An Introduction to the Motion Picture Camera

A basic motion picture camera is a simple mechanical device. In order to understand how a motion picture camera works, it is first necessary to understand what exactly a motion picture is.

A **motion picture** is not actually a picture that moves. Rather it is comprised of a series of still images, that when viewed in rapid succession appear to be moving. How then is it that we are able to perceive motion from a series of still images?

There are two principles responsible for creating the illusion of smooth movement, they are: displacement and persistence of vision.

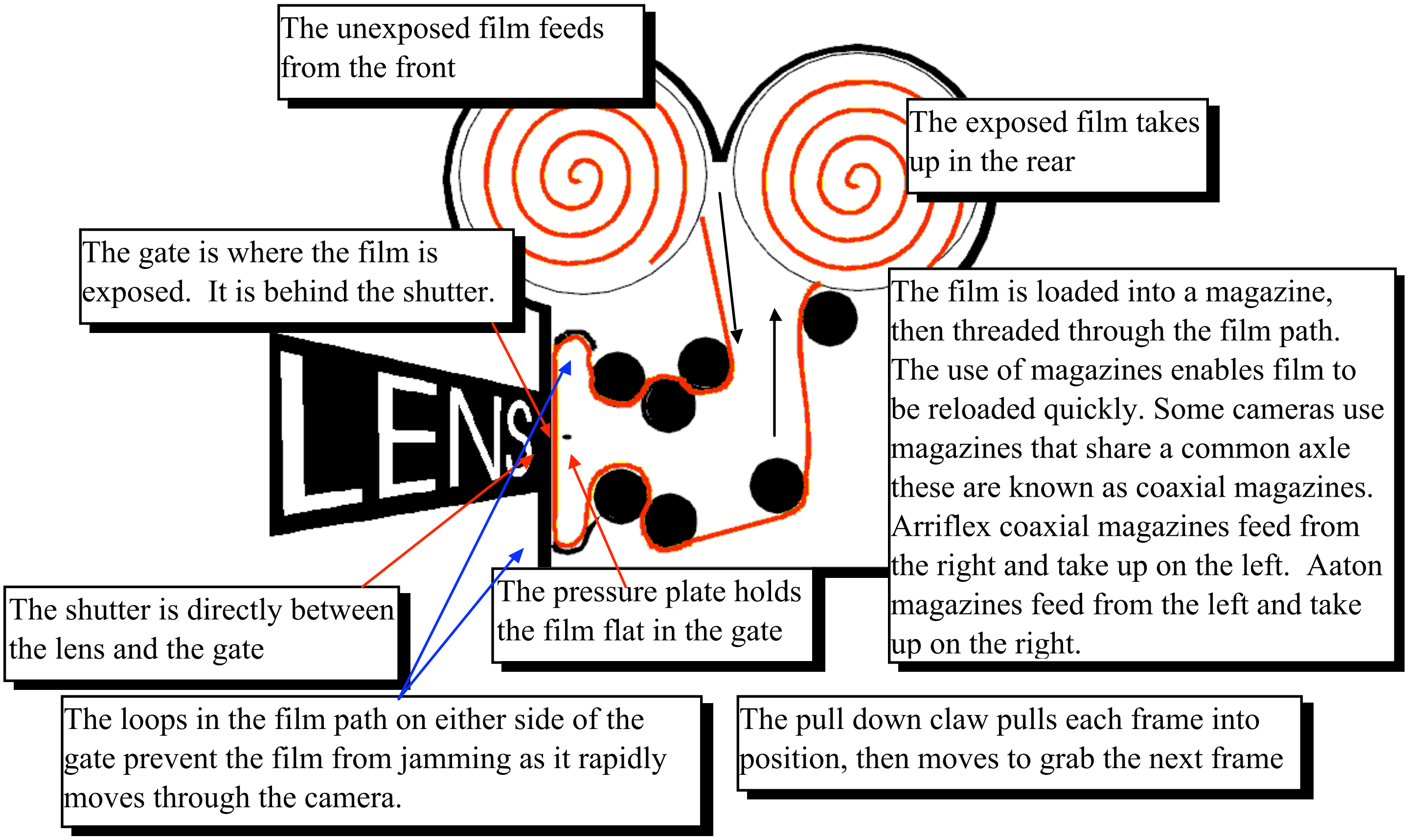
Displacement is the phenomenon that creates the illusion of movement. As the image changes slightly from frame to frame, we recognize the new physical position of the subject in relationship to the rest of the image and fill in the space between the frames so that we believe we are seeing movement.

