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Image Stabilization
by Larry Thorpe

Preface

Laurence J. Thorpe is National Marketing Executive for Broadcast & Communications, Canon USA Inc. He joined Canon U.S.A.'s Broadcast and Communications division in 2004, working with with networks, broadcasters, mobile production companies, program producers, ad agencies, and filmmakers. Before Canon, Larry spent more than 20 years at Sony Electronic, begining 1982. He worked for RCA's Broadcast Division from 1966 to 1982, where he developed a range of color television cameras and telecine products. In 1981, Thorpe won the David Sarnoff Award for his innovation in developing the first automatic color studio camera.

From 1961 to 1966, Thorpe worked in the Designs Dept. of the BBC in London, England, where he participated in the development of a range of color television studio products.

Larry has written more than 70 technical articles. He is a lively and wonderfully articulate speaker, in great demand at major industry events. This article began as a fascinating lecture at NAB 2010.

Photo by Mark Forman.

Introduction

Lens and camera shake is a significant cause of blurred images. These disturbances can come as jolts when a camera is handheld or shoulder mounted, from vibrations when tripod-mounted on an unstable platform or in windblown environments, or as higher vibration frequencies when operating from vehicles, boats, and aircraft.

A variety of technologies have been applied in the quest for real-time compensation of image unsteadiness.

1. Mechanical: where the lens-camera system is mounted within a gyro-stabilized housing. This can be very successful for certain applications.

2. Electronic: here, the unwanted movements of the image are sensed electronically and corrected by counter shifts in the readout of the image sensors, or by correction shifts in the reading of digital memory.

3. Optical: A third method intercepts the unwanted image movements and applies a compensating optical correction that cancels out the inadvertent optical image shifts.

Two Different Approaches to In-Lens Optical Stabilization

In the mid 1980s, Canon embarked on two separate approaches to in-lens optical stabilization. They differ in the way the optical elements are controlled:

1. A flexible prism intercepts the light rays entering the lens. This is known as the Vari-Angle Prism Image Stabilization (VAP-IS).

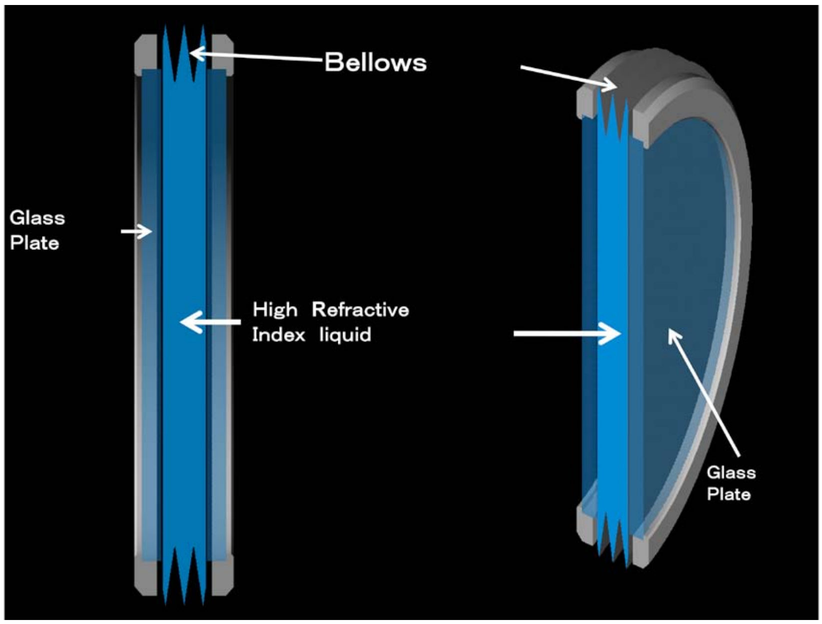
2. A moveable lens group within the lens. This is called Shift Lens Image Stabilization (Shift-IS)

They both share the same associated control system principles. They detect lens motion, create control signals proportional to that motion, and, in turn, drive actuators that manipulate the optical elements.

Variable-Angle Prism Image Stabilization (VAP-IS)

The variable angle prism technology was originally developed by Juan de la Cierva, founder of the Dynasciences Corporation in Philadelphia, and inventor of the Dynalens.

The Variable-Angle Prism is a truly ingenious innovation. It consists of two precision glass plates mounted in a hermetically sealed arrangement that contains a special high-refractive index liquid. The housing has a flexible bellows made of a multi-plastic material. The bellows, the liquid, the technique of filling and hermetically sealing the assembly—all constituted a design challenge spanning some years. Ensuring the integrity of the prism's operation over a wide temperature range of -27 degrees F to + 176 degrees F, and tens of millions of reliable operations, led to high sophistication in materials developments and related manufacturing processes. These continued over the decade that led to the HDTV lens. Here's what a Vari-Angle Prism looks like:



Variable Angle Prism-IS in the New HDTV Portable Lens HJ15ex8.5B

The latest embodiment of Variable Angle Prism Image Stabilization technology was applied to a new Canon portable high definition lens. It includes a variety of advances over the technologies employed on the earlier generation lens. These include improvements to the Vari-Angle prism itself and to the overall feedback control loop.

