as follows:

① The lens barrel must, in every conceivable situation, hold the lens elements in precise position according to the optical design values in order to maintain optimum optical performance at all times.
② Mechanisms must be positioned for superior operability.
③ The size and weight should be appropriate for superior portability.
④ The construction should be designed to ensure maximum mass production stability.
⑤ The inner walls of the lens barrel should prevent harmful reflections.
⑥ The barrel should be provided with sufficient mechanical strength, durability and weatherability.

The factors listed below must be taken into consideration when designing the lens barrels for EF lenses, which have been made completely electronic.

● An electronic mount and various electrical circuitry must be built into the lens.

Figure-11
Cross-Section of the EF 24-70mm f/2.8L USM

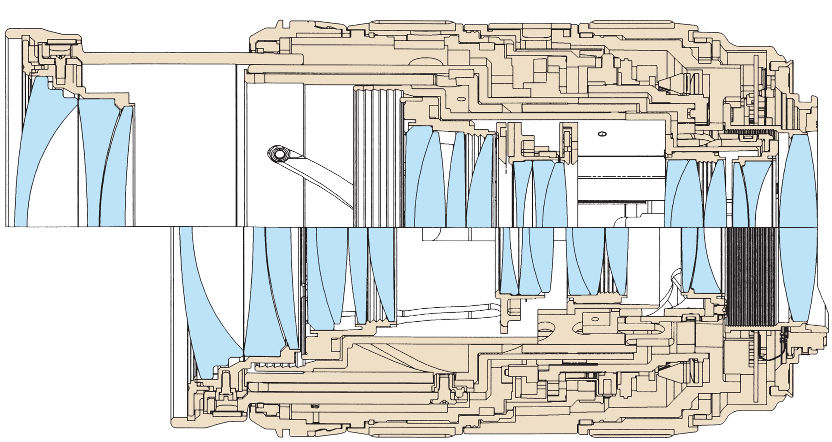


Photo-4 Precision Zoom Cam Lens Barrel

● A construction which achieves both high-speed auto focus and outstanding manual focus operation.
● Incorporation of new actuators such as USM, EMD, and IS.
● Multi-group zoom design and rear and inner focusing lens designs.
● Light weight, compact size, and low cost.

Incorporating these factors has made lens barrel design more complex and more precise with each passing year, but even with the increased complexity, however, optimum designs are obtained using CAD (computer-aided design), which allows us to make designs with a thorough three-dimensional understanding of the lens construction, and various computer simulation techniques which let us analyze and optimise the design. To make compact and lightweight lenses, engineering plastic materials are liberally used. Such use of engineering plastics was made possible only after many years of analysis of the material characteristics, the establishment of ultra-high-precision molding technology, and countless rigorous product tests designed to ensure ample durability and reliability.

Thorough prototype performance checks and reliability evaluations

After a prototype is made based on the design drawings, the lens is rigorously tested to see if its performance actually satisfies the design goals. Many different tests are carried out, including comparison with existing products of the same class; precision measurement of specifications such as focal length, aperture ratio, aberration correction level, aperture efficiency, resolving power, MTF performance and colour balance; field tests under various shooting conditions; ghost/flare spot tests; operability tests; temperature and humidity weather resistance tests; vibration resistance tests; operation durability tests and shock tests. That information is fed back to the design group and the lens is redesigned until all the results from these tests satisfy Canon's standards.

At present, even lenses in the highly-reputed EF lens group have to be tested to ensure they meet initial goals during prototype process before mass production begins and the lens hits the market as a Canon product. To maintain stable product quality at the mass production stage, analysis of manufacturing errors and the setting of appropriate tolerance levels obtained from the analysis results using computer simulations starting from initial development are extremely important factors. In this way, the high performance and quality of Canon EF lenses is ensured through a fusion of sophisticated technologies including aberration correction algorithms and their application, advanced automated design technology employing high-performance computers and specialised software, high-level measurement and performance evaluation technologies, manufacturing error analysis and tolerance setting technologies, and precision molding technologies. Then, and only then, are the lenses sent out into the world proudly bearing the name Canon.

2 Eyes Fixed On the Future: Advanced Electronic Control System Design

Selection of a new system with a view to the future

In the EOS system, why is rangefinding carried out in the camera body and lens drive carried out by a motor built into each lens?

The answer goes back to 1985, when in order to respond to the new trend in SLRs towards full-fledged autofocusing, most AF SLR camera makers other than Canon opted for a body rangefinding/body drive system (a system where the AF drive motor is built into the camera body and lens drive is carried out through a mechanical coupler). This system works well with standard zoom lenses and lenses of standard focal lengths; however, when considering the biggest feature of an SLR — the ability to interchange all types of lenses from fisheyes to super-telephotos — Canon decided not to use it for the following reasons:

① Since one motor must be able to handle the load of all types of interchangeable lenses (which can vary in focus torque by as much as a factor of 10), system efficiency is poor.

② Inserting an extender between the lens and body breaks the mechanical linkage used for transmitting AF drive power, impeding future system expansions.

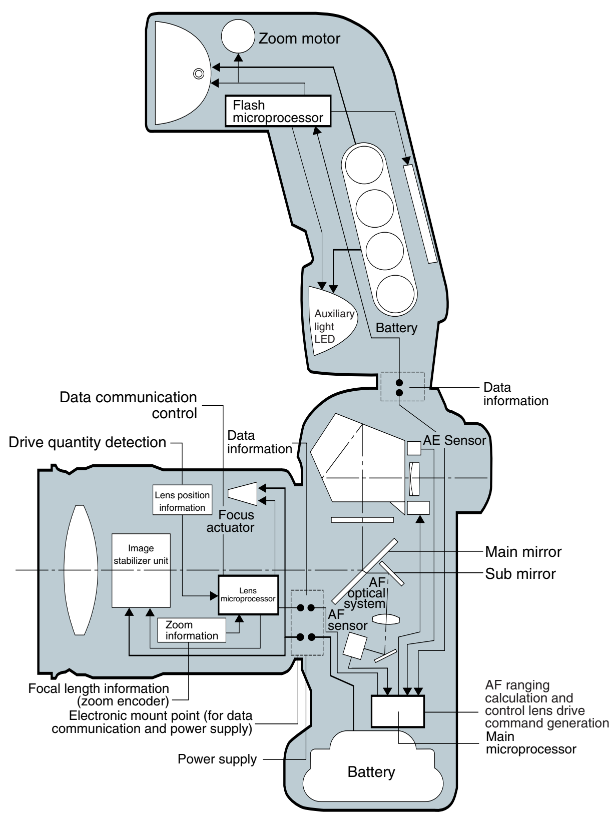
③ For a camera which must provide constant performance in all types of environments from Arctic cold to tropical heat, relying on one motor for all lenses is undesirable in terms of environment resistance and operation durability.

In addition to these basic technological weak points, the in-body motor system does not conform to Canon's basic concept of mechatronics camera system design, which emphasises system efficiency and flexibility by allowing the ideal actuator for each task to be located close to the corresponding drive unit and enabling electronic control of all data transmission and drive operations.

Moreover, Canon also judged that this trend toward automation not only concerned the simple addition of an autofocusing function to SLR cameras, but signaled the arrival of an innovative period which would not mature until sometime later in the future. Canon looked at the advanced technologies it was developing at the time, such as USM, BASIS (Base-stored Image Sensor) and EMD component technologies, and carefully studied them from the viewpoints of the fusion of innovative technologies and new functions (autofocus) and the future potential for technological development, and decided that for both users and Canon to take a bold leap forward, the best course would be to shake off old, impeding technologies and build a new system which will eventually surpass all other systems. Thus, Canon decided to develop the EOS system based on Canon's original body focusing/in-lens motor drive system and fully-electronic mount system.

Proving that Canon's decision was correct, other camera companies began incorporating in-lens motor drive systems and eliminating mechanically-mounted data communication systems.

Figure-12 Control System Basic Structure



Basic EOS system control structure

The EOS system is centered around regular and digital camera bodies and consists of various components such as a full line of EF lenses and flashes. From an overall system control standpoint, the various sensors, microprocessors, actuators, light emitters, electronic dials, input switches and power sources are skillfully intertwined, and the various functions of all the different components work together to operate systematically as an image expression tool for recording and expressing selected instants in the flow of time. The three main features of this system are as follows:

① Multi-processor system control

The high-speed super-microcomputer in the camera body interfaces with the microcomputers in the lens and flash (for high-speed data processing, calculation and data communication) to carry out high-level system operation control.

② Multi-actuator system

The ideal actuator for each drive unit is located in the vicinity of the drive unit, forming an integrated multi-actuator system which realises high-level automation, high efficiency and high performance.

③ Fully-electronic interfaces

All transfer of data between the body, lens, and flash is carried out electronically without a single mechanical linkage. This not only increases the functionality of the present system but also forms a network ready to accept future system developments.

Fully electronic mount system and data communications

The key to the realization of fully electronic data transfer between the body and lens is the EF mount. This is a large mount having an attachment rotation angle of 60° and a flange-back distance (distance from the mount reference surface to the focal plane) of 44.00mm.

Information transfer between the body and lens is carried out instantaneously via 8-bit bidirectional digital communications using three pairs of pins and contacts from the eight pins on the body mount and the seven contacts (which include common contacts) on the lens mount. Four types of commands are sent from the camera's high speed super-microcomputer to the lens:

① Send the specified lens data.
② Drive the lens as specified.
③ Close the diaphragm by the specified number of stops.
④ Open the diaphragm to the full-open position.

Primary data sent from the lens in response to command ① is shown in Table-1. Data communications are carried out immediately after the lens is mounted on the body and thereafter whenever some type of operation is carried out. Transfer of approximately 50 types of data is performed in real-time according to the situation.

Table-1 Data Communication Content

Type of information	Purpose		
	AF precision	AF control	AE control
①Lens type (ID-code)			
②Lens status		●	
③Metering information			
1.Full aperture F No.		●	●
2.Minimum aperture			●
④Focal length information	●	●	●
⑤AF drive information			
1.Focusing ring drive quantity (lens position)	●	●	
2.Lens extension response factor		●	
3.Lens extension response correction factor		●	
4.Focusing ring drive constant		●	
5.Maximum defocus quantity		●	
6.Best focus compensation amount	●		

Advantages of the fully electronic mount system

Features of the large-diameter, fully electronic mount include the following:

① Realization of quiet, high-speed, high-precision AF. Since the optimum actuator can be selected and incorporated in each lens, silent, fast and accurate autofocusing can be realised for all lenses from fisheyes to super-telephotos.

② Realization of quiet, high-precision aperture control. By incorporating the ideal EMD in each lens, high-precision digital diaphragm control is realised.

③ Built-in EMD allows the aperture to be closed down for checking the depth of field at the touch of a button. Moreover, the built-in EMD improves sequence control freedom by allowing the aperture to remain stopped down during continuous shooting to increase shooting speed.

④ The fully electronic aperture control system has permitted the development of TS-E lenses — the world's first lenses which tilt and shift with fully automatic diaphragm operation.

⑤ Achievement of the large-aperture EF 50mm f/1.0L USM lens. (A feat only physically possible thanks to the large-diameter EOS mount.)

⑥ Realization of full-frame viewfinder coverage. (Virtually 100% coverage is realised in EOS-1 series cameras.)

⑦ Elimination of viewfinder and mirror blockage with super-telephoto lenses.

⑧ When using a zoom lens which varies the maximum aperture according to the focal length, aperture values which are calculated by the camera or set manually (except for maximum aperture) are automatically compensated so that the aperture setting does not change during zooming. For example, when using the EF 28-300mm f/3.5-5.6L IS USM with a manually set aperture of f/5.6 or smaller, the aperture setting does not change when the lens is zoomed even though the lens' maximum aperture value changes. This means that when using a handheld exposure meter or flash meter to determine the appropriate camera settings for a certain scene, you can simply set the aperture value manually according to the meter reading without worrying about the zoom position.

⑨ Since it automatically compensates and displays the change in the lens' effective F-number when an extender is mounted, even when using a handheld meter no additional compensation is needed when you set the camera according to the metering reading.

⑩ Being able to make the rear aperture of the lens larger than before is beneficial for improving marginal illumination in the optical system. Advantages are also gained in terms of optical performance improvement when an extender is used with a super telephoto lens.

⑪ Since the fully-electronic mount system has none of the shock, operation noise, abrasion, play, lubrication requirements, poor response, reductions in precision caused by lever operation or design restrictions related to linkage mechanisms present in systems which use mechanical linkages to transfer data, operation reliability is significantly improved.

⑫ There is no need for the mechanical auto diaphragm linkage mechanism or aperture control mechanism in the camera body, making possible a lighter and more compact body design together with improved system operation reliability.

⑬ A lens operation self-test system using the lens' built-in microcomputer (which displays a warning in the camera's LCD (Liquid Crystal Display) panel in the event of a malfunction) ensures high reliability.

⑭ Since all control is carried out electronically, designers have great flexibility with regard to incorporating future new technologies such as image stabilization and improving camera performance.

Compatibility with new technologies and future system upgrades has already been proven with increased AF functionality (higher speeds, better predictive autofocus for moving subjects, multi-point autofocusing compatibility), the achievement of auto-aperture TS-E lenses mentioned above, the use of USMs in most EF lenses, the development of the first image stabilizer lens in the world, and the creation of a digital SLR camera system that can work with all EF lenses.