Persistence of vision is the phenomenon that allows us to see the individual frames as one constant image without the intrusion of seeing space between the frames. The space between the frames is void of light. Our brains make a visual imprint when we see an image and that image lingers until the next image takes its place (providing that the images come close enough to one another that we do not lose the lingering image).

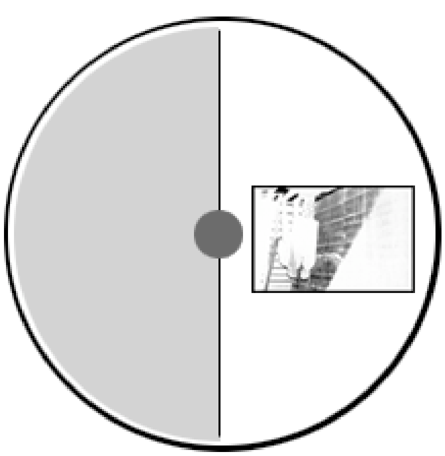
Images that are projected at 12 fps (frames per second) or fewer (slower) exhibit a visible flicker which intrudes into the film goers visual experience and denies the illusion of “persistence of vision” which makes the film appear to be one fluid, moving image. As projection rates increase, the time between the frames is also reduced and therefore the “persistence of vision” is able to smooth out the flicker from image to image. The normal frame rate for films in the US is 24 fps (In Europe it is 25fps).

How then is a motion picture camera able to record in rapid succession, a series of stills photographs that when projected normally appear to be filled with subjects which move so fluidly?

The basic motion picture camera consists of a few key components: The shutter, the gate, the pull down claw, and the pressure plate. All of this is contained in a light proof box with a lens attached to it, though which film passes and during which time, each individual frame is exposed to the proper amount of light for the prescribed amount of time.



**Remember to load the film so the emulsion side faces forward when in the gate.*



The **shutter** is a circular disk which rotates with each frame. The duration of the exposure is dependant on both the frame rate (number of frames each second) and the shutter angle. When the shutter is open, the film in the gate is exposed. When the shutter is closed, the film is advanced to the next frame so that it will be in position when the shutter opens.

If the shutter angle is set for the standard 180^o, then the shutter will be open for half the frame rate. In other words, at 24fps and a shutter angle of 180^o, each frame will be exposed for $1/48^{th}$ of a
second.

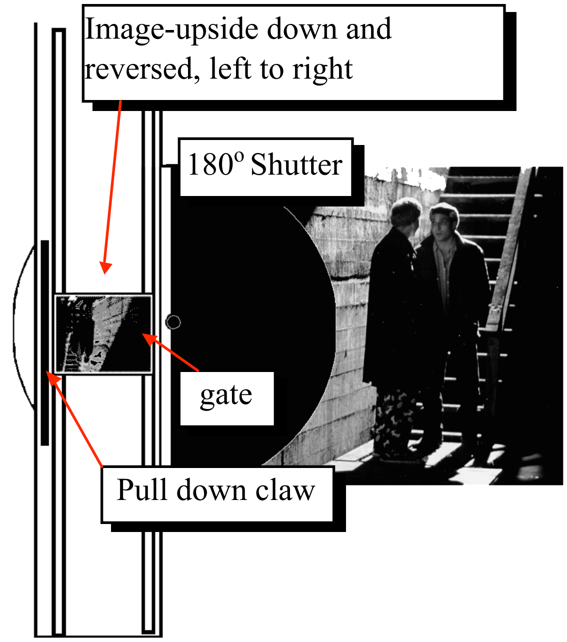
To understand this better remember, at 24 fps, The shutter makes 24 revolutions each second, therefore the time required for the shutter to make one complete revolution is $1/24^{th}$ of a second. Since the shutter angle is 180^o and a circle is 360^o the shutter is only open for 180/360 or $^1/_2$ the time required for a full revolution. $^1/_{24} \times {}^1/_2 = {}^1/_{48}$. The film is therefore exposed for $1/48^{th}$ of a second.