The Vari-Angle Prism unit itself, its mounting units, control actuators and drivers, the microcomputer, and the two lens motion sensors are all housed within the enlarged housing near the front of the lens (with the gold "Image Stabilizer" label on it). The analog control loop that formed the first generation VAP-IS lenses has been advanced to an all-digital control system that has elevated the control loop speed twenty times.

For the new HJ15ex8.5B lens, a 100:1 reduction in image unsteadiness (shake) is achieved over a disturbance frequency range of 1.5 – to almost 10Hz.

The Correcting Action of Variable Angle Prism Image Stabilization

How does a Variable Angle Prism correct image unsteadiness? In the pictures below, imagine you're shooting from a tripod on top of a truck. The engine is running, which creates vibration. Your lens is vibrating up and down.

The top drawing in Figures 2 and 3 shows the lens in its normal state. The red line represents the central ray of that optical image landing in the precise center of the imager.

In the middle drawing of Figures 2 and 3, the vibration causes that central light ray to be knocked up or down. If a wedge prism is in place at the front of the lens, and its wedge angle is appropriately altered (by a correction feedback loop), then the central light ray will be deflected back to its correct central position on the camera imager. Note the two different adjustments of the Vari-Angle Prism that are required to deal with the separate up and down movements of the lens. The same principle applies for horizontal deviations. The system is brilliantly simple in concept – but the devil of challenge surely lay in the technical details.