Photo-5 Electronic Mount — Body Side

Photo-6 Electronic Mount — Lens Side

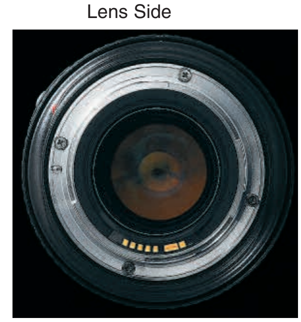
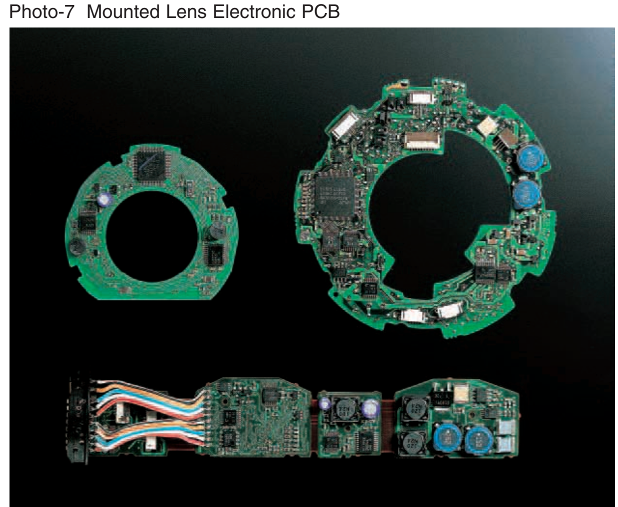


Photo-7 Mounted Lens Electronic PCB



3 Sixteen Technologies Used in High-Performance EF Lenses

1 Transcending the Theoretical Limit of Spherical Lenses: Super-Precision Aspherical Lenses

Most lenses used for photographic purposes are made by combining several spherical lens elements. The radius of curvature and type of optical glass used for each element and the amount of air space between the elements are designed in such a way that the final lens combination eliminates the various lens aberrations to a degree large enough to achieve the desired performance. Today, computers provide us with automatic design and simulation techniques which enable development of high-performance lenses in a short period of time. Use of only spherical lenses, however, presents a basic problem in which parallel light rays entering a spherical lens theoretically do not perfectly converge at a single point, introducing restrictions with regard to:

- performance of large aperture lenses,
- distortion compensation in super-wide-angle lenses, and
- minimum size of compact lenses.

To remove these restrictions and realise lenses with even higher performance, less distortion and smaller size, the only way is to utilise aspherical lens technology.

Canon started developing aspherical lens technology in the mid-1960s and established design theories and precision processing and measurement technologies in the early 1970s. In 1971, Canon succeeded in commercially releasing an SLR lens incorporating an aspherical lens element – the FD 55mm f/1.2AL. This success can be attributed to the following two points:

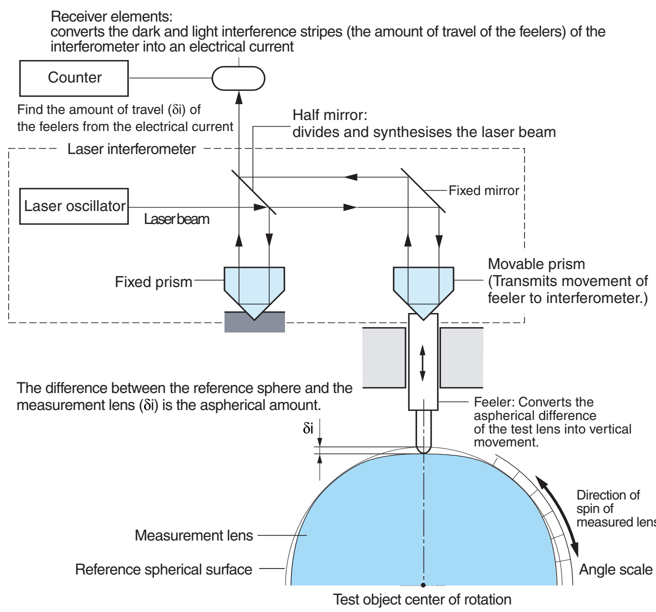
① Establishment of ultra-precision measurement technology

For measuring aspherical lens surfaces, Canon independently developed the “polar coordinate conversion measurement system,” in which the object to be measured is placed on a rotating table and rotated around its center of curvature while a gauge interferometer is used to measure the difference between the object surface and a reference spherical surface. Measurement results are then processed by a computer to determine the surface shape. With this technique, an ultra-high precision of 1/32 the light wavelength - or 0.02 micron (20 millionths of a millimeter) - is realised.

This measurement technology formed the backbone indispensable to the subsequent development of various aspherical lens-processing technologies.

Photo-8 Precision Aspherical Lenses

Figure-13 Canon’s Polar Coordinate Conversion Measurement System



② Establishment of aspherical lens processing system incorporating special grinding and uniform polishing techniques

For precision processing of aspherical lenses, Canon established a special aspherical lens processing system which grinds the lens with high precision to an aspherical shape and then polishes the lens to attain a uniform surface without losing the aspherical shape.

Initially, the aspherical surface processing and ultra-precision shape measurement steps had to be repeated over and over so that each lens was in effect made by hand.

Then, in 1974, Canon developed a special machine which had the capability of producing more than 1,000 aspherical lenses per month, thus paving the way for mass production.

Photo-9 Spherical Lens Example

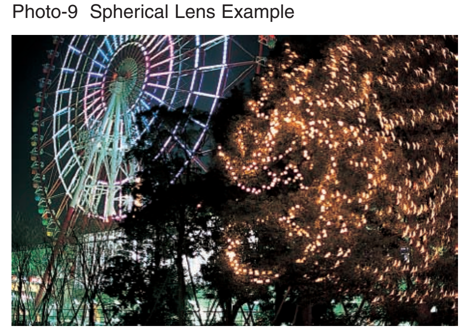


Photo-10 Aspherical Lens Example

Figure-14 EF 85mm f/1.2L II USM Optical System - Ray Tracing Diagram

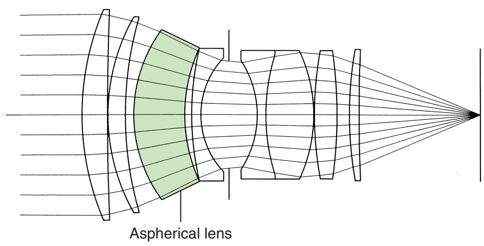


Figure-15 EF 14mm f/2.8L USM Optical System - Ray Tracing Diagram

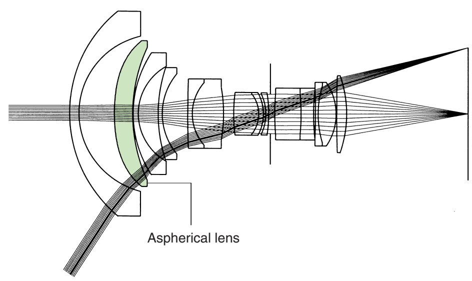


Figure-16 EF/FD Zoom Lens: Size Comparison

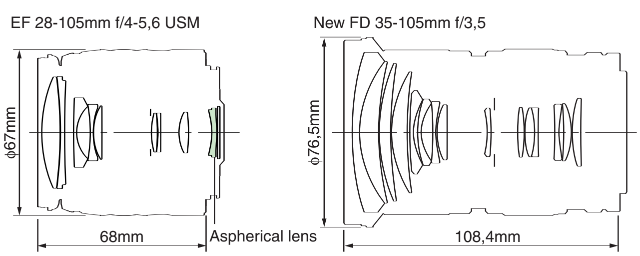
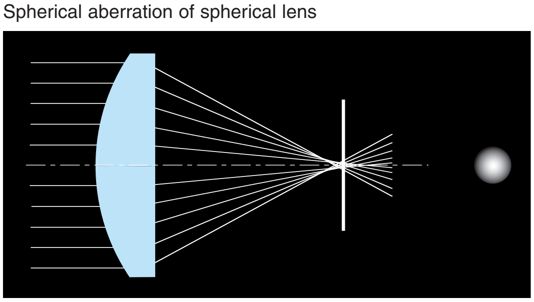
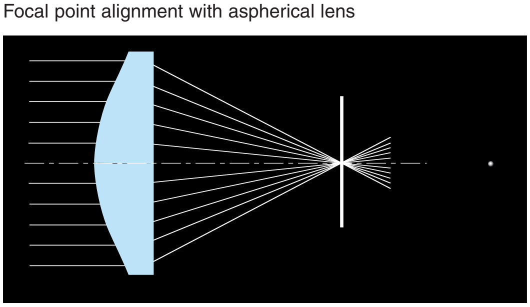


Figure-17 Principle of Aspherical Lens Effect

Spherical aberration of spherical lens



Focal point alignment with aspherical lens



However, there were limits on the mass production of ground-glass aspherical lenses, so around 1978, Canon succeeded in applying this aspherical processing technology to a die molding process and developed a practical, high-precision plastic molding system for producing small-aperture aspherical lenses in mass quantity and at low cost. Lenses manufactured with this system were employed in compact cameras in the AF rangefinding system and in some shooting lenses (Snappy/AF35MII). In the early 1980s, Canon continued its research and development efforts in the area of large-aperture glass-molded aspherical lenses, and succeeded in developing a practical production system in 1985.

These glass-molded aspherical lenses are manufactured by directly molding glass material in a molding machine incorporating an ultra-high-precision aspherical metal die. This enables high precision sufficient to satisfy the performance requirements of SLR interchangeable lenses as well as mass production at relatively low cost. In 1990, Canon added a fourth aspherical lens production technology to its arsenal by developing technology for producing replica aspherical lenses by using ultraviolet-light-hardening resin to form an aspherical surface layer on a spherical glass lens. In the development of EF lenses, these four aspherical lens types give Canon lens designers great flexibility in being able to choose the best type of lens for each application. Aspherical lenses are particularly useful for

- compensating spherical aberrations in large-aperture lenses,
- compensating distortion in wide-angle lenses, and
- enabling production of compact, high-quality zoom lenses.

Actual examples of such applications are shown in Figure-14

Figure-18 Aspherical Surface Shape Precision Measurement Results

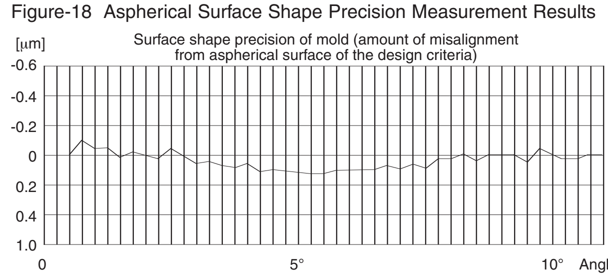


Photo-11 Ultra-High-Precision Glass Molded Aspherical Lens Die

to Figure-16.
The EF 85mm f/1.2L II USM in Figure-14 is designed with aspherical lens elements which cause all light rays passing through the lens to converge at a single point. The image formed by light rays entering the lens along a cross section perpendicular to the paper surface will flare at the maximum aperture. The aspherical lens elements act to both eliminate this flare and compensate the comatic flare component. This lens utilises two aspherical elements to achieve good compensation over the whole image area from the center to the edges.
The ultra wide-angle lens in Figure-15 incorporates an aspherical lens element designed with a freecurved surface and light ray transmission angle which optimises the lens' image formation characteristics at every point in the image area. Use of this aspherical lens greatly compensates for the distortion and peripheral image smearing previously unavoidable in ultra wide-angle lenses.
Figure-16 shows a comparison between a previous FD zoom lens constructed only of spherical lens elements and a new EF zoom lens of the same class incorporating an aspherical lens element. Use of the aspherical lens element realises a shorter overall lens length and significantly reduced curvature of field and distortion.

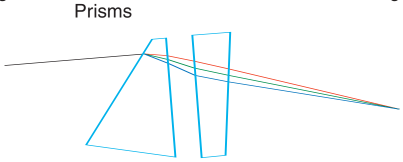
2 Fluorite and UD Lenses—Sharp Enough to Capture Even the Air

Canon's white-barreled super-telephoto L lens series are continuously extolled by professional photographers throughout the world as being super-high-performance lenses with unrivaled sharpness. The key to this performance is the complete elimination of the secondary spectrum through liberal use of fluorite and UD glass lenses.

Fluorite

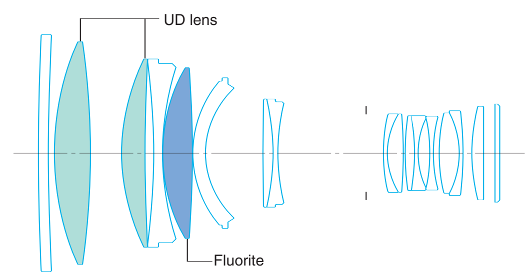
● With super-telephoto lenses, there is a limit to the degree of performance improvement possible using optical glass lens elements.
The level of residual chromatic aberration has a significant effect on the degree of image sharpness that can be obtained with telephoto and super-telephoto lenses. As shown in the colour-canceling prism example in Figure-19, chromatic aberrations are corrected by utilising the different dispersion characteristics of different types of optical glass to align the propagation directions of light rays with different wavelengths in the same direction.

Figure-19 Chromatic Aberration Correction Using Prisms



In photographic lenses, as well, it is possible

Figure-20 EF 300mm f/2.8L USM Optical System



bring two wavelengths (such as red and blue) together at the same focal point by combining a small-dispersion convex lens with a large-dispersion concave lens. A lens in which two colours (wavelengths) are so corrected is called an achromatic lens, or simply an achromat. However, although two colours meet at the same focal point, the intermediate colour (green) still converges at a different focal point. This chromatic aberration, which remains even after chromatic aberration correction design measures are carried out, is called secondary chromatic aberration, or secondary spectrum. When using only optical glass lens elements, this secondary spectrum cannot be reduced to less than "focal length x 2/1000 mm" due to theoretical limitations. This is due to the fact that even with different types of optical glass having different rates of dispersion, the proportional amount of dispersion for each wavelength tends to remain fixed.
● Use of fluorite to produce ultra-high-performance lenses
Fluorite is a material that makes it possible to remove the theoretical limit imposed by optical glass and realise virtually ideal correction of chromatic aberrations.
Optical glass is a material produced from silica as the main material together with additives such as barium oxide and lanthanum. During manufacture, these substances are combined in a furnace, melted together at a high temperature of 1,300° to 1,400°C, and then slowly cooled.
Fluorite, on the other hand, has a crystalline structure and is equipped with extraordinary characteristics unobtainable with optical glass-a low index of refraction and low dispersion (Figure-23). Moreover, the dispersion characteristics of fluorite are nearly identical with optical glass for wavelengths in the range from red to green, but differ greatly for wavelengths in the range from green to blue (a characteristic called extraordinary partial dispersion). Use of these special properties makes it possible to significantly improve the imaging performance of super-telephoto lenses, as described below.
① Thorough elimination of the secondary spectrum
When a convex fluorite lens is combined with a large-dispersion optical glass concave lens according to design rules for correcting red and blue wavelengths, the extraordinary partial dispersion characteristics of the fluorite work to effectively compensate for the green wavelength as well, reducing the secondary spectrum to an extremely low level

Figure-21 Secondary Spectrum

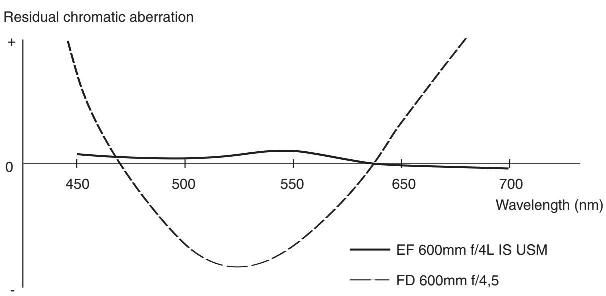


Photo-12 Artificial Fluorite Crystals and Fluorite Lenses

and bringing all three wavelengths-red, green and blue-together at the same focal point, realising virtually ideal chromatic aberration compensation (apochromatic performance), as shown in Figure-21.