If the shutter angle were 90^o, then the shutter will only be open for $^{90}/_{360}$ or $^1/_4$ of the time required to move a frame of film into the gate, expose it and replace it with the next frame or $1/96^{th}$ of a second.

The **gate** is the opening where each frame of film stops so that it can be exposed to light when the shutter opens. It is directly behind the shutter.

The **pull down claw** actually pulls each frame of film into place and then retracts in time to grab the next frame and pull it into place

The **pressure plate** holds the film firmly in the gate so that across the entire field of the frame, the film lies flat and steady within the depth of focus of the lens. This ensures that there will not be focus problems do to improper film position. This allows each image (frame) to be captured without the motion blur that would occur if the film were moving as it was exposed.



The **loop** in the film path is to allow the necessary slack so that the film can advance, stop, be pulled from the bottom as it is pushed form the top, stop and continue 24 times every second. If the loops are too small, the film will jam and if the loops are too large, the emulsion will scratch as it moves along the path from the feed to the take up side.

Another key component of any camera is the viewing system. Most modern motion picture cameras use reflex viewing systems. **Reflex cameras** have a mirror attached to the front of the shutter so that when the shutter is closed and the film is advancing, the camera operator can see the image through the same lens that projects its image onto the film. When the shutter is open (exposing the film), the film is held steady in the gate and the mirror is not in position for the camera operator to see.

As with the projected image, persistence of vision creates the illusion that the camera operator is viewing a constant, flicker free image. The difference being, the image that the camera operator sees is the space between the frames and not the frames that are actually being photographed. This becomes most clear when photographing a gun shot. When the camera operator sees the flash from the gun barrel, the flash may not be exposed on film. When the operator does not see the flash, it may be recorded on the film. *(This will depend on the size and duration of the flash)*

When looking through the eyepiece of your camera, if the image is "soft" or out of focus, your first inclination may be to try to focus the lens. This might help to some degree, but the image may not become completely sharp. This is most likely because the **diopter** (optical element through which you are looking) is not focused for your eye.

In order to ensure that you can judge accurate focus when operating, you should focus the diopter for your eye before you try to focus your lens.

The easiest way to **focus the diopter** is to remove the lens and point the camera at a light area, either the sky, a white wall or a light source. Then adjust the focus ring on the diopter until the cross hairs are sharply focused. The cross hairs are etched into the ground glass, so when they are in focus you have effectively focused the diopter on the ground glass. Now when your lens in focused it will project an image on the ground glass that is in focus.

ground glass is not focused

ground glass is in focus

If you do not want to remove the lens, then you will need to throw the lens as far out of focus as possible so you cannot clearly focus on the image. The best way to do this is to set the focus on the lens at the opposite end of the range from the subject at which you are pointing. If you are pointing at the sky, set the focus to the close end of the range. If your are pointing at a lamp or flashlight close to the lens, set the focus to infinity. You will also want to open the iris on your lens to its widest opening (smallest number) in order to decrease the depth of field. And if you are using a zoom lens, you will want to zoom in to the longest focal length, which will also reduce the depth of field.

When focusing the diopter, you are in reality focusing the optical element in the viewfinder to a ground glass which is the same distance from the rear element of the lens as the film plane. You are not affecting the image as it is being recorded on film.

Production still from the independent feature: Joe Joe Angel & The Dead Guy

sharp ground glass, out of focus image

Photographs by Bjorn Kommerell

sharp ground glass and sharp image

Once your ground glass is properly focused, then you will be able to focus your lens with the confidence of knowing that what appears in focus will be in focus on film.

Focusing your camera can be done in two ways. You can either: measure the distance from your subject to the rear focal plane (the gate) and set your lens according to the focus marks etched on the lens barrel; or, when working with a zoom lens, you can zoom in all the way to the long end of your lens, open the aperture to its widest opening (smallest number) and focus by eye (assuming that you have already focused your diopter). Then you can reset the aperture and the focal length to the desired settings, and you are ready to shoot.

If your subject or the camera will be moving during the shot, you will want to take a series of focus marks and have an assistant "**pull focus**" with the subject as the distance between the subject and the rear focal plane changes during the shot.

