

ALEXA Studio/XT Studio Electronic and Mirror Shutter

White Paper, March 14, 2015

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Introduction

The ALEXA Studio and ALEXA XT Studio cameras (called 'ALEXA Studio' from here on) are unique in two ways:

- They are the only digital cameras available for purchase that utilizes an optical viewfinder.
- They can use either an electronic shutter or a physical mirror shutter to determine exposure timing.



Many of the basic concepts of these features are based on experience gained through the ALEXA Studio's predecessor, the ARRIFLEX D-21, which also had a rotating mirror shutter and an optical viewfinder. This paper explains the basic functioning of a mirror shutter, the relationship between shutter angles and exposure time and the resulting visual similarities and differences. It then gives a blow by blow explanation of how an electronic and a mirror shutter expose each frame. At the end it provides some practical tips for using each shutter mode.

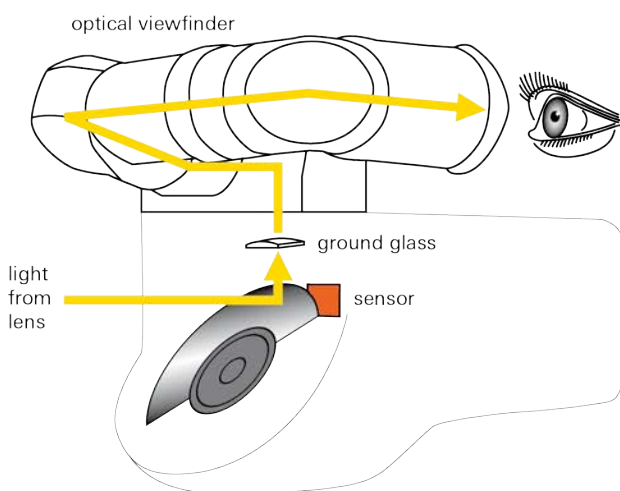
Mirror Shutter Basics

A mirror shutter is a mirror, located at an angle in front of the sensor, that continuously rotates. Half the time it reflects light up into the optical viewfinder and the other half it lets light fall onto the sensor. Thereby the mirror shutter makes the optical viewfinder possible and determines the exposure.

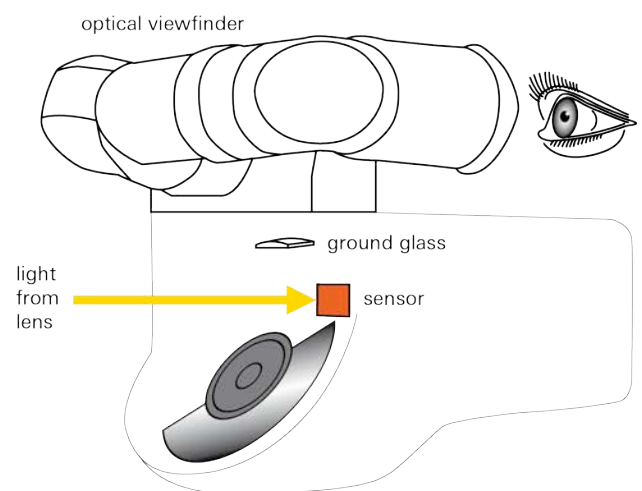
VIEW and GATE Phases

When running, half the time the mirror covers the sensor and reflects the light from the lens onto the ground glass, where an image forms. The optical viewfinder magnifies this image. This is called the VIEW phase. Thus the camera operator can literally see through the lens.

The other half of the time the mirror shutter reveals the sensor which exposes the photosites to light from the lens. However, no light reaches the optical viewfinder. This is called the GATE phase. GATE is a term derived from the open aperture behind which the film is located on film cameras.



VIEW Phase



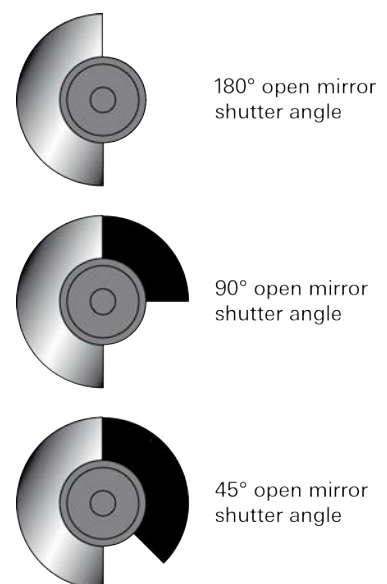
GATE Phase

The Open Shutter Angle

The open half of the mirror shutter is generally referred to as the shutter angle. The largest possible open shutter angle is 180°. The shutter angle can be reduced by means of a thin carbon blade that is situated behind the mirror and can be extended to fill the previously open space. Thus the open angle can be reduced from 180° to 11.2°.