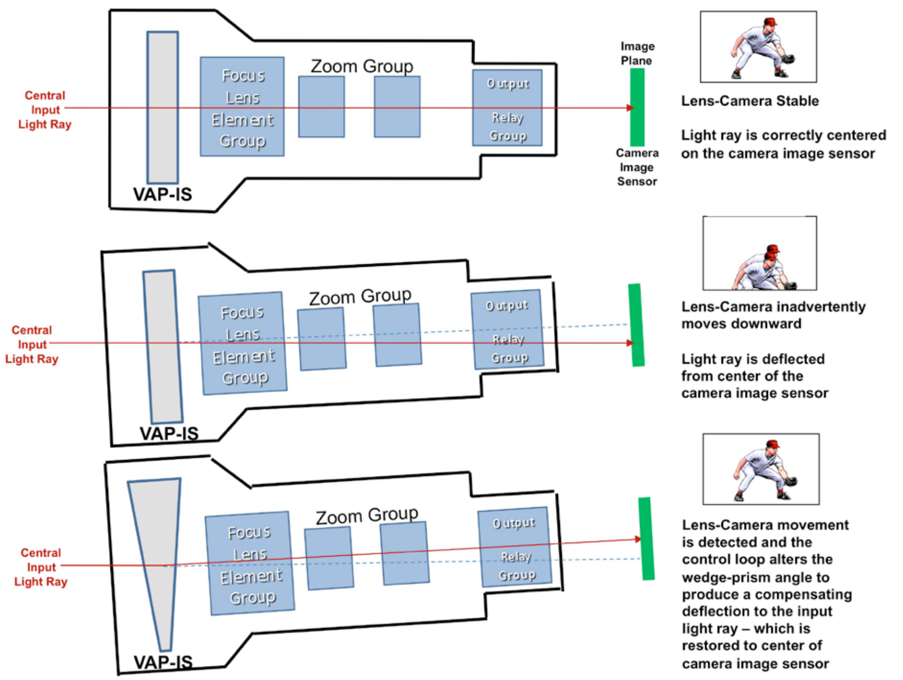


Figure 2: Showing correcting action when lens vibration is in downward direction

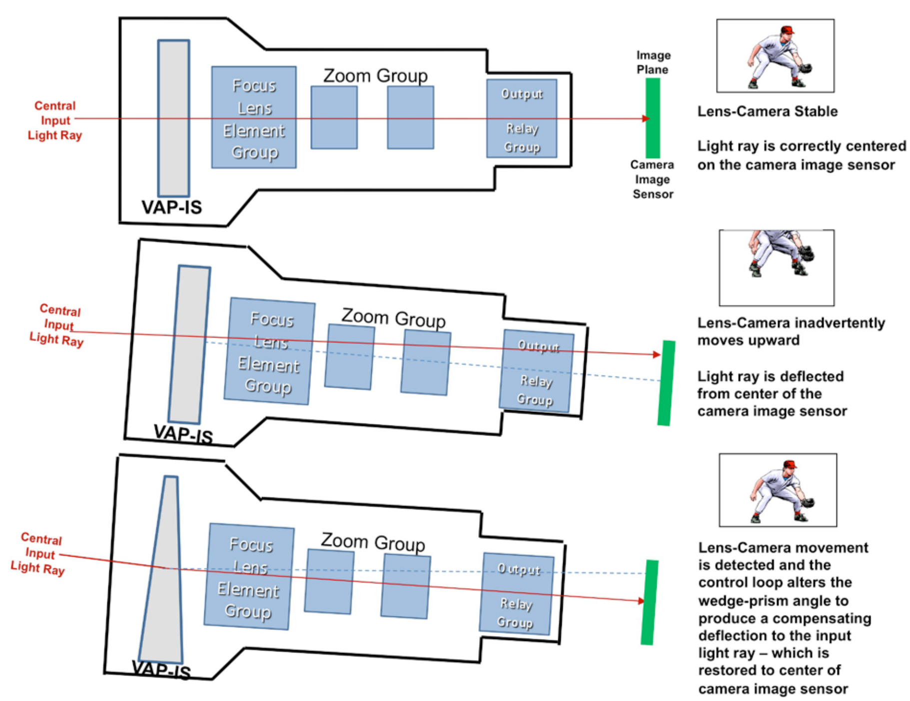
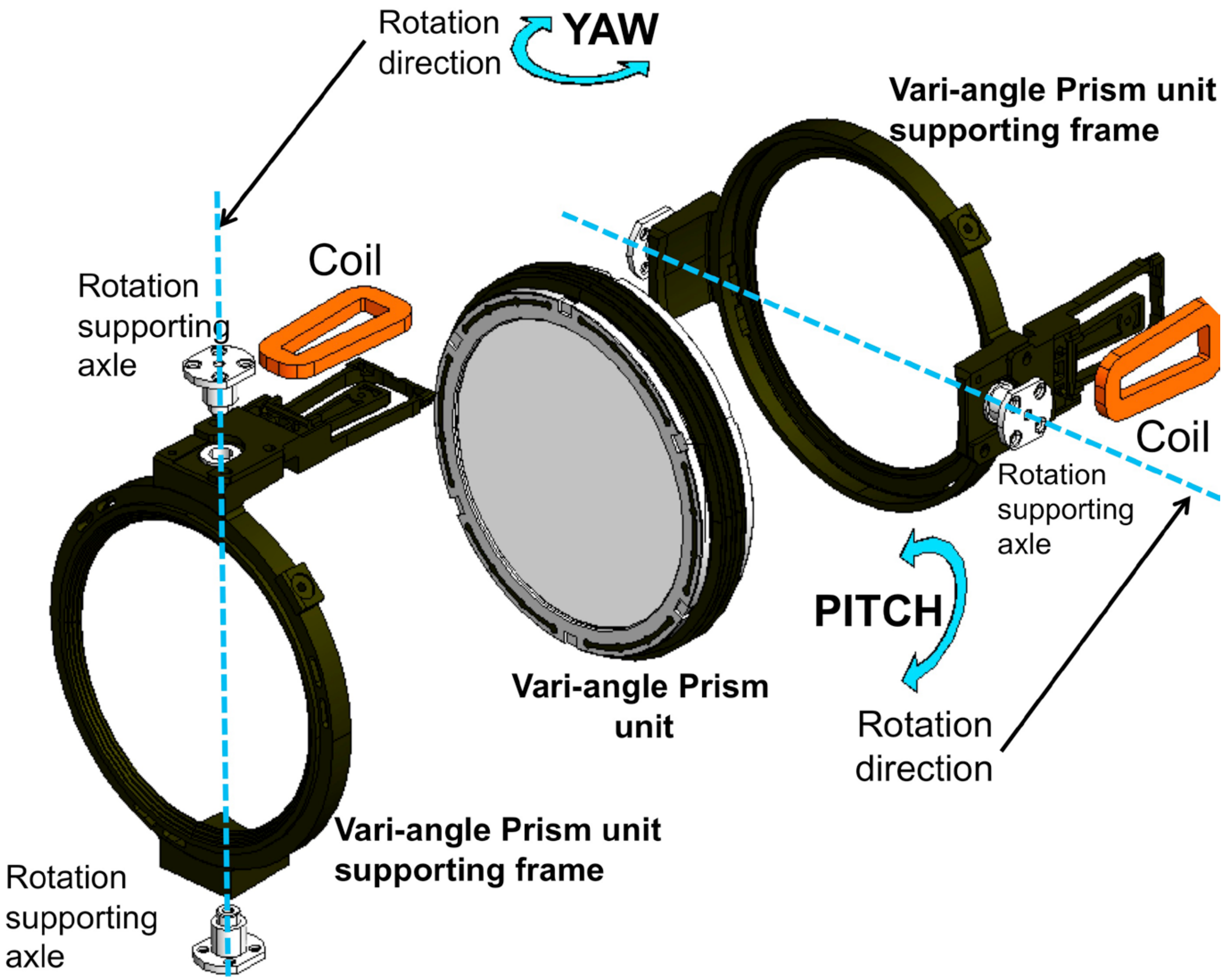