The Video Camera

Video cameras work along the same principles as film cameras with a few notable exceptions.

1. The images will be recorded on a video tape rather than on film.
2. Rather than the rotating mechanical shutter, video cameras have an electronic shutter that regulates the duration of the exposure.
3. When one changes the shutter speed with a film camera, it also necessarily alters the frame rate, which affects the perception of speed of movement - slow frame rates accelerate apparent motion and faster frame rates record slow motion effects. When one changes the shutter speed in video, it does not alter the apparent motion of the subject.
4. Changing the shutter speed in video, as in film does affect: 1) the exposure by affecting the duration for which each frame of recording media is exposed and 2) motion blur. Slower shutter speeds increase the degree of motion blur, faster shutter speeds reduce motion blur.
5. A film camera allows light to be focused onto a photosensitive emulsion, which is then chemically processed to reveal an image. Negative emulsions produce a negative image and reversal stocks produce a positive image.
6. Video cameras focus the light onto either one electronic photoreceptor or three electronic photo receptors depending on the camera. These chip(s) gather the necessary information and create an electronic signal which is then recorded onto the video tape.
7. Analogue video records a signal that is a series of electronic undulations or pulses which vary depending on the strength of the signal. Each time an analogue recording is re-recorded or dubbed onto another recording medium, it picks up electronic noise and loses some resolution or image quality. Digital video is recorded as digital information, a series of ones and zeros. (III0I00I) each time these ones and zeros are recorded onto another medium, they do not suffer from generation loss.
8. Whereas film in the US is recorded at 24 fps., NTSC Video is recorded at 29.97 fps.
9. Each frame of NTSC video contains 525 lines of information which is divided into two interlaced fields. First all the odd lines are recorded, then all the even lines are recorded. Since there are two fields per frame and 29.97 per second, there are 59.94 fields per second.

Operational procedures for working with your video camera are not terribly different from those employed when working in film. You will begin by focusing your diopter on the screen in your viewfinder. I recommend focusing on the display characters. Once these are in focus, you can be confident that your diopter is focused and you can accurately judge the focus through the lens by eye.

Video Time Code

When looking at a length of exposed motion picture film, it's easy to see each individual frame. There is a visible image on each frame and each frame is separated from the next by a line. And along the edge of the motion picture film is a series of sprocket holes. In 16mm film, there is a perforation between each frame. In 35mm film there are various formats: 2 perforation technovision, a 3 perf format and the standard 4 perf format. But video tape is different.

Video tape exhibits no changes to the naked eye once exposed. There is no visible image, no clear delineation between the frames and no sprocket holes. Video tape is not an optical medium, but rather it is a magnetic medium. Video tape consists of a polyester base material onto which ferrous oxide (rust) is affixed. When light exposes a CCD chip an electronic signal is sent to the record deck, which records magnetic information on the tape. There are no sprocket holes, no perforations, nothing to indicate by visual inspection that anything is recorded on the tape.

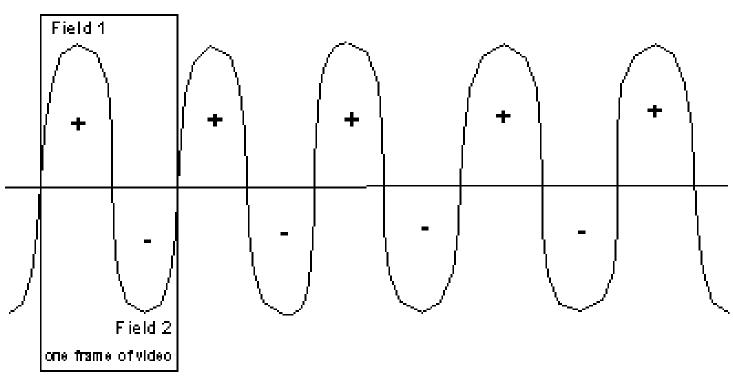
Motion pictures with synchronous sound in the US are projected at a constant rate of 24 frames per second. Video tape in the US was originally designed to run at 30 frames per second. But there are no perforations to indicate the frames. Among the information recorded on a video tape are various tracks: picture , audio, control and address.