② Image quality improvement over total image area With telephoto type lenses using a front-convex/rear-concave power distribution design, the overall physical length can be less than the focal length. To achieve a high level of sharpness all the way from the center of the image to the edges with this type of lens, it is desirable for the index of refraction of the front convex lens group to be as small as possible. Accordingly, use of fluorite with its low index of refraction is effective in improving image quality over the total image area.

③ Overall lens length reduction

To reduce the overall length of a telephoto lens, it is desirable to make the mutual power of the convex-concave construction as strong as possible.

With ordinary optical glass, however, increasing the mutual power makes it difficult to correct curvature of field and degrades image quality. With fluorite, on the other hand, the material's low index of refraction is beneficial for the conditions set forth by Petzval's sum, making it possible to achieve significant reductions in lens length while maintaining high image quality.

Although fluorite's extraordinary optical characteristics have been known since the 1800's, natural fluorite only occurs in nature in small sizes usable only for the object lenses in microscopes. Although lens designers long wanted to use fluorite in photographic lenses, it was generally extremely difficult or impossible to obtain naturally formed pieces large enough for lens use. To solve this problem, Canon worked hard at developing synthetic fluorite crystal formation technology and finally succeeded in establishing practical fluorite production technology (calcium fluoride <CaF_2> synthetic crystal formation technology) near the end of the 1960's. This is one example of Canon's undying spirit and efforts to make use of our own abilities to create whatever is necessary to approach the realization of the ideal. The first use of artificially crystallised fluorite in photographic lenses was for the FL-F 300mm f/5.6 in 1969, and it has since been incorporated in the FD, New FD, EF, and many other Canon

Figure-22 Comparison of Colour Aberration Correction

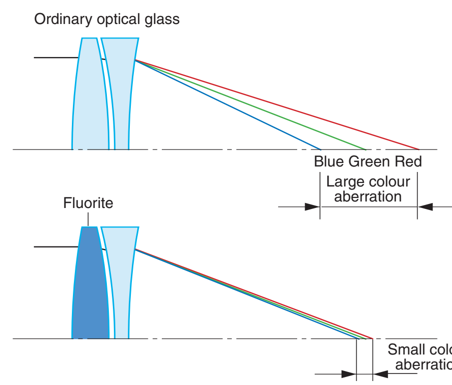


Figure-23 Optical Characteristics of Optical Glass and Fluorite

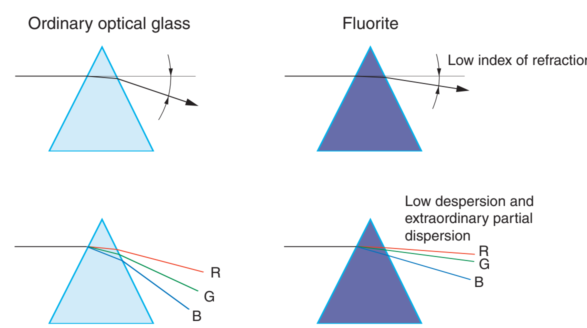


Photo-13 Optimally Coated EF Lenses

lenses. Today, the only SLR interchangeable lenses incorporating fluorite are the EF lenses.

UD lenses

The use of fluorite to improve the performance of super-telephoto lenses is well established, but there remains a problem with using fluorite in other types of lenses. That problem is fluorite's extremely high cost arising from the synthetic crystal production process. Because of this, lens designers long desired a special optical glass which could provide characteristics similar to fluorite but at lower cost.

This desire was finally satisfied in the latter half of the 1970's with the development of UD (ultra-low dispersion) glass. The index of refraction and dispersion of UD glass, while not as low as fluorite, are both significantly lower than other types of optical glass. Moreover, UD glass exhibits extraordinary partial dispersion characteristics. Accordingly, use of UD glass can provide nearly the same effect as fluorite (two UD lens elements are equivalent to one fluorite element) by selecting the proper lens combination in consideration of various factors such as focal length.

Fluorite and/or UD glass lens elements are employed in various EF lenses including the EF 135mm f/2L USM and EF 600mm f/4L IS USM telephoto/super telephoto lens group and the EF 28-300mm f/3.5-5.6L IS USM, EF 70-200mm f/2.8L IS USM, EF 70-200mm f/2.8L USM, EF 70-200mm f/4L IS USM, EF 70-200mm f/4L USM and EF 100-400mm f/4.5-5.6L IS USM telephoto zoom lenses. UD lenses are also incorporated into the wide angle EF 24mm f/1.4L USM, EF 16-35mm f/2.8L USM, EF 17-40mm f/4L USM and EF 24-70mm f/2.8L USM lenses in order to correct chromatic aberration. In 1993, after dramatically improving the performance of conventional UD lenses, a super UD lens was successfully developed reproducing almost the same characteristics as fluorite, and used in the EF 400mm f/5.6L USM.

The rapidly expanding field of digital photography has also seen increased emphasis placed on correcting chromatic aberration in photographic lenses. To meet this challenge, fluorite, UD, and super UD lenses will start being used in even more EF lenses in the future, from wide angle to super telephoto.

3 Unrivaled Clarity, Ideal Colour Reproduction
Super Spectra Coating

Lens coating is a technology which uses a vacuum deposition process to form an extremely thin transparent film on the surface of a lens. Reasons for coating a lens include

① improving transmittance and minimising flare and ghosting,

② achieving optimum colour balance, and

③ oxidising ('burning') the lens surface, and thus is effective for changing or improving the properties of the lens and providing lens surface protection.

Figure-24 Surface Reflections with Non-Coated Glass

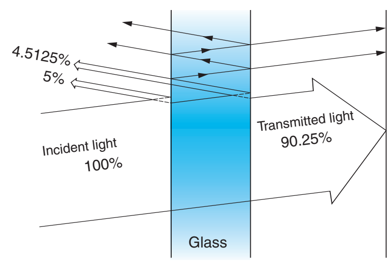


Figure-25 Lens Light Absorption and Surface Reflection

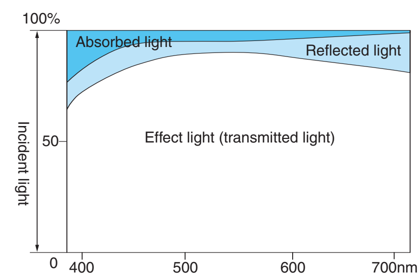
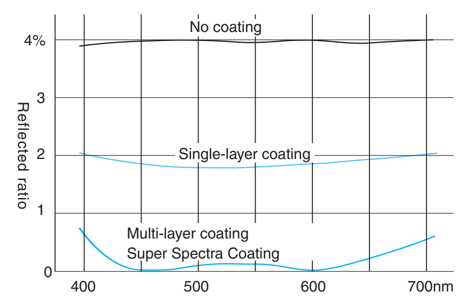


Figure-26 Super Spectra Coating Characteristics (Reflectivity)



When light enters a lens, approximately 4-10% of the light is reflected back at each lens surface (glass-air boundary), resulting in significant light loss in photographic lenses constructed of several elements or more. Also, repeated reflections between the lens surfaces that reach the focal plane may cause flare or ghosting in the image. These harmful reflections can be largely eliminated for a wide range of wavelengths by coating each lens surface with a multi-layer coating consisting of several thin film layers having different indexes of refraction. At Canon, we use several types of multi-layer coatings which are optimised according to the index of refraction of the lens element to be coated.

Also, some types of glass - especially those having high indexes of refraction - tend to absorb blue light due to the components combined to produce the glass, resulting in an overall yellow colour. If this yellowish glass were simply coated with a multi-layer coating like other lenses, light passing through the lens would have a slightly yellowish cast, producing a tinge of yellow in the white areas of pictures

Figure-27 Short Zoom Lens Construction (EF 28-80mm f/3.5-5.6 V USM)

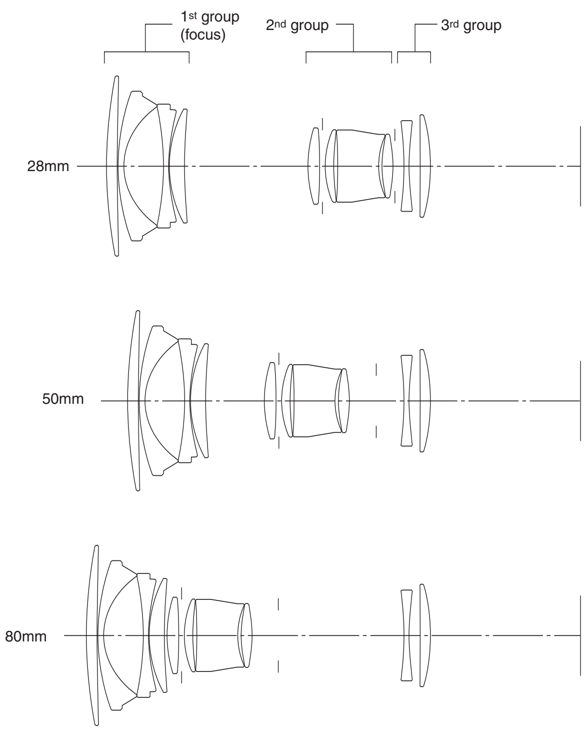
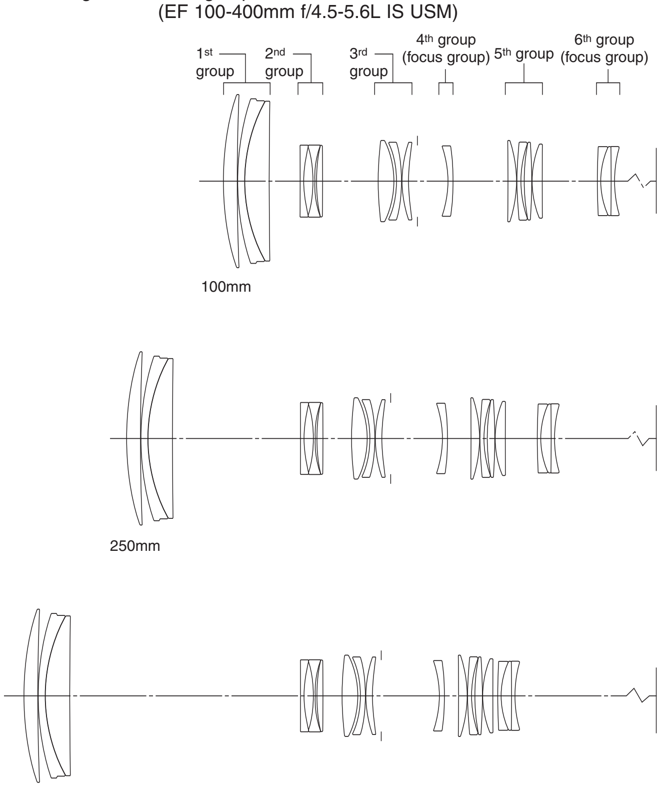


Figure-28 Multi-group Zoom Lens Construction (EF 100-400mm f/4.5-5.6L IS USM)



taken on colour film. To counteract this, surfaces which have little effect on flare and ghosting are coated with single-layer coatings of appropriate colours such as amber, magenta, purple and blue to ensure identical colour balance among all EF interchangeable lenses.

All EF lenses are coated to original standards which are even stricter than the CCI (Colour Contribution Index) tolerance range set by the ISO (International Organization for Standardization). This coating process is called Super Spectra Coating within Canon, and offers features such as high transmittance, ultraviolet ray filtering, highly durable surface hardness and stable characteristics.

Through these exacting coating procedures, EF lenses feature superior imaging characteristics such as

① sharp, high-contrast, vivid images

② uniform colour balance among all EF lens

③ true colour reproduction which does not change over time.

4 Born From Innovation: Multi-Group Zoom Lenses

A zoom lens allows the focal length to be continuously varied over a certain range and can maintain focus during zooming (Zoom lenses in which the focus changes with the focal length are known as “vari-focal lenses.”) In a zoom lens, part of the lens system is moved along the optical axis to change the focal length, and another part is moved at the same time to compensate for the resulting shift in focus.

Thus, a zoom lens must have at least two lens groups which can be moved along the optical axis. Figure-27 shows the lens construction of EF 28-80mm f/3.5-5.6 V USM, a typical two-movable-group short zoom lens (a zoom lens with a length of 40mm or less at the shortest focal length position).

The 2nd group is called a “variator,” meaning a group which is moved to change the focal length. The 1st group at the end of the lens moves simultaneously with the 2nd group to compensate focus shift, and is thus called a “compensator.” The 2nd group also fulfills the role of focusing by adjusting the focal point.