Figure 3: Showing correcting action when lens vibration is in upward direction

Practical Implementation of the Vari-Angle Prism System



This is an exploded view that shows the Vari-Angle Prism unit centered between the two metal supporting frames that actually grip the two metal outer rings of the prism itself. Both of the supporting frames can pivot on supporting axles. One pivots on a vertical axis (imparting a YAW or horizontal control), and the other pivots on a horizontal axis (a PITCH control).

The two pivoting actions are driven by the rotary movement of two coils that are mounted on non-magnetic armatures. These coils are free to move within metallic enclosures having a fixed strong permanent magnetic field. The combination of the coil and magnetic field constitute a Voice Coil Motor (VCM)—so called because of the way a coil of wire creates a magnetic field that drives a loudspeaker. If DC current is fed to the "voice coil", the coil will be physically displaced in proportion to the current. Because the coil is wedge-shaped and is attached to a pivot point, its motion will be rotary. It is this rotary actuation that imparts the pivoting controls required for the requisite "squeezing" of the Vari-Angle Prism.

Voice coil motors have an actuator with excellent control characteristics when movement with precision force is required over short distances within an electronic control system. The voice coil motor can develop a strong force in either direction by reversing polarity of the exciting current through the coil. If the coil is of low inductance very fast cycle times are achievable. These are all attributes which are central to the successful implementation of a reliable and flexible stabilization system. For a correcting control system that can actuate the Vari-Angle Prism with the requisite rapidity and precision required for close to real-time removal of image shake, a closed loop feedback control system must be realized where all elements of that servo system function with high precision at very high speed. In particular, the transient response of the feedback control loop must be critically damped with particular attention paid to elimination of any overshoots or backlash in the actuators controlling the movements of the Vari-angle Prism unit. The voice coil motor action perfectly ensures this requirement.

The heart of the all-digital feedback control loop includes a high-speed microcomputer that accepts, analyzes, and processes the electronic information from the motion sensors, sophicated control algorithms, and ability to operate under different conditions.