Picture and audio are self explanatory. On the control track is recorded a series of "beeps" or electronic pulses which designates each frame as it is recorded and counts each frame as it is played back. These electronic "beeps" function as a simple counter, they do not specifically identify each frame other than to acknowledge it is there. By counting the "beeps", the video deck can ensure that it is running at a constant speed. (In much the same way as a metronome counts time for a musician)

The address track is where time code is recorded. Time code is much more specific than control track. The time code identifies each individual frame by a number, designated in HOURS: MINUTES: SECONDS: FRAMES or 00:00:00:00. There are 23 hours, 59 minutes, 59 seconds and 29 frames in a day. The 30th frame is counted as 00. On the 30th frame, the seconds roll to 00, the minutes roll to 00, the hours roll to 00 to start the count over again.

This is where it can get a bit confusing. When video was invented, it’s rate was determined by the frequency of the electrical system. In the US, our household current is 120 volts at a constant frequency of 60Hz. That is 60 cycles per second.

This provided the "clock" for a video system with a frame rate of 30 frames per second. Each frame consists of two interlaced fields and so, 60 fields are recorded each second, one field on each cycle of the electrical current. The fields are scanned onto the television screen alternately so the two images are seen as one.

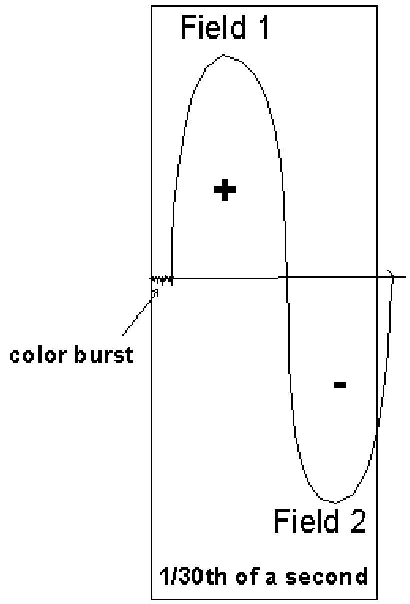


Each field represents 1/60th of a second, each frame 1/30th of a second

This worked well until the advent of color television. The color video signal required that the same luminance information be broadcast, but also that additional color information be broadcast. The first color system was also a 30fps system, but it proved incompatible with the existing black and white 30 fps system.

The television industry had grown so large, that the economics dictated the necessity to create a system that would work for both black and white and color video signals.

The engineers decided to keep the existing video signal, but to include at the head of each cycle a "color burst", that is the necessary encoding of color information so that those with color television capability could see color and those without color capability would still be able to view the program in black and white.



This additional information could not be crammed into the same time allotment. Instead it had to be added to the start of each cycle, thus pushing each frame slightly back in the timeline. This slowed each frame of video down by one one thousanth (1/1000th) of a second. Therefore, by the time the 30th frame had past, a second had already completed 3/100ths of a second earlier.

Now, in the space of one second, thirty frames would not be viewed, instead only 29.97 frames would complete their cycles. The new frame rate for video in the US became standardized at 29.97 frames per second.

Time code was not designed to count partial frames. It counted 30 fps. But now that fewer than 30 frames were broadcast in a second, a program that timed out to one hour according to the time code counter actually ran longer than an hour of real time...because the images were running slower than the time code counter.

The solution was "drop frame" time code. (The original time code became called non-drop frame) Drop frame time code is often misunderstood. It's name would suggest that certain frames are lost to accommodate the necessary time adjustment for broadcasting the new video signal. But this is not true.

There is no difference in the actual frames in drop frame or non-drop frame video. The difference is in the numbering or counting system. Drop frame time code counts every frame just as does non-drop frame code. The counter skips two frame numbers every minute, except every tenth minute. The picture and audio remain untouched.

With this system, a program with a time code count of one hour actually has a real time of one hour. The frame count numbers are dropped to make up for the lag in video signal.

In the US, both black and white and color television use the standard 29.97 fps, drop frame time code for broadcast.