In a short zoom, the 1st group has negative refraction (divergence), the 2nd group has positive refraction (convergence), and the lens is designed with a retrofocus type construction. This type of design is especially well suited for wide-angle zooms due to the following features:

① The front lens element is given a small diameter, making it easy to achieve a

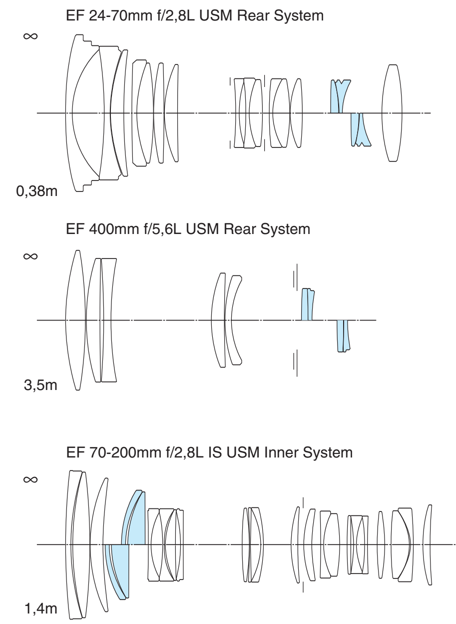
Photo-14
High-Precision Zoom Cam Ring
(EF 100-400mm f/4.5-5.6L IS USM)

design which is compact and low cost.
② There is little barrel distortion at the short focal length position.
③ The 1st-group-focusing lens design allows focusing down to close distances.
This type of design, however, presents a problem in that, if the zoom ratio in a short zoom lens is made too large, the movement amount of the 2nd group increases, thus increasing both the length of the lens and the maximum aperture variation amount. A large zoom ratio would also require an increase in the refractive power of the 2nd group, thus necessitating a greater number of lens elements to compensate for aberrations and increasing the overall size of the lens, which would make it very difficult to achieve a large ratio and a compact size. The solution to this problem is the multi-group zoom lens design, a technology developed to break through the limitations of small zoom lenses and achieve both a large ratio and a compact size.
In a short zoom lens, focal length variation (zooming) is carried out by the 2nd group alone; in a multi-group zoom, this task is allotted to several lens groups. Thus, a multi-group zoom is a zoom lens which has three or more movable lens groups.
Advantages of the multi-group zoom design are as follows:
① Since several lens groups are moved to vary the focal length, the movement amount of each lens group can be made small, allowing a compact lens design. Moreover, the change in apertures can be set as desired without requiring a complex diaphragm mechanism.
② Since zooming is distributed among several lens groups, each group can be designed with relatively weak refraction, making it possible to compensate aberrations with relatively few lens elements.
③ Since several lens groups are used, optical design freedom is increased and more options are available for compensating aberrations, such as designing lens groups to mutually cancel out their respective aberrations (cross compensation)
Multi-group zoom technology is high-level optical technology which can meet a wide range of lens design requirements, but it is only made possible with the support of advanced lens barrel design, processing and production technologies that make multiple group movements possible. Currently, the EF 28-90mm f/4-5.6 III, EF 24-85mm f/3.5-4.5 USM, EF 100-400mm f/4.5-5.6L IS USM, and all the other EF zoom lenses are designed using multi-group zoom technology, achieving large ratio, compact size, and outstanding picture quality, all at the same time.

5 Quick and Smooth Focusing: Rear and Inner Focusing Systems

General photographic lenses carry out focusing using either the all-group focusing method, in which all lens groups are moved together along the optical axis, or the front-group focusing method, in which only the front lens group is moved. The all-group focusing method has the advantage of introducing relatively little change in aberration with respect to change in shooting distance, and is therefore the most commonly used focusing method in single focal length lenses. With telephoto and super-telephoto lenses, however, this method becomes less beneficial in terms of operability because of the increased size and weight of the lens system.

Figure-29 Rear and Inner Focusing Systems



Front-group focusing, on the other hand, is primarily used in zoom lenses and has the advantage of affording a comparatively simple lens construction. However, this method has disadvantages because it places restrictions on zoom magnification and size reductions. To overcome the weak points of these two methods, Canon developed an ideal focusing method called rear focusing (or inner focusing) for use in telephoto and super-telephoto lenses. This method divides the lens system into several parts and moves the rear or middle lens group to perform focusing.
Besides the EF telephoto and super-telephoto lenses, rear focusing is currently employed in the EF 16-35mm f/2.8L USM and other zoom lenses. A rear focusing method employing a floating effect was also developed for use in wide-angle lenses such as the EF 14mm f/2.8L USM, EF 20mm f/2.8 USM and EF 24mm f/2.8.
Canon has also succeeded in employing rear focusing in zoom lenses.
These rear focusing/inner focusing designs have the following features:
① Since a lightweight lens group is moved during focusing, manual focusing operation has an extremely light feel. Moreover, quick-response autofocusing is possible.
② The lens length does not change during focusing. Also, the lens can be designed with a one-piece construction, resulting

in improved rigidity.
③ Since the focusing ring can be placed in the optimum position for focusing, and since the ring does not move back and forth during focusing, superior balance can be achieved.
④ The lens system can be made with a more compact design.
⑤ The minimum focusing distance can be made shorter than with conventional focusing methods.
⑥ Since the filter attachment ring does not rotate during focusing, superior operability is achieved with polarizing filters.
⑦ Since the front frame does not move during focusing, not only can petal hoods with good hooding effect be used, but accessories such as gelatin filter holders can also be used with the autofocus.
At Canon, lenses in which element groups behind the aperture position (towards the film surface) move are called rear focusing, while lenses in which element groups between the aperture and the front element move are called inner focusing.

6 Remarkably Improved Close-Distance Image Quality: Floating System

Conventional lenses are designed to achieve an optimum balance of aberration compensation at only one or possibly two shooting distance points throughout the focus range considered most common for that lens. Thus, although aberrations are well-compensated at the ideal shooting distance(s), aberrations increase and cause image degradation at other shooting distances. The degree to which this image degradation occurs differs according to the lens type and aperture size, with image degradation relatively small in symmetrical lenses but relatively large in asymmetrical lenses such as retro-focus type lenses. With retro-focus type lenses, in particular, aberration fluctuation increases as the focal length decreases or the aperture size increases. With wide-angle interchangeable lenses for SLR cameras - most of which necessarily employ retro-focus designs due to the need for back-focus - aberrations are small when focusing far distances, but curvature of field becomes significantly pronounced at close focusing distances, causing the peripheral image to go out of focus, or causing the central image to go out of focus if the focus is adjusted for the periphery.

Figure-30 EF 24mm f/1.4L USM Floating System

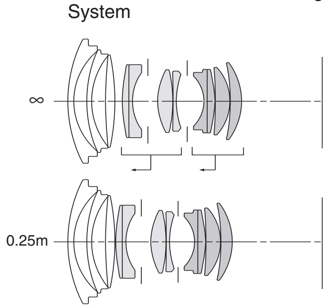


Figure-31 Floating Effect (at 0.25m)

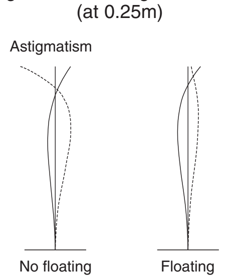


Figure-32 EF 85mm f/1.2L Ⅱ USM Floating System

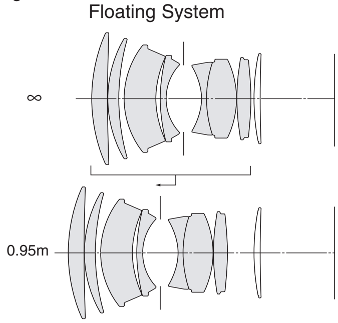
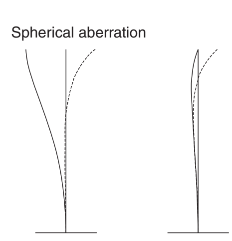


Figure-33 Floating Effect (at 0.95m)



To ensure ideal aberration correction throughout the range of focusing distances, Canon developed the floating system, in which the part of the lens system used for correcting aberration moves, or "floats," when adjusting the focus. This system is employed in the EF 24mm f/1.4L USM and other large aperture wide-angle lenses as well as the EF 180mm f/3.5L Macro USM to improve close-distance performance.
Canon also developed a method for adding a floating effect to rear-focusing lenses. In the EF 14mm f/2.8L USM, for example, the lens system is divided into front and rear groups and only the rear group is used for focusing. Looking at the lens system as a whole, this rear-group focusing movement changes the distance between lens elements according to the shooting distance and thus provides a floating effect. Since the lens optics were designed from the start with this floating effect in mind, close-distance aberrations are corrected to a high degree.
Another application of the floating effect is to prevent spherical aberration, which tends to become significantly large at close focusing distances with large aperture lenses. This is the main reason why a floating system is employed in lenses such as the EF 50mm f/1.2L USM, EF 85mm f/1.2L II USM, and EF-S 60mm f/2.8 Macro USM. The floating system in these lenses differs from that of wide-angle lenses in that it leaves the rear lens group fixed and extends the remainder of the lens system during focusing. This design achieves almost completely flare-free, high-quality imaging performance at all shooting distances.

7 Extracting the Utmost in Lens Performance: Elimination of Internal Reflections

Ghosting and flare are caused by harmful light reflections within the lens, adversely affecting picture quality. EF lenses are therefore designed to eliminate reflections both in the lenses and barrel. Each lens element is treated with a special coating to prevent harmful light from occurring by suppressing lens surface reflection. Lens barrel reflection is taken care of by selecting the best anti-reflection methods for each individual lens from among various techniques listed on the next page.

Figure-34 EF 300mm f/2.8L IS USM Flocked Parts to Eliminate Internal Reflections

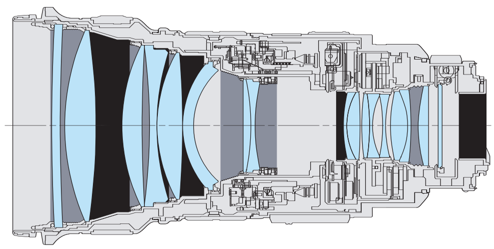


Figure-35 EF 28-135mm f/3.5-5.6 IS USM flare cut moving aperture diaphragm

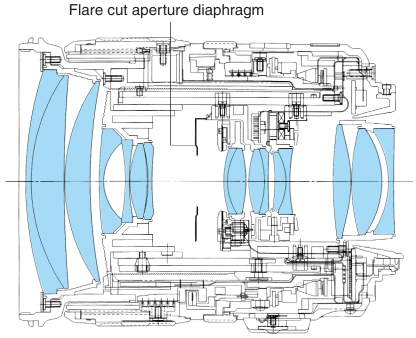
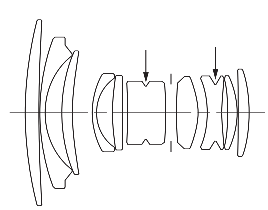


Photo-15 EF 300mm f/4L IS USM Flocking Process

Figure-36 EF 24mm f/2.8 Internal Light Blocking Grooves



① Anti-Reflection Coating Techniques
This method employs a special paint on angled surfaces and joining surfaces where the lens elements are held in place by the lens barrel to stop light entering the lens from reflecting from these parts. If a standard coating is used, reflections actually increase due to the large size of the pigment grains and the fact that the coating has a lower index of refraction than the glass. Canon therefore developed several types of special anti-reflection coatings which have a high index of refraction and ultra-fine pigment grains, and can be used according to the location and objective, achieving a superior anti-reflection effect.
② Electrostatic Flocking Techniques
This method is a technique which uses an electrostatic flocking process to directly apply an extremely fine pile to surfaces requiring an anti-reflection finish. Since the pile stands perpendicular to the wall surfaces, this technique is extremely effective especially in the long barrel sections of telephoto and super-telephoto single focal length lenses as well as zoom lenses and inside hoods.

③ Anti-Reflection Construction Techniques
In addition to use of special coatings and flocking, prevention of internal reflections is also achieved using various structural techniques such as use of light blocking grooves and knife edges to reduce the reflection surface area (Figure-34 and Figure-35), use of light blocking grooves at the lens' wide edge surface (the groove is filled with anti-reflection coating material and acts as a fixed diaphragm: Figure-36), and fixed and movable diaphragms (in zoom lenses) which double as flare-cutting devices. These measures extend to the blades, as well, with the surface of the aperture blades in the EMD unit (made from plastic and metal) treated with a special anti-reflection coating that also acts as a lubricant, to prevent ghost images from forming in the shape of the maximum apertures.

8 The Key to Quiet, Fast and Smooth Autofocus: Fully Electronic Mount & Lens-incorporated Motor Drive System

The fully electronic mount and lens-incorporated motor drive system is Canon's answer to the problems inherent in body-incorporated drive systems and the key point in the realization of the silent, smooth, fast, high-precision autofocusing the EOS system is known for. This system represents the true realization of Canon's mechatronic camera system design concept, which is "the placement of the optimum actuator close to each corresponding drive unit, and full electronic control of all data transmission and control signals." This extremely streamlined and logical system offers the following advantages over conventional systems.

● Features

① Since each EF lens can be equipped with the optimum actuator matched to its specific AF operation characteristics, strain-free, high-speed lens drive is possible for all lenses ranging from fisheye to super-telephoto. The advantage of this system over body-incorporated drive systems increases as the drive unit becomes farther away from the body in long super-telephoto lenses, enabling Canon to incorporate autofocusing in all of its super-telephoto lenses including the EF 600mm f/4L IS USM.
② Since the actuator is physically close to the drive unit, drive energy is transmitted efficiently with minimal loss and drive noise.
③ Use of the electronic mount system allows lens designers to select from a wide selection of actuator types.
④ The system allows easy incorporation of new high-performance actuators as they are developed, providing great future development potential.
Canon currently utilises the following five types of actuators, selecting the best type according to the characteristics of each lens.

● Ring-type USM
● Micro USM

● AFD (Arc-Form Drive: circular deformation brushless motor)
● Coreless general-purpose DC micro motor
● Cored general-purpose DC micro motor

Another type of actuator used in EF lenses is the EMD (electromagnetic diaphragm), which integrates an aperture-control deformation stepping motor and a diaphragm blade unit in a single unit. For details, see page 182.

9 Born With The EOS System: Advanced Ultrasonic Motor

The Ultrasonic Motor (USM) is a new type of motor which found its first application as a camera lens motor in Canon EF lenses. The ring USM which made its debut in 1987 in the EF 300mm f/2.8L USM amazed the world with its silent, super-fast autofocusing performance. Then, in 1990 Canon established new mass-production technology realising the development of a ring-type USM for use in popular-class lenses. This was followed by the successful development in 1992 of the Micro USM, a new type of USM enabling the use of automated production techniques, and in 2002 of the ultra-compact Micro USM II, half the length of the Micro USM. With this USM arsenal, the day is very near when Canon will finally realise its dream of employing a USM in every EF lens.

■ Ring-type USM Description

Conventional motors come in many different types and designs, but in principle they all convert electromagnetic force into rotational force. Ultrasonic motors, on the other hand, are based on a completely new principle in which rotational force is generated from ultrasonic vibrational energy. Including USMs still in the research and development phase, three types of USMs-classified by the method used to convert vibrational energy into rotational force-have been announced to date: the standing wave type, the traveling wave type, and the vibrating reed type. According to this classification, all USMs used in Canon lenses are of the traveling wave type. The basic motor construction is very simple, consisting of an elastic stator and a rotating rotor. The stator's bottom section consists of an elastic metal ring with a piezoelectric ceramic element attached, and its top section consists of many uniformly-spaced projections which have trapezoidal cross sections. The stator is made of a special material which has a coefficient of thermal expansion nearly the same as the piezoelectric ceramic element, which minimises ring distortion due to temperature changes. Because of this, stable operation is guaranteed over a broad temperature range. The rotor is an aluminum ring which has a flange-shaped spring where it contacts the stator, and so is held in contact with the stator under pressure. Since aluminum is a relatively soft material, the location where the rotor contacts the stator is provided with a special abrasion-resistant surface finish.