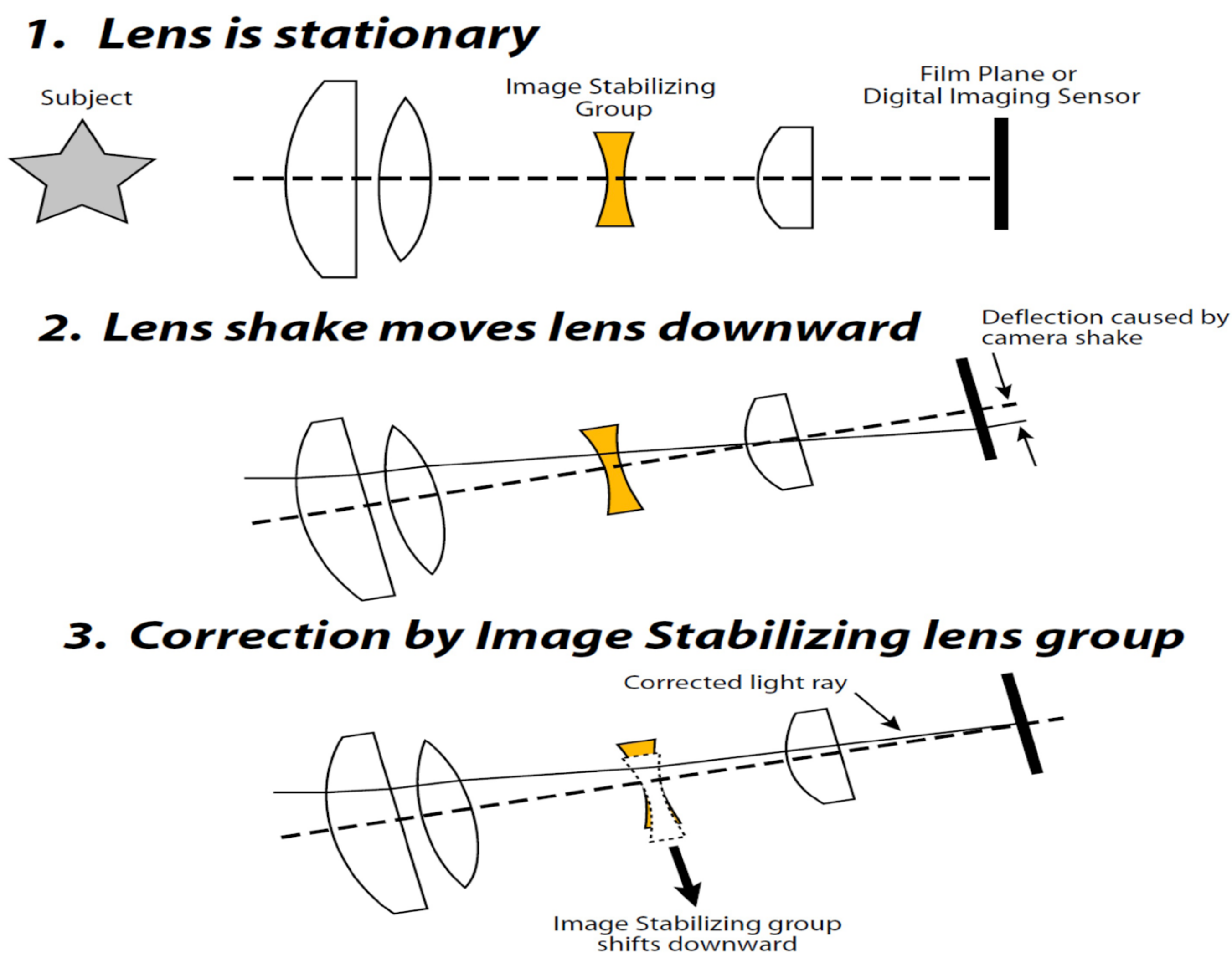
Shift Image Stabilization

A second technological approach to optical image stabilization was undertaken by Canon R&D a few years following initiation of the Variable Angle Prism-IS project. The challenge of long focal length lenses spurred development of this alternative Shift-IS technology.

For digital SLR cameras, many of the associated lenses have progressively increased in focal length to accommodate the extremely wide range of shooting environments in sports, documentaries, news etc. Separately, in broadcast television field cameras, the global demands for exterior broadcast coverage – especially sports coverage – has steadily extended zoom ratios to three digits.

The Shift-IS technology lends itself very well to correcting modest amplitude disturbances and vibrations in those long focal range lenses. In this technology, a lens group is placed near the rear of the lens system and the correcting action entails a horizontal or vertical (or both) physical shifting of that lens group to implement the requisite change in the path of the light rays.

The correction principle is explained in the following figure, outlining the correcting action of the Shift-Lens when the lens-camera system is subjected to a sudden physical disturbance.



Shift Image Stabilization in Canon Still Lenses

The first introduction of Shift-IS technology was in the Canon EF lens EF 75-300mm f/4-5.6 IS USM, which was announced in 1995. There are now approximately 25 IS lenses in the EF and EF-S line-ups with Shift-IS stabilization.