Interlaced vs. Progressive Scan

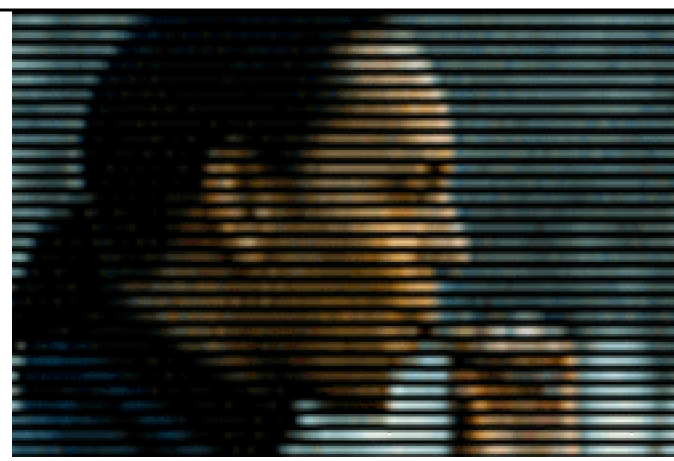
The broadcast standard for NTSC video is a resolution of 525 horizontal lines. There are recorded 29.97 frames per second, two fields per frame or 59.94 fields per second. Each field corresponds to the electrical pulse of the frequency of our standard 60hz alternating electrical current, in conjunction with the technical considerations necessary to include color information into the original broadcast standards adopted when television was black and white. (for a description of this, see above.)

On the first half of the cycle all the odd numbered lines are scanned (1, 3, 5, 7, 9...). On the second half of the cycle all the even lines are scanned (2, 4, 6, 8...). These scanned lines are then interlaced so that we actually see 59.94 individual images per second.

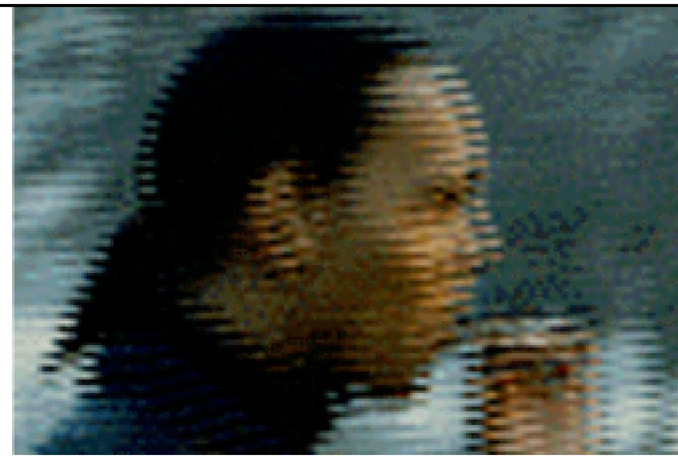

odd lines


odd lines (enlarged view)


even lines


even lines (enlarged view)

2 fields, not aligned



2 fields, not aligned (enlarged view)

interlaced

progressive scan (non-interlaced)

To understand progressive scan, think of the mechanical rotating shutter in a motion picture camera. As the shutter rotates, part of the frame is exposed, as the shutter continues to rotate, more of the frame is exposed until the entire frame is exposed. This continues until the part of the frame that was initially exposed, is covered followed by the rest of the frame area.

Rather than exposing each individual line of each individual field for approximately 1/120th of a second (60 fields), each video frame is exposed for approximately 1/60th of a second (30 frames).

This affects the perception of motion. Rather than capturing two distinctly different images that were frozen in time at approximately 60 images per second as with interlaced video, progressive scan video captures one only 30 distinct images per second. This slower frame rate also softens the effect of motion (or stop motion) by increasing motion blur. Additionally, rather than juxtaposing two distinct images upon one another and asking our brains to interpret them as one with all the artifacts they create, progressive scan video only requires our brains to view a single image at one time.

With a progressive scan system, motion appears more naturally. Consider this, since interlaced video consists of pairs of disinct images, one recorded before the other, the motion across the x axis is not continuous. But with progressive scan, each successive frame, is the next in a series from one to the other. Movement appears more naturally and with fewer artifacts.

One final thought about progressive scan. Each distinct image contains more information and therefore has a higher resolution. Rather than looking at an interlaced 59.94 fields, one with 263 lines and one with 262 lines, progressive scan completes each distinct image (29.97 per second) with the the total 525 lines of resolution.