■ Ring-type USM Features

The basic features of ultrasonic motors are as follows:

① Low-speed, high-torque output characteristics (a USM can generate a larger amount of power at lower speeds than a conventional motor which rotates using electromagnetic force) can be easily realised, enabling direct drive without the need for a speed-reducing gear train.

② Holding torque is large. In other words, when the motor is stopped the lens is automatically held in place by a disc brake effect.

Figure-37 Various Lens Actuators

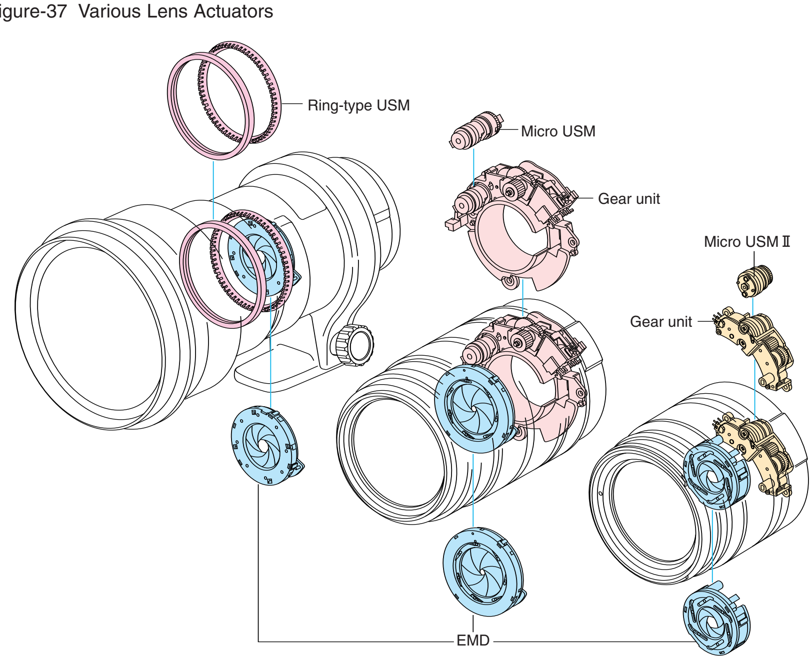
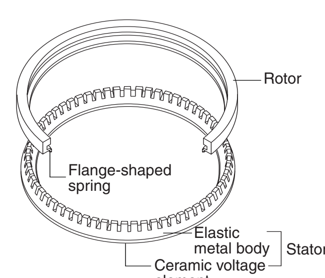


Figure-38 EF 28-135mm f/3.5-5.6 IS USM showing USM

Figure-39 Ring-type USM Construction



③ Construction is extremely simple.
④ Starting and stopping response and controllability are good. (Quick starting and stopping is possible, and operation can be precisely controlled.)
⑤ Operation is extremely quiet (virtually noiseless).
In addition to the above, Canon's ring USMs also offer the following features:
⑥ High efficiency and low power consumption allow the USM to be powered from the camera's battery.
⑦ The motor's ring shape is the optimum shape for incorporation into a lens barrel.
⑧ Low rotation speed is optimally suited for lens drive purposes.
⑨ Rotation speed can be continuously controlled within a wide range from 0.2 rpm (one rotation every five minutes) to 80 rpm, enabling high-precision, high-speed lens drive control.
⑩ Stable operation is achieved under the harshest of conditions, with a broad range of temperature usability, from -30°C to +60°C.
For any motor, the motor drive control system is an important subsystem necessary for fully extracting the motor's particular characteristics. The same is true for ultrasonic motors. In Canon's USM lenses, functions such as detection of the ultrasonic resonance state with respect to temperature variation, generation of two AC voltages of different phase, starting and stopping control, and electronic manual focus speed adjustment are all controlled by a microcomputer incorporated in the lens.

Photo-16 Ring-type USM

Ring-type USM Rotation Principle

The operation principle of a Ring-type USM is as follows: vibrations are applied to the elastic body called the stator, thus generating vibrations in the stator.
That vibrational energy is used to continuously rotate the rotor through the pressure contact between the rotor and stator. In more technical terms, the frictional force generated by flexural traveling waves in the stator is the source of rotational motive force. The manner in which the force from the flexural traveling waves generated in the stator is transmitted to the rotor is illustrated in Figure-40. If we watch the movement of the tip of each projection P as the wave advances from left to right, it can be seen that the tip moves in the direction opposite that of the wave. The rotor is driven by the frictional force at each point P, thus completing the operation sequence. As shown in Figure-41 and Figure-42, flexural traveling waves are generated by the piezo-electric ceramic element (an element which expands and contracts when applied with an AC voltage) which is attached to the bottom of the stator and driven by an electronic circuit. This piezoelectric ceramic element is alternately polarized in the direction of its thickness, and is applied with an AC voltage having a fre-quency near the stator's flexural vibration resonant fre-quency of approx. 30,000Hz (this fre-quency is in the ultra-sonic range, which is where the USM gets its name). The applied voltage generates vi-brations (having an amplitude width of only around 0.001mm) in the stator which are combined with vibrations of a different phase generated by a piezoelectric element attached to the bottom of the stator at a separate location shifted by one-fourth the periodic phase. This combined wave-a flexural traveling wave (7 vibrational waves per cycle) moving along the stator-is the source of the motor's rotational energy.

Figure-40 Rotor Rotation Due to Flexural Propagation of Waves

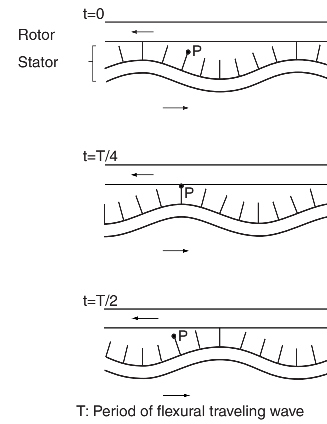


Figure-41 Vibrations Generated by Piezoelectric Ceramic Element

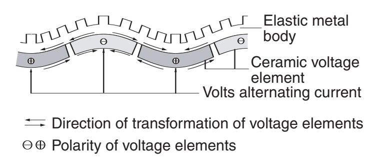
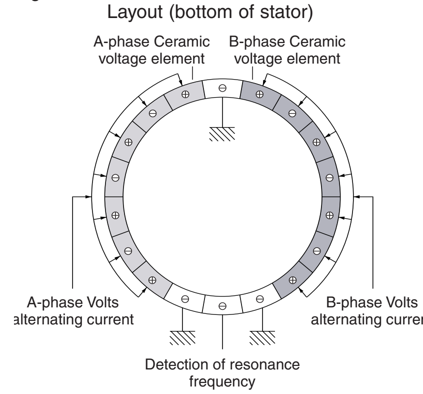


Figure-42 Piezoelectric Ceramic Element Layout (bottom of stator)



Micro USM Description and Features

The Ring-type USM is an ultrasonic motor developed from the beginning for incorporation into round-barreled lenses. In contrast, the Micro USM is a new motor developed as a "multi-purpose miniature ultrasonic motor." Features of the Micro USM are as follows:
● Since there are no lens diameter restrictions, the Micro USM can be incorporated in a wide variety of lenses regardless of optical system construction.
● The stator, rotor and output gear are integrated in a single

Photo-17 Micro USM (Left) Micro USM Ⅱ (Right)

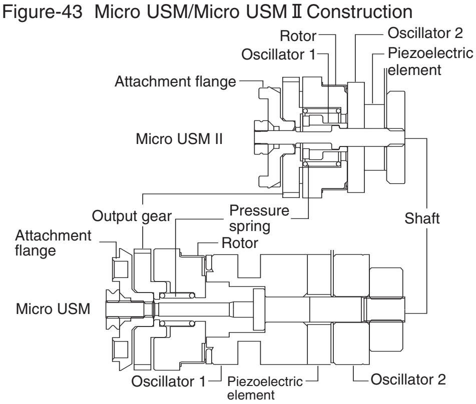
compact unit approximately half the size and weight of a Ring-type USM.

● Cost is lower than that of the Ring-type USM, enabling use in popularly priced lenses.

Micro USM Basic Construction

As shown in Figure-43, the Micro USM has an integrated construction in which the piezoelectric element, stator and rotor are stacked vertically and combined with the output gear in a single compact unit. The stator consists of five piezoe-lectric element layers, with each layer sandwiched above and below by metal vibrator discs. As a whole, the stator unit functions as an elastic, cylindrical rod.

Figure-43 Micro USM/Micro USM Ⅱ Construction



The rotor, which is combined with the spring case, is held in contact with the stator under pressure by the springs built into the inner circumference of the spring case. Rotor rotation is transmitted directly to the output gear in a 1:1 ratio. The various components of the motor — the stator, rotor and output gear — are combined into a single Micro USM unit by a stator shaft which runs through the center of the components and a flange at the top which holds everything together. The motor is incorporated in a lens as shown in Figure-37.

Micro USM Operation Principle

The ultrasonic vibrations which are the source of rotational energy are generated using an electronic circuit to drive the four layers of piezoelectric elements which have the characteristics shown in Figure-44. Each of the four piezo-electric layers is constructed of two piezoelectric elements divided into two phases — the A phase and the B phase — which are offset from each other positioned by a phase difference of 90°. At the very bottom of the stack is a fifth piezoelectric element layer used for resonant vibration wave detection (Figure-45).

Figure-46 Micro USM Stator Vibration Principle

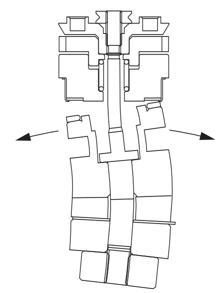


Figure-47 Micro USM Rotor Rotation Drive Principle

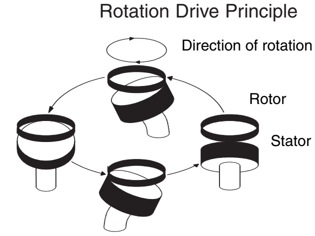


Figure-44 Piezoelectric Element Characteristics

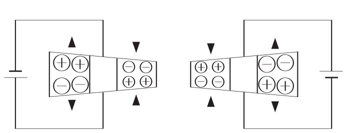


Figure-45 Micro USM Piezoelectric Element Construction

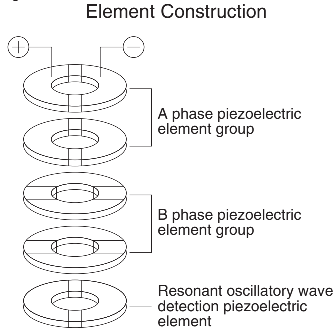


Table-2 USM Types and Mounted Lens

Item	Micro USM	Micro USM Ⅱ	Ring-type USM (MI type)		Ring-type USM (LI type)
Integrated lens	EF 50mm f/1,4 USM EF 28-90mm f/4-5,6 Ⅱ USM EF 28-200mm f/3,5-5,6 USM EF 55-200mm f/4,5-5,6 Ⅱ USM EF 70-300mm f/4-5,6 IS USM EF 75-300mm f/4,5-5,6 Ⅲ USM EF 90-300mm f/4,5-5,6 USM	EF 28-105mm f/4-5,6 USM EF-S 18-55mm f/3,5-5,6 Ⅱ USM	EF 14mm f/2,8L USM EF 20mm f/2,8 USM EF 24mm f/1,4L USM EF 28mm f/1,8 USM EF 35mm f/1,4L USM EF 50mm f/1,2L USM EF 85mm f/1,8 USM EF 100mm f/2 USM EF 100mm f/2,8 Macro USM EF 135mm f/2L USM EF 180mm f/3,5L Macro USM EF 200mm f/2,8L Ⅱ USM EF 300mm f/4L IS USM EF 400mm f/4 DO IS USM EF 400mm f/5,6L USM EF-S 60mm f/2,8 Macro USM	EF 16-35mm f/2,8L USM EF 17-40mm f/4L USM EF 20-35mm f/3,5-4,5 USM EF 24-70mm f/2,8L USM EF 24-85mm f/4-5,6 USM EF 24-105mm f/4L IS USM EF 28-105mm f/3,5-4,5 Ⅱ USM EF 28-135mm f/3,5-5,6 IS USM EF 28-300mm f/3,5-5,6L IS USM EF 70-200mm f/2,8L IS USM EF 70-200mm f/2,8L USM EF 70-200mm f/4L IS USM EF 70-200mm f/4L USM EF 70-300mm f/4,5-5,6 DO IS USM EF 100-300mm f/4,5-5,6 USM EF 100-400mm f/4,5-5,6L IS USM EF-S 10-22mm f/3,5-4,5 USM EF-S 17-55mm f/2,8 IS USM EF-S 17-85mm f/4-5,6 IS USM	EF 85mm f/1,2L Ⅱ USM EF 300mm f/2,8L IS USM EF 400mm f/2,8L IS USM EF 500mm f/4L IS USM EF 600mm f/4L IS USM
Outer diameter (mm)	ϕ11	ϕ11	ϕ62		ϕ77
Length (mm)	26,7	13,4	10		10
Mass (g)	11	6	26		45

These five layers are incorporated into the base of the stator. If AC voltage is applied only to the A phase of this piezoelectric element group, the expansion and contraction of the piezoelectric elements causes the tip of the stator to vibrate slightly left and right (Figure-46). If AC voltage is applied only to the B phase, the expansion and contraction of the piezoelectric elements cause the tip of the stator to vibrate slightly backward and forward. Finally, if an alternating current which varies by 90° is added to the A phase and the B phase, the vibrations of both phases will combine and generate a small rotational vibration wave (1 vibration wave per cycle, amplitude: 0.002mm) which causes the tip of the stator to swing in a small circular motion as shown in Figure-47. In turn, the rotor which is always in contact with the stator due to the added spring power will also start rotating due to the friction generated by the rotational vibration wave. The rotation of the rotor in turn causes the output gear, to which it is directly connected, to rotate. With a Ring-type USM, the frictional vibration caused by the flexural traveling waves generated in the stator are the operational principle, and where the rotor rotated in the opposite direction of the waves, this basically holds true for the Micro USM.