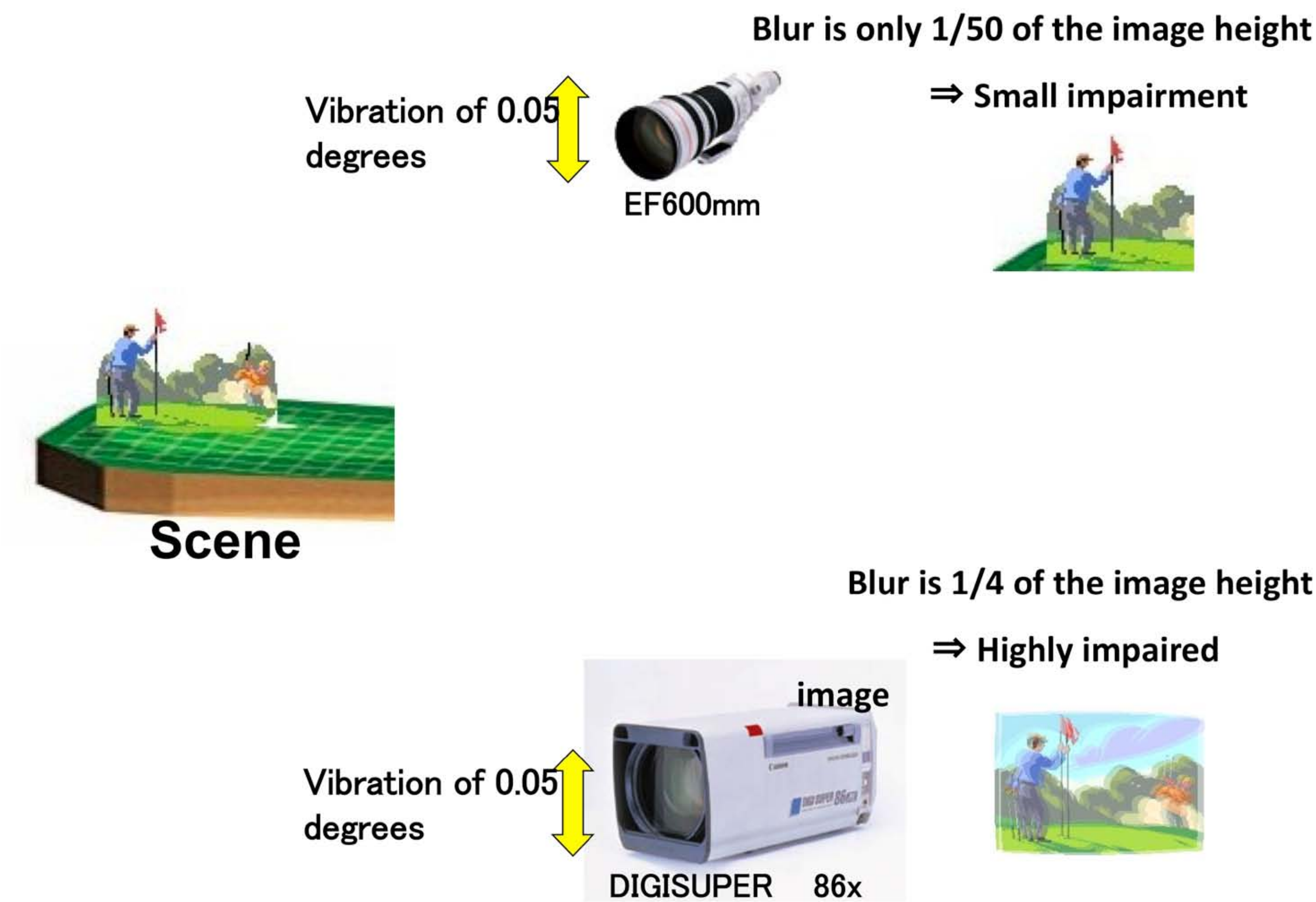
Canon EF 70-300mm f/4-5.6L IS USM lens

The EF 70-300mm f/4-5.6L IS USM lens was redesigned in 2010. An updated optical image stabilization system compensates for camera shake up to an equivalent of four full shutter-speed steps, a full step improvement compared to earlier EF 70-300mm lenses. The lens features two UD ultra-low dispersion glass elements for enhanced sharpness, L-series weather and dust sealing for shooting in harsh conditions, improved mechanical design, and streamlined ergonomics to help avoid inadvertent mode switch operation. A sophisticated floating system optical formula optimizes image quality at all distance settings and reduces minimum focusing distance by more than a foot.

Shift Image Stabilization in New 400 mm f/2.8L IS II USM lens

The Canon EF 400mm f/2.8L IS II USM is the 5th generation in Canon's 400mm f/2.8 series. Canon has reduced the overall weight of the lens by 28% from 189.4 oz to 135.8 oz, making it Canon's lightest weight 400mm f/2.8 lens ever. The Image Stabilizer provides an equivalent of approximately four full shutter speed steps of shake compensation and has been enhanced through the incorporation of a rolling-ball-friction system in place of sliding parts in the compensation optics barrel.

Sensitivity Of Image Shake In Relation To Focal Length



This picture shows the sensitivity of image shake in relation to focal length. It illustrates the effect of a low amplitude vibration on the image unsteadiness created by a 35mm long zoom lens and a 2/3-inch HDTV field lens when both are operating at maximum focal length.

It assumes a small level of physical vibration having a deflection of 0.05 degrees applied to two lenses – one, a 35mm long-zoom EF lens, and the second, is a 2/3-inch long-zoom field lens. For the EF lens, this level of vibration would translate to image unsteadiness in the camera output video of about 1/50th of the image height – still a quite useable picture. However, for a broadcast HDTV 2/3-inch field lens with an 86:1 zoom ratio, that same level of vibration would produce an optical image disturbance that is a 1/4 of the picture height when the lens was set to maximum focal length and the 2x extender switched in. This would create a totally unacceptable HDTV image.

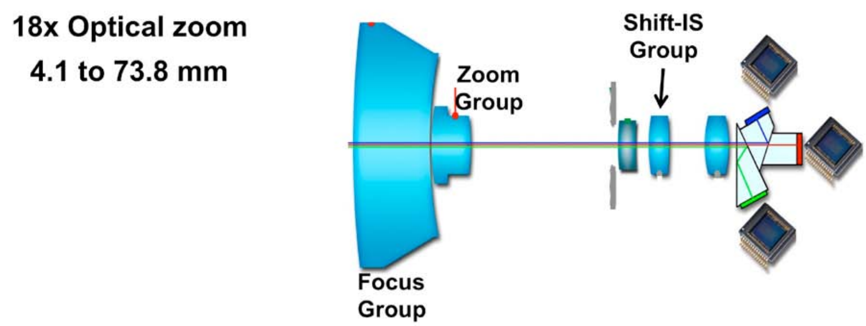
The Shift-IS system is particularly well-suited to correcting for higher vibration frequencies – such as might be encountered on a tripod when a wind is blowing, or when a long-zoom field lens is mounted on top of a tower as is common at major sporting events. The tremors introduced by hand-holding a camera occur more frequently at very low frequencies – over the range of a few Hz. The tower mounted lens-camera typically has a high vibration occurrence in the neighborhood of 4 – 5Hz.