■ Micro USM II

The Micro USM II is an ultra-compact ultrasonic motor developed to meet the demand for an even smaller space for incorporating the AF drive actuator, due to the increasingly compact size of lens barrels. Its features are as follows.
In conventional Micro USMs, the stator and the rotor are arranged in a row. If the length of the unit were simply shortened without modifying this arrangement, the resonance frequency of the flexural vibration in the stator would become extremely high, preventing achievement of sufficient vibrational amplitude. To overcome this problem, an arrangement which places part of the stator inside the area for the rotor was developed along with a completely new vibrational format for the Micro USM II in order to shorten the length of the unit without raising the resonance frequency. The result is an ultra-compact unit at around half the length and mass of the Micro USM, but with approximately the same performance. The Micro USM II was first included in the EF 28-105mm f/4-5.6 USM, and plans are in the works to expand its use into other lenses, mainly ultra-compact zoom lenses.

10 Accurate, Unrivaled Digital Electronic Control: EMD

Every EF lens incorporates an EMD (electromagnetic diaphragm) which electronically controls the lens aperture diameter and is designed for use with EOS's fully-electronic data transmission mount system. The EMD is a diaphragm drive control actuator shaped to fit comfortably within the round barrel of a lens, and actually is a component integrating both a deformation stepping motor and a diaphragm blade unit in a single unit. (Photo-18)
Control of the aperture diameter is carried out by an electrical pulse signal which corresponds to a setting value manually selected with the camera's electronic dial or automatically determined by the camera's microcomputer.
Features of the EMD are as follows:
① Since control is carried out electronically, control precision is much higher.
② Since the drive is provided by the stepping motor, superior start/stop response and controllability are achieved.
③ Since linkage shock inherent in mechanical lever systems is eliminated, operation is extremely quiet.
④ The aperture can be closed down for checking the depth of field with a simple button operation at any time regardless of whether the exposure control mode set on the camera is automatic or manual.
⑤ Superior durability and reliability are realised thanks to less burden during drive.
⑥ By raising the motor drive power, the system can work with large-diameter apertures.
⑦ No need for a mechanical connection to the camera body permits a high degree of freedom in designing the aperture layout.

Photo-18 EMD Unit

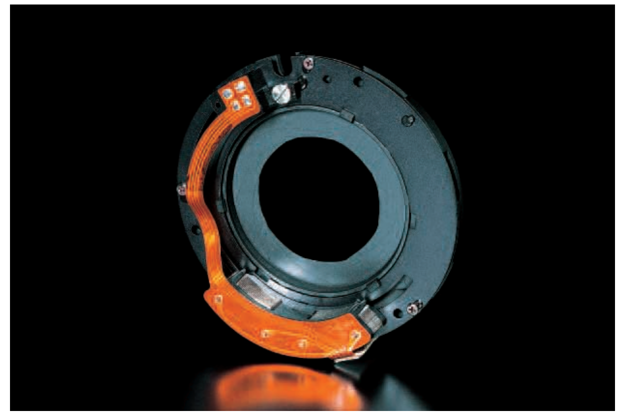


Figure-48 EMD Construction

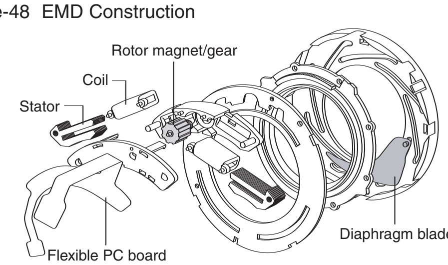
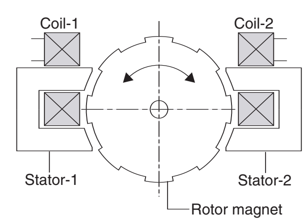


Figure-49 Stepping Motor Construction



The actual construction of the EMD (Figure-48) uses a stepping motor and a pinion to control the rotation of a ring engaged with the diaphragm blades. The deformation stepping motor, which acts as the drive source, utilises the mutual opposing and attracting forces of magnets attached to the stator and rotor arranged as shown in Figure-49 to rotate the rotor one step for every electrical pulse. When an aperture control signal is sent from the camera body to the lens, the lens' built-in microcomputer converts the signal into the corresponding number of pulses and uses digital control to accurately set the diaphragm to the required diameter. In this way, aperture control in EMD-equipped EF lenses is carried out completely within the lens itself once the electrical control signal is received from the camera body. The advantages of this system allow for extensive future development, and have already made it possible for Canon to develop the first tilt-shift lenses (TS-E lenses) in the world equipped with an automatic diaphragm, as well as enabling use of EF lenses on other equipment such as Canon's XL2 interchangeable lens video camera. The newest models of EMD employ a barrel aperture in which the blade shape is optimised for best blur effect.

11 The Fusion of AF and Manual Full-Time Manual Focus

The EOS system was built to deliver completely automated photography, but at the same time has been designed to leave final control over the elements that define the photographer's envisioned image in his or her hands, based on the fundamental concept of delivering automation which conforms to the will of the photographer. This concept can be seen at work in EF lenses, too, in the full time manual focus that allows final focus adjustment after autofocus.

● Full-time mechanical manual focusing

This function allows the photographer to manually focus the lens as soon as one-shot AF control is completed without switching the focus mode switch to manual focus. Full-time manual focusing originally employed an electronic focusing method for the EF 85mm f/1.2L USM and other early EF lenses, but today uses a mechanical system in almost all USM lenses equipped with a manual focusing ring and a distance scale, such as the EF 24-85mm f/3.5-4.5 USM, the EF 16-35mm f/2.8L USM, and the EF 300mm f/2.8L IS USM.

This full-time mechanical manual focus mechanism is a type of differential mechanism comprising three rings and a roller built into one of the rings. A description of the construction follows.

Ring 1 is rotated around the optical axis by the USM, ring 2 rotates around the optical axis when manually turned. The roller is located between the rings 1 and 2, and its rotational axis is connected to the output ring.

Rotating ring 1 or 2 when in autofocus or manual focus causes the roller to move around the optical axis, pushed by the rotation of either of the rings. Since the roller's rotational axis is fixed to the output ring, the movement of the roller in turn rotates the output ring, making the output ring rotate around the optical axis. The focus group is moved by transmitting the rotation of the output ring to a helicoid or cam.

Full-time manual focus is also achieved in the EF 50mm f/1.4 USM, which is equipped with a Micro USM, thanks to a differential mechanism built into the gear unit.

Photo-19 Focus Unit Integrated Full-time Mechanical Manual Focus Mechanism

Figure-50 Output Power Transmission Mechanism

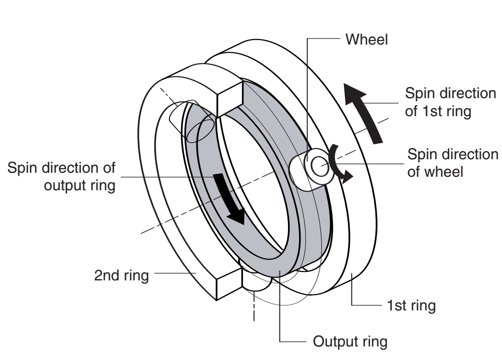
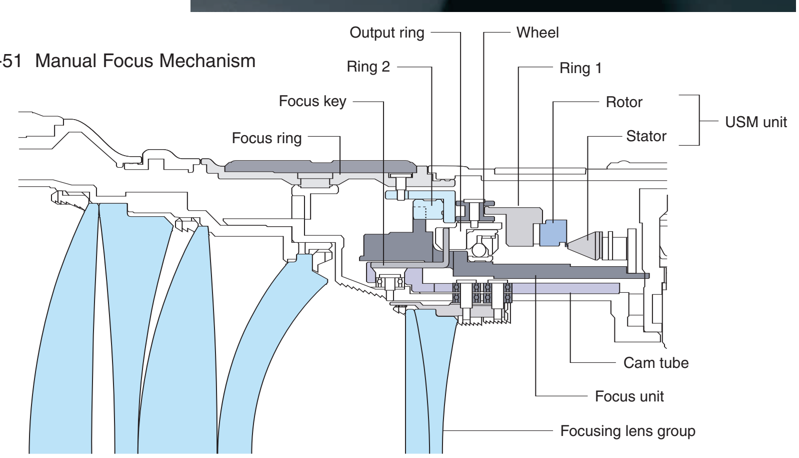


Figure-51 Manual Focus Mechanism



12 Microcomputer-Controlled Electronic Focus Preset

Figure-52 Focus Preset Photography

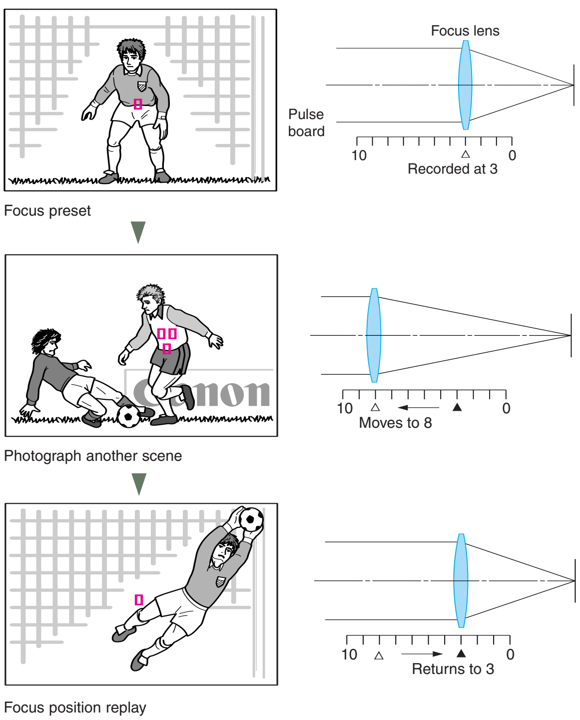
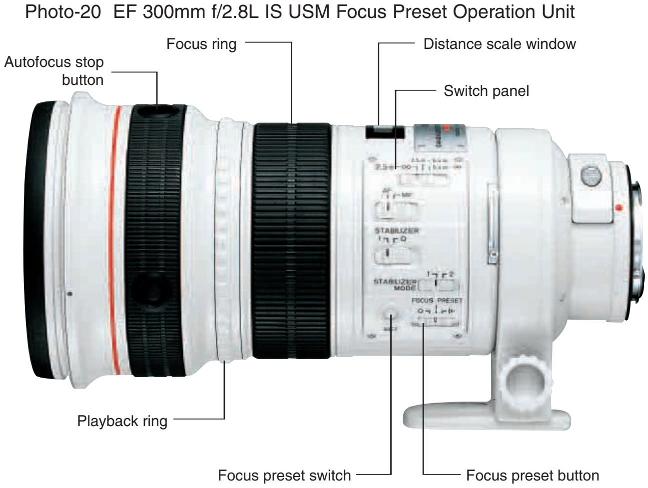


Photo-20 EF 300mm f/2.8L IS USM Focus Preset Operation Unit



Focus preset is a function currently provided on 4 super-telephoto lenses (EF 300mm f/2.8L IS USM, EF 400mm f/2.8L IS USM, EF 500mm f/4L IS USM and EF 600mm f/4L IS USM) which electronically memorises a freely selected focus position to allow the photographer to instantly preset the lens to that focus position whenever desired. By pressing the preset switch on the switch panel, the position of the focus lens at that moment is memorised by the microcomputer inside the lens. In this state, normal autofocusing can still be carried out as usual. Then, whenever necessary, turning the playback ring sets the lens to the memorised focus position within 0.5 seconds. This function can be used effectively in situations such as the following:

① Frequently taking pictures at a certain fixed distance
Focus preset is useful in situations such as sports events where most pictures are taken at a certain distance and normal AF operation is used occasionally, or the reverse, where normal AF operation is used most of the time but pictures at a certain fixed distance are sometimes required. Once the focus position is preset, there is no need to refocus the lens to that position for every shot. Moreover, since the focus position is memorised by the lens's microcomputer, focusing to the preset position is possible even if the subject is not covered by the viewfinder's AF frame.

② Memorising "infinity"
When frequently taking pictures at a shooting distance of "infinity," operability can be significantly improved by using the focus preset function rather than using manual focusing or autofocusing to focus the lens for every shot. (Due to the effect of temperature fluctuations, the infinity position of super-telephoto lenses is provided with a certain amount of play, or "leeway." Because of this, the focus position set when the manual focusing ring is turned all the way in the direction of infinity is not actually infinity.)

③ Minimising time loss caused by AF misfocusing
During AI Servo autofocusing, the lens may shift considerably out of focus if an obstruction should enter the path between the lens and subject. By presetting the focus position to a distance frequently occupied by the main subject, you can use the playback ring whenever this occurs to quickly reset the lens focus to the general subject distance, minimising the time lost in refocusing.

13 AF Stop Function: Temporarily Turns Off Autofocus

The AF Stop function is available on the EF 300mm f/2.8L IS USM and other large aperture super telephoto L type IS series lenses.
It allows the photographer to temporarily turn off autofocus when an obstruction passes between the camera and the subject during AI Servo autofocusing, so the object being focused on will not switch from the subject to the obstruction. AF Stop buttons are at four locations around the grip used for handheld photography at the front of the lens. Pressing an AF Stop button temporarily stops autofocus and releasing the button restarts autofocus.

14 Superior Dust-proof and Drip-proof Construction to withstand even the most Rugged Shooting Conditions

The EF 300mm f/2.8L IS USM super telephoto lens, the EF 24-70mm f/2.8L USM, and other L-series zoom lenses are designed so they can be used under harsh professional photography conditions by providing dust-proof and drip-proof joints on their external parts.

① A rubber ring on the mount connection blocks the gap between the lens and the camera.

② The moving parts of the manual focus, zoom, and playback rings are shaped to be dust-proof and drip-proof. A dust-proof and drip-proof construction has also been employed on the zooming extension for the EF 24-70mm f/2.8L USM.

③ AF Stop and Focus Preset but-tons feature dust-proof and drip-proof construction.

④ Dust-proof and drip-proof rubber material is in-stalled on the connections of the switch panel and other external parts.

⑤ Rubber is installed at the opening where the rear drop-in filter holder is inserted, blocking the gap between the lens body and the drop-in filter holder to keep out water droplets and dust particles.

The EOS-1V/HS, EOS-1Ds Mark II, EOS-1Ds, EOS-1D Mark II N, EOS-1D Mark II and EOS-1D have dust-proof and drip-proof bodies

15 Breakthrough in Lens Technology: Image Stabilizer

Camera shake is a major cause of blurred images especially with telephoto lenses, Normally, a shutter speed at least as fast as the reciprocal of the lens focal length (Ex.:1/300 sec. for 300mm) can prevent a blurred image due to camera shake. However, under low-light conditions or with slow film, a slower shutter speed will be required, resulting in image blur for handheld shots. Canon has developed the Image Stabilizer (IS) to help resolve this problem.

How the Image Stabilizer Works

The Image Stabilizer (IS) shifts a lens group in parallel to the focal plane.

When the lens jerks due to camera shake, the light rays from the subject are bent relative to the optical axis, resulting in a blurred image. When the lens is decentered, the light rays are deflected. By shifting the IS lens group on a plane perpendicular to the optical axis to suit the degree of image shake, the light rays reaching the focal plane can be steadied.

Figure-53 Image Stabilizer Parallel Movement Principle

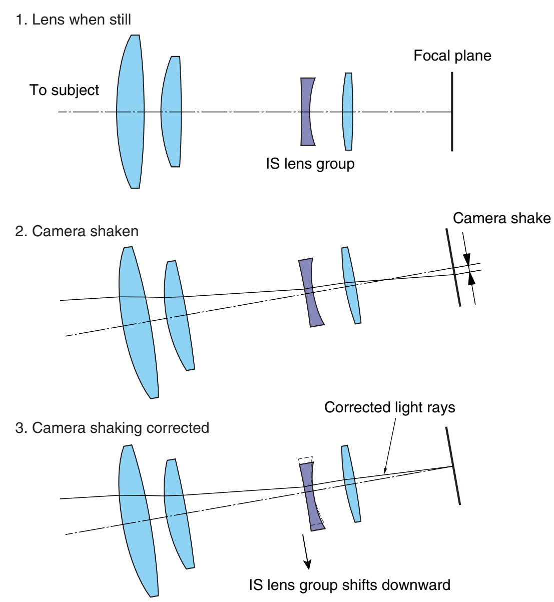
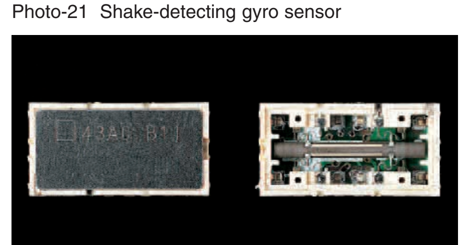


Figure-53 shows what happens when the lens is jerked downward. The center of the image moves downward on the focal plane. When the IS lens group shifts on the vertical plane, the light rays are refracted so that the image center returns to the center of the focal plane. Since image shake occurs in both the horizontal and vertical directions, the IS lens group can shift vertically and horizontally on a plane perpendicular to the optical axis to counteract the image shake.

Camera shake is detected by two gyro sensors (one each for the yaw and pitch). Shown in Photo-21, the gyro sensors detect the angle and speed of the camera shake caused by handheld shooting. To prevent gyro sensor output errors caused by mirror and shutter move-ments, the gyro sensors in the lens are protected by a casing.

Photo-21 Shake-detecting gyro sensor



The IS lens group is driven directly by a moving coil. It is small, light, and highly responsive with excellent control. It can handle a wide frequency range (approx. 0.5 Hz to 20 Hz). The IS lens group's position is detected by the IREDs (Infrared Emitting Diodes) on the IS lens group barrel and the PSD (Position Sensing Device) on the circuit board. Feedback control is thereby incorporated for fine adjustments. The IS unit also has a locking mechanism which locks the IS lens group at the center when the IS or camera is turned off (Figure-54).

Image Stabilizer system

The Image Stabilizer operates as follows.

① When the camera's shutter button is pushed down half way, the lock on the stabilizer optical system is released and at the same time the vibration gyro starts up.

② The vibration gyro detects the angular velocity component of the lens vibration caused by hand-shake, and transmits a detection signal to the microcomputer.

③ The detection signal is converted to a stabilizer optical system drive signal by the microcomputer, which then transmits this signal to the stabilizer optical system drive circuit.

④ The stabilizer optical system actuator moves the system in parallel in response to the drive signal.

⑤ The drive status of the stabilizer optical system is converted into a detection signal by the location sensor and detection circuit both installed on the Image Stabilizer unit, and this signal is then transmitted to the microcomputer.

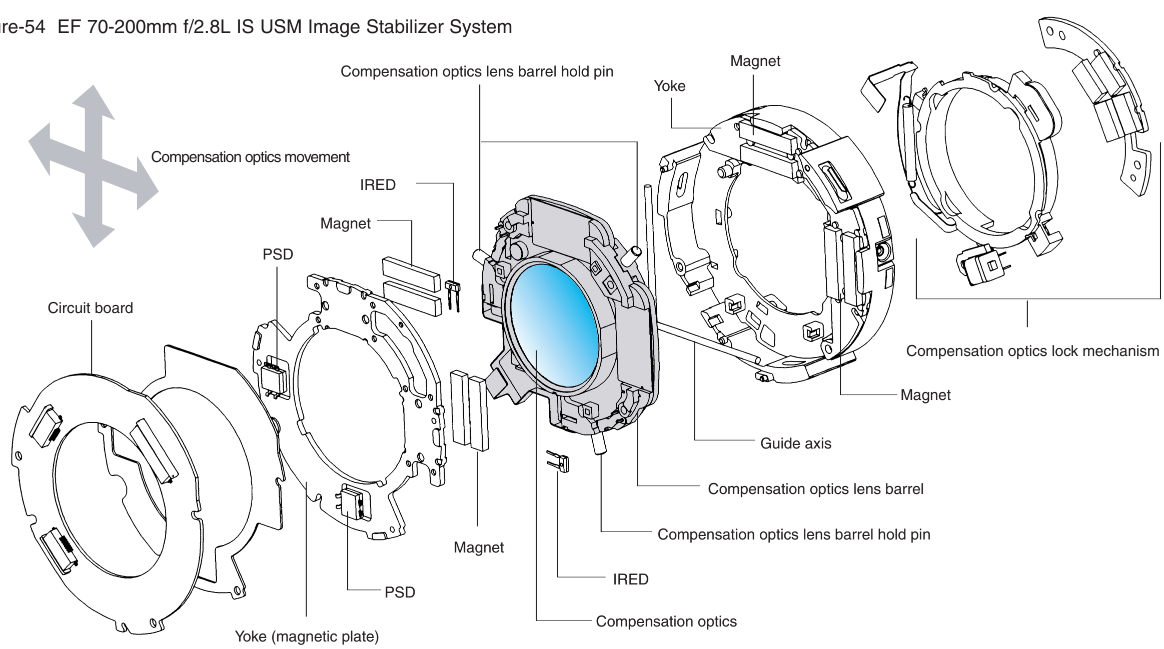
⑥ The microcomputer compares the drive signal referred to in 3 with the detection signal referred to in 5 and performs feedback control, thus increasing the controllability of the stabilizer optical system. This microcomputer, the first high speed 16-bit type in an EF lens, can simultaneously control image stabilization, USM, and EMD. (Figure-56)

Photo-22 Image Stabilizer Unit

Image Stabilizer Mode 2

The stabilization characteristics of the Image Stabilizer described above are set so that it is most effective when photographing stationary subjects, but when panning of a moving subject is attempted, shake-return may affect the finder image, interfering with framing. This occurs because camera movement such as panning is judged to be shaking, activating the image stabilizer.

Figure-54 EF 70-200mm f/2.8L IS USM Image Stabilizer System



To resolve this problem, Canon developed Image Stabilizer Mode 2. In this mode, if large movement such as panning continues for a preset time, image stabilization in the direction of the motion is shut off. As this stabilizes the finder image during movement, accurate framing is possible. In Image Stabilizer Mode 2, if you are panning, image stabilization continues vertically relative to the movement of the camera, making it possible to control vertical shaking during panning. (Figure-55)
Image Stabilizer Mode 2 was introduced for the first time on the EF 300mm f/4L IS USM. It has since been mounted on other lenses, mainly telephoto/tele-zoom lenses.

Tripod-compatible Image Stabilizer

When the first IS lenses were used with a tripod, the image stabilizer malfunctioned, requiring the photographer to turn off the image stabilizer function. However, the EF 300mm

Figure-55 Image Stabilizer Mode 2 stabilization control

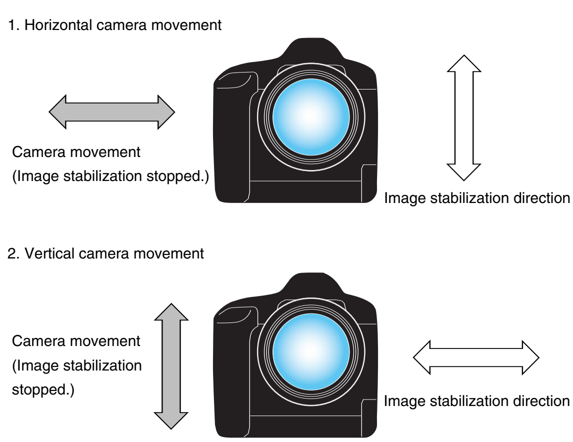


Figure-56 Image Stabilizer System Process Flow

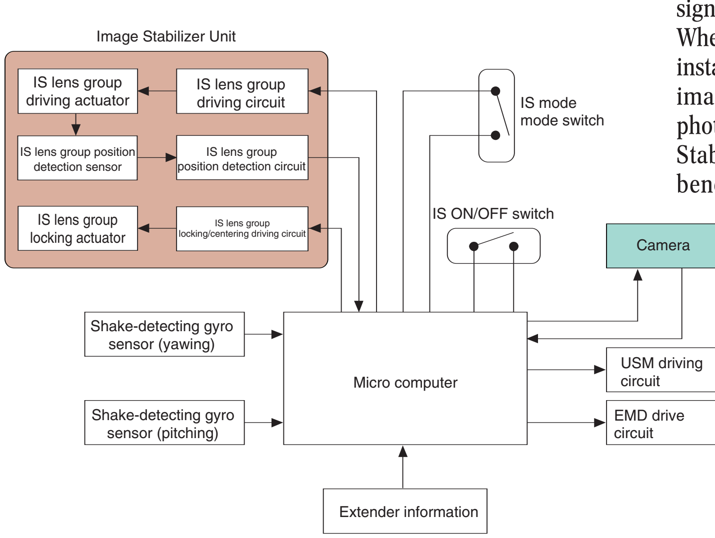
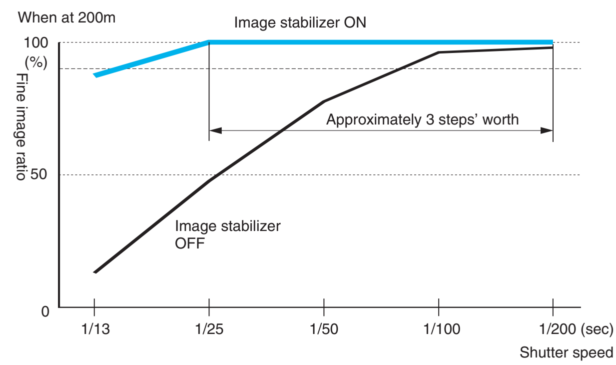


Figure-57 EF 70-200mm f/2.8L IS USM Image Stabilizer Effect Graph



f/2.8L IS USM and other new models in the super telephoto L type IS series are equipped with an image stabilizer that can be used with a tripod, which prevents malfunctioning. Since the system uses a vibration gyro to automatically detect when the camera is mounted on a tripod, the photographer can focus on the photograph without having to think about turning the stabilizer on and off. And when a monopod is used with any lens in the IS series, image stabilization is identical to that achieved during hand-held photography.

Effect of Image Stabilization

The image stabilization function for EF lenses was first used on the EF 75-300mm f/4-5.6 IS USM in 1995. Converted into shutter speed, the effect of image stabilization equals about two steps. With a 300mm telephoto lens, it permits hand-held photography at 1/60 second. Later, through improvements to the design of the image stabilizer unit and the algorithm used, the performance of the effect was raised even further, to three steps, with the EF 70-200mm f/2.8L IS USM which went on sale in 2001, and to 4 steps with the EF 70-200mm f/4L IS USM which went on sale in 2006. The lower limit on hand-held photography at slow shutter speeds was thus reduced significantly.
When the Image Stabilizer Mode 2 is on and an extender is installed, it provides equivalent image stabilization effects. The image stabilizer function is also effective during close-up photography and photography in unstable places. The Image Stabilizer function that brings photographers these many benefits will be installed on many more EF lenses as a standard EF lens technology, evolving even further for use in even more lenses in the future.

16 New Possibilities in Optical Systems: The DO Lens (Multi-Layered Diffractive Optical Element)

Diffractive optical elements are, as the name states, optical elements applied to the phenomenon of diffraction. They attracted much attention for their ability to adjust for chromatic aberration, better than UD or fluorite lenses despite being asymmetrical in form. Incorporation of such elements into photographic lenses was nevertheless difficult, mainly due to problems of diffraction flare. Canon solved this problem by developing its uniquely structured “DO lens” and by becoming the first lens manufacturer in the world to incorporate this lens in a photographic lens. The first model to employ this lens—the EF 400mm f/4 DO IS USM—is a super telephoto lens achieving both compact and lightweight specifications, and outstanding image quality.

■ Diffraction

This is a phenomenon in which light waves pass around the edges of an object and enter the shadowed area of that object. Diffraction flare is a common diffraction phenomenon seen in photographic lenses when the aperture diameter is small. This phenomenon is caused by the wavelike nature of light.
While diffraction flare is actually harmful light rays that adversely affect picture quality by passing around the back of the diaphragm, the same principle can be used to control the direction of the light.
For example, when light enters two slits which are very close together, the same type of flare is produced as when using a small aperture. In this case, as shown in the figure below, a certain direction emerges, along which it is easier for the light waves to propagate. Here, the direction in which the wave movement becomes more intense is the direction in which the phases of the light waves spreading out from the two slits line up. For this reason, the light waves propagate, causing each other to become more intense in several directions, one direction in which the wavelengths shift one cycle and overlap, one direction in which they shift two cycles and overlap, and so on. The direction in which the wavelengths shift one cycle (one wavelength) and overlap is called the primary diffraction, and this slit construction is called a diffraction lattice. The features of the diffraction lattice include:
① Changing the spacing between the slits (the lattice period) changes the direction of diffraction.
② The larger the diffraction cycle, the larger the amount of diffraction (the “diffraction angle”).
③ Light with longer wavelengths has a large diffraction angle.