The implementation of Shift-IS technology in the long-zoom HDTV lens uses the same basic Voice Coil Motor (VCM) technology as earlier described for the portable lens VAP-IS system. But, important modifications were incorporated. This system has been specifically tailored to control the physically larger lens group with very high speed and high accuracy. Strong magnets rigidly hold the metallic frame housing the shift lens group. The movement of this lens group is accomplished by rapid control of the current through the voice coil.

Similar to the portable lens, two motion sensors within the large field lens detect horizontal and vertical movements of the lens and report these to the microcomputer. Because such a lens entails many lens elements that move under operational control (for focus and especially for zoom) these movements are also reported to the microcomputer. A control algorithm, that has been continuously refined based upon some years of operational experiences, guides the computations made that are ultimately translated into two control current drives directed to the horizontal and vertical VCMs.

Shift-IS Stabilization in New HD Camcorder

At NAB 2010 Canon introduced the XF305/300 professional high definition camcorders. These are three-CMOS cameras with 1/3-inch image sensors. They both have a built-in HD lens with an 18:1 zoom range. This lens incorporates Shift-IS stabilization technology.



Use of Both Stabilization Technologies in Digital Camcorders

Both Variable Angle Prism-IS and Shift-IS stabilization systems have been used across a range of Canon professional and consumer digital camcorders (both HD and SD):

Relative Merits of Variable Angle Prism-IS and Shift-IS Stabilization

The primary attribute of the VAP-IS system is the large correction angle that can be achieved. This was considered important in broadcast portable lenses because of the extensive amount of hand-held and shoulder-mount shooting that can be entailed in ENG shooting. To fully capitalize on that large correction angle, however, the wedge prism must be placed at the front end of the overall lens. A modest curtailment in sensitivity is incurred. The maximum relative aperture of a typical high-end 2/3-inch lens is F1.8 – and this lowers to F2.5 for the HJ15ex8.5B lens. With the VAP-IS system, it is also difficult to maintain high performance stabilization if the lens focal length becomes too long.

The salient advantage of the Shift-IS system is that a high degree of correction can be realized at very long focal lengths. This became especially important when focal lengths of SLR lenses moved into the hundreds of millimeters, and HDTV field lenses became longer than 1000mm. The degree of correction is also greater for modest amplitude vibrations at higher frequencies – such as is commonly encountered when lens-camera systems are mounted on tripods.

The Shift-IS system allowed an elegant integration within the overall optical system of the long-zoom HDTV field lenses and had no adverse effect on the essential operational optical performance parameters of Sensitivity, Focal length, and the accuracy of the optical axis. Integration of the IS electronics within the overall lens electronic control system produced no increase in overall power consumption. Nor were there any alterations to the physics of the overall lens – in terms of length, center of gravity, or weight.

Historical notes by Jon Fauer:

I wrote the following in "Shooting Digital Video," published by Focal Press in 2001:

Image Stabilization.

When you have a handheld camera, of little apparent weight, appended to your hand with a thin leather strap, every move you make and every breath you take will show up on screen in headache-inducing magnification. The remedy for video induced nausea is image stabilization. There are two kinds: optical and digital. The idea is to shift the image in the opposite direction of the camera's movement. Suppose you're shooting a Western. The bad guy is galloping in front of you on his horse. You're shooting from a camera car. The car hits a bump. Your arm bounces up. The bad guy is no longer in frame. The only thing in frame are a couple of buzzards circling overhead, waiting for the imminent demise of your career. Had you turned on your image stabilizer, you would have been saved. When your arm bounced up, actuators would have told the lens elements to aim down, keeping the cowboy centered in frame.

Optical Stabilization Optical stabilization dates back to the 1960s and 1970s when two optical-mechanical devices were invented: the Dynalens and the ARRI Image Stabilizer. Both attached to the front of existing lenses; they were large and heavy. Built-in gyroscopes adjusted the optical path to compensate for camera movement and shake. The Dynalens was a sandwich of two optical elements with silicon fluid inside. Whenever the camera shook, the elements compensated in the opposite direction. The silicon helped dampen the vibration, but it also degraded the image by diffusing it a little. ARRI's Stabilizer came out a few years later, adapted from British Aerospace technology used in binoculars. It was lighter and didn't soften the image; but wouldn't work on wide-angle lenses. It consisted of mirror pairs that shifted to keep the picture smooth. Consumer camcorders use two similar methods of optical stabilization, but improve the original concept enormously through miniaturization and electronics. Heavy gyros have been replaced by motion sensors and microprocessors.