Figure-58 Diffraction

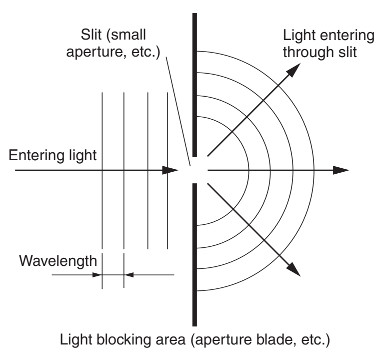
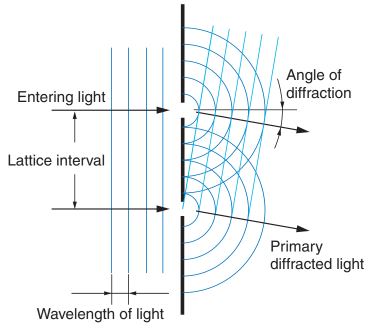


Figure-59 Principle of diffracted light generation



■ Single-Layer Diffractive Optical Elements

Since diffraction lattices utilising a slit construction (amplitude-type diffraction lattices) generate diffracted light by blocking light, they cannot be employed in optical systems. A phase-type diffraction lattice was suggested, in which the lattice would be in the shape of an axe-blade, and thus not block any light. A phase-type diffraction lattice would generate diffracted light by forming the diffraction lattice in a concentric circle, like a Fresnel lens. By partially changing the period of the lattice (the spacing of the lattice), an effect identical to that of an aspherical lens could be achieved, making it possible to compensate for a variety of issues, including spherical aberration.
As mentioned above, the light exiting the diffraction lattice has a larger diffraction angle at longer wavelengths. In other words, light with a longer wavelength forms an image closer to the diffraction lattice, while light with a shorter wavelength forms an image farther away. In contrast, for light entering a refraction lens (convex lens) with a positive power, light with a shorter wavelength forms an image closer to the diffraction lattice, while light with a longer wavelength forms an image farther away. This means that the order of the chromatic aberration is reversed with a refractive lens and a diffractive optical element. If they are combined, they cancel out one another’s chromatic aberration, making possible an effective chromatic aberration correction. Unlike the previous chromatic aberration compensation technique, which combined convex and concave lenses, the new one is achieved using only convex lenses, making it possible to weaken the power of each element group in the lens, thereby permitting effective correction of other aberrations besides colour.

Photo-23 DO lens

Figure-60 Construction of DO lens (illustration)

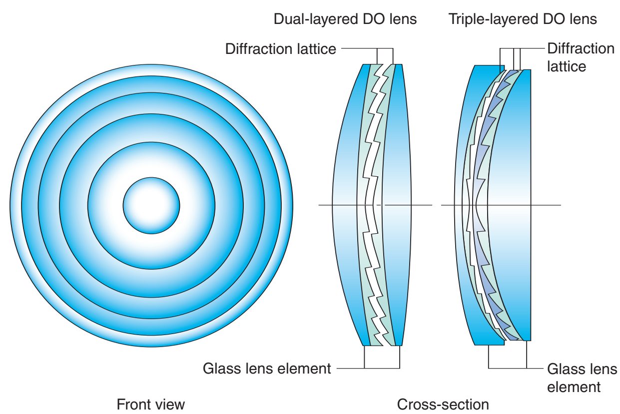


Figure-61 Chromatic Aberration Correction Principal by DO lens

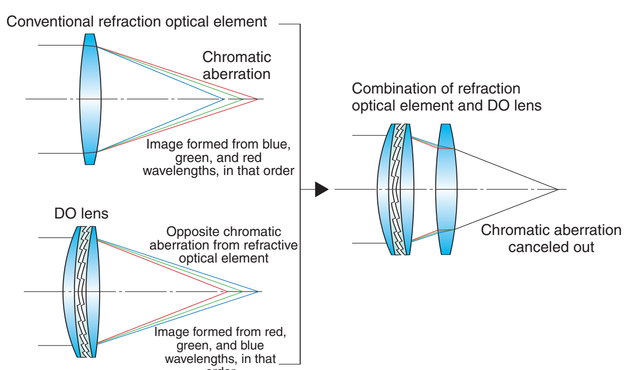
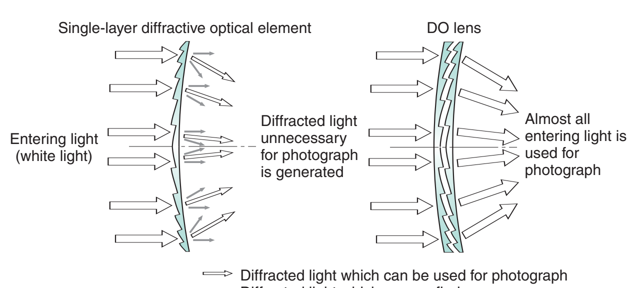


Figure-62 Difference in Diffracted Light between Single-Layered Diffractive Optical Element and DO lens



Development of the DO Lens

Single-layer diffractive optical elements, while used in the optical readers for CD and DVD players, which use lasers, could not be used in the field of photographic lenses. This is because, unlike laser light, the light used by photographic lenses (the region of visible light) is made up of a number of different wavelengths. To use diffractive optical elements in a photographic lens, all the light entering the lens must be 100% diffracted. The DO lens, with its multi-layered diffractive structure, was developed as a method for transforming all regions of visible light into photographic light. The DO lens in the case of the EF 400mm f/4 DO IS USM incorporates two single-layer diffractive optical elements with concentric circle diffraction lattices, which are arranged so that they face one another (Figure-62). Because the light that enters the lens does not generate needless diffracted light, the DO lens succeeds in using almost all of this light as photographic light, making application to photographic lenses possible. The actual DO lens is made up of a spherical glass lens and a diffraction lattice formed in a mold using a special plastic on the surface. The thickness of the diffraction lattice is only a few micrometers, and the lattice period gradually changes from a few millimeters to a few dozen micrometers. In order to form this diffraction lattice, the precision of the diffraction lattice period, height, and positioning has to be controlled to units smaller than a micrometer. Many technologies were used to achieve this level of precision, including a 3D ultrahigh-precision micro-fabrication technology developed specifically for this purpose, as well as the replica aspherical lens manufacturing technology gained with the EF lenses, high-precision positioning technology, and much more.

Photo-24 With DO lens installed

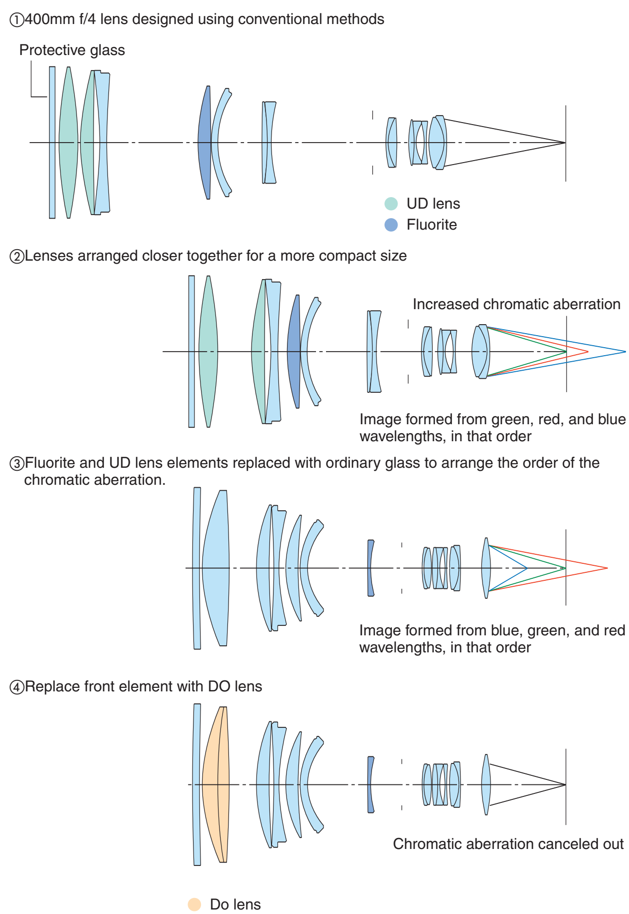
Making Smaller Lenses

Using the EF 400mm f/4 DO IS USM as an example, let us take a look at the process of how telephoto lenses are made more compact by applying a DO lens.

With diffractive optical elements, the locations where the image is formed along the optical axis for wavelengths of 400nm, 500nm, and 600nm will line up at equal intervals. However, since optical glass has non-linear dispersion characteristics, the locations of image formation for each wavelength will be unequally spaced for refractive optical elements. Accordingly, the following methods were used to maximise the effectiveness of the chromatic aberration compensation of the DO lens.

Figure-63-① shows a 400mm f/4 lens designed using only

Figure-63 Principle behind Smaller Optics Thanks to DO lens



conventional refractive optical elements. If, as shown in Figure-63-②, the refractive power of each lens element is raised, and the lens elements are placed closer together in order to make the whole lens more compact, the chromatic aberration—particularly for blue—degenerates to a remarkable degree. This means that inclusion of a diffractive optical element will be insufficient to compensate for the chromatic aberration. So, as shown in Figure-63-③, the dispersion of each lens element was optimised to make the chromatic aberration line up in order by wavelength. Lastly, as shown in Figure-63-④, by placing a DO lens with the appropriate refractive power in front of the front lens element, chromatic aberration compensation is complete. Thus, compared with optical systems designed only with conventional refractive optical elements, the EF 400mm f/4 DO IS USM achieves a 27% reduction in length (317mm → 232.7mm) and a 31% reduction in weight (3000g → 2080g), making it indeed a compact, lightweight lens (Figure-64).

Improved Picture Quality

Since the DO lens placed in the front group almost completely cancels out the chromatic aberration generated in the refractive lens group, residual chromatic aberration is suppressed to extremely low levels. And since diffractive optical elements are also characterised by aspherical behavior, spherical aberration is also efficiently corrected, achieving exceptional image quality with high resolution and contrast.
DO Lens will be included in many EF lenses in the future as innovative optical elements which outperform fluorite, UD, and aspherical lenses.

Triple-Layered DO Lens

In principle, the DO lens carries the potential to contribute to more compact zoom lenses, as well. However, it would be difficult to employ the dual-layered DO lens used in the

Figure-64 Compact Single-Focal Length Lens Thanks to DO Lens

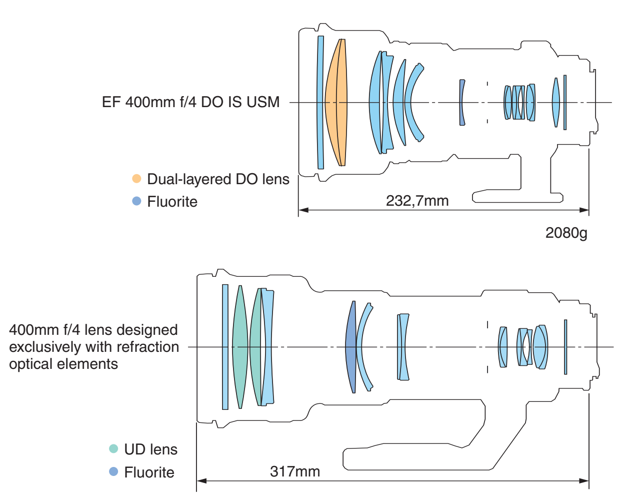


Figure-65 Compact Zoom Lens Thanks to DO Lens

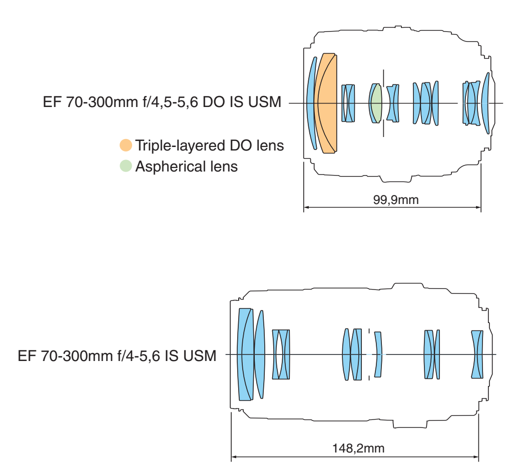
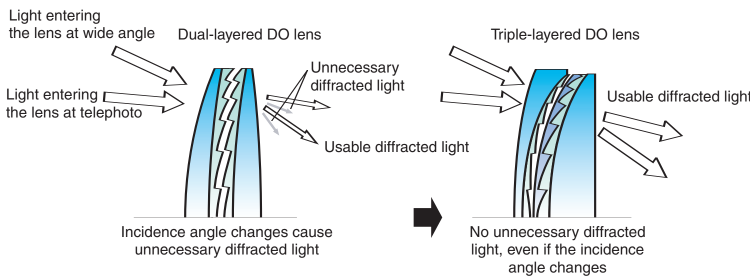


Figure-66 Differences in Diffraction between Dual-Layered and Triple-Layered DO Lenses



EF 400mm f/4 DO IS USM in zoom lenses for the following reasons.

In single focal-length lenses such as the EF 400mm f/4 DO IS USM, the angle of light entering the lens (incidence angle) is fixed for the most part. In zoom lenses, however, because the angle of view changes in accordance with the focal length, the incidence angle also undergoes significant change. With the conventional DO lens, changes in the incidence angle would cause the generation of diffracted light that is not needed for photography, which would become flares and greatly reduce imaging performance. To resolve this problem, Canon developed a triple-layered DO lens, a new type of DO lens with three diffractive lattices arranged on the optical axis, which can compensate for changes in focal length.

By using three layers of diffractive lattices, even if the angle of light entering the DO lens changes, no unnecessary diffracted light is generated, and almost all of the incident light can be used as photographic light (Figure-66).

The triple-layered DO lens was first applied in the EF 70-300mm f/4.5-5.6 DO IS USM lens. Below is an explanation of the processes by which this lens was made compact.

① The refractivity of each lens element in the base lens system (EF 75-300mm f/4-5.6 IS USM) was raised, and the space between individual lenses was narrowed.

② Chromatic and spherical aberration, which were worsened by making the lens more compact, were simultaneously compensated for by the triple-layered DO lens placed in front of the forward lens.

As a result, the EF 70-300mm f/4.5-5.6 DO IS USM is 30% shorter (142.8mm→99.9mm) than the conventional EF 75-300mm f/4-5.6 IS USM (Figure-65), which has only a refractive optical elements, and it compensates for any remaining chromatic and spherical aberration while achieving high image quality comparable to that of L lenses.

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