Dynalens

At the 42nd Academy Awards in 1969, John Wayne won best actor for "True Grit," Maggie Smith for "The Prime of Miss Jean Brodie," best picture and best director went to "Midnight Cowboy," best foreign film was awarded to "Z", William Goldman won for story and screenplay of "Butch Cassidy and the Sundance Kid," and best cinematography went to Conrad Hall, ASC for "Butch Cassidy and the Sundance Kid." And a Sci-Tech Plaque went To Juan De La Cierva and Dynasciences Corporation for the design and development of the Dynalens optical image motion compensator. Dynalenses had been used on major Hollywood pictures, including "Tora! Tora! Tora!"

Juan de la Cierva y Hoces was born in Madrid, Spain in 1929. He was attended the Colegio de Areneros and the Escuela Superior de Ingenieros de Telecomunicación de Madrid. In 1947 he invented a system to record photo finishes for horse racing, which he sold to a Swiss watch company that markets it to this day.

In 1954 de la Cierva was transferred to Cuba, where he designed and constructed the C-54 helicopter in association with the Compañía Cubana de Aviación. Events in Cuba in 1959 prompted his emigration to the US, where he founded Dynasciences Corporation in Philadelphia, PA.

At Dynasciences, he invented and directed the manufacture of many opticial and electro-optical devices, including the Dynalens stabilizer for camera lenses. After working on several classified projects for the US Department of Defense, he returned to Spain and continued developing systems for the horseracing industry. De la Cierva returned to the US in 1979 and continued to develop projects for the Defense Department, including the small C-95 autogyro, a pilotless fly-by-wire observation aircraft with GPS for day or night observation.

Then it was back to Spain in 1997, where he still resides. In 2004, he invented the Heligiro. He is the brother of the historian and former minister of culture Ricardo de la Cierva, and nephew of the inventor of the autogyro, Juan de la Cierva.

Time Magazine wrote about the Dynalens in a Feb 7, 1969 article, Optics: Steadying Images by Bending Light: "In Viet Nam, an Army photographer shoots sharp reconnaissance pictures despite the vibration of his small observation plane. From a shaky and make shift platform in Washington, a TV camera crew gives viewers a clear close-up portrait of Richard Nixon making his inaugural address. In North Miami, a policeman with a television camera takes shots showing distinct facial features of individuals creating a civil disturbance hundreds of feet below his quivering helicopter. In these and dozens of other applications, a remarkable new optical system is providing clear and steady images under circumstances that ordinarily cause blurred photo graphs or jiggling, distorted views.

"In earlier attempts to overcome the problems caused by vibration or rapid motion, the armed forces and movie and TV companies set up their cameras and other optical devices on gyroscopically stabilized platforms that tilted to compensate for any disturbing motion. But the platforms weighed hundreds of pounds and were both expensive and difficult to install. So engineers at the Dynasciences Corp. in Blue Bell, Pa., decided to take a radically new approach. Instead of steadying the viewing instrument, they decided, it might be more practical to stabilize the image by bending light beams from the target so that they would always hit the camera film or the retina of the viewer's eye at the same point.

“Using this concept, the Pennsylvania company developed a portable system that weighs only a few pounds. Mounted like a collar around the lens of a camera or other optical instrument, it steadies the image more effectively than stabilization platforms.

“Tiny Gyroscopes. The key part of the “Dynalens” system is an adjustable prism that is placed in front of the lens. It consists of two circular glass disks, one at each end of a short cylinder formed by a flexible bellows. The inside of the cylinder is filled with a clear liquid, usually alcohol. By tilting one or both of the glass plates, the cylinder can be made wedge-shaped, like a prism. Light beams entering the glass plate at one end of the prism are thus bent and emerge from the other plate at a different angle.

“When an optical instrument is shaken or moved, two tiny gyroscopes in the Dynalens collar sense the motion and send signals that control miniature electric motors connected to the glass plates at each end of the prism. The motors, which respond almost instantaneously to movements of the optical instrument, tilt the plates to change the shape of the prism, thus bending the incoming light beams just enough to compensate for the motion. The result is a clear and remarkably steady image.

“Telescopic Shots. The advantages of the Dynalens system have not been lost on Hollywood studios, which are already using it for filming aerial telescopic shots. TV networks are also equipping their mobile units with the device. And the armed forces are not only using the system for photography and surveillance but are also experimenting with Dynalens-equipped gun sights that remain fixed on their target and keep gun barrels pointed in the right direction, despite any movement of the platform itself.”