Advantages of Optical Viewfinders

An optical viewfinder offers the most comfortable, accurate and efficient operating experience. Optical viewfinders have zero delay and show a bright and sharp full color image through the taking lens. Since they exhibit no motion blur, judging focus during movement is easy. They show natural motion portrayal, accurate color fidelity and proper white balance, i.e. that of the scene. Operators see exactly what is happening as it happens and experience less eye fatigue. Cinematographers appreciate the ability to judge lighting through the viewfinder and to work with the camera even when it is powered down. Choosing lenses, blocking, setting

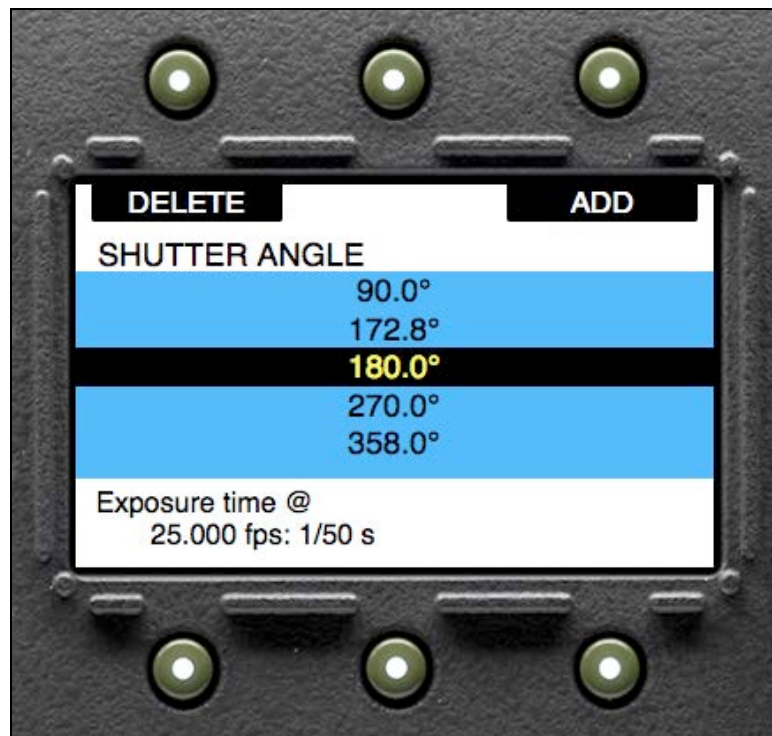


up shots, pre-lighting or rehearsing before the camera is powered up can save precious time on the set.

Exposure Time and Shutter Angle

The length of time during which each frame is exposed is based on the camera's frame rate and on what portion of each frame cycle is used to expose the image. This second value is often expressed as the shutter angle in degrees, a terminology that stems from rotating mirror shutters used in film cameras. As many crews are familiar with this terminology, we have maintained it for all ALEXA cameras.

Calculating the exposure time for a given frame rate and shutter angle is relatively straightforward. Rather than going into the math (which a myriad of apps can do for you), it is simpler to say that a 180° shutter angle, which is half the theoretical maximum of 360°, results in an exposure time half of the frame rate. For instance, at 25 fps and a 180° shutter each exposure lasts 1/50th of a second. If we keep the frame rate at 25 fps but halve the shutter angle to 90°, we also halve the exposure time again to 1/100th of a second. Each time the shutter angle is halved, the exposure time is halved.



When changing shutter angles on ALEXA cameras, the resulting exposure time is automatically displayed at the bottom of the FPS screen.

Typical Uses of Shutter Angles

Changing the shutter angle changes the exposure time, which can be used to adjust the amount of motion blur, the amount of strobing and/or the light level reaching the sensor.

A longer exposure time results in more motion blur while a shorter exposure time results in less motion blur. A combination of the exposure time and the duration between the end of one exposure and the beginning of the next determines the amount of strobing the scene will exhibit. Typical examples are shooting at 6 fps with a 180° shutter for a very blurry effect (often used when a boxer gets punched, for example) or shooting at 35 fps with a 45° shutter for a staccato, strobe-like effect (often used in war movies during battle scenes).

Changing the amount of light reaching the sensor by changing the mirror shutter angle is sometimes preferable to using the lens iris since it does not change the depth of field. However, this should be done within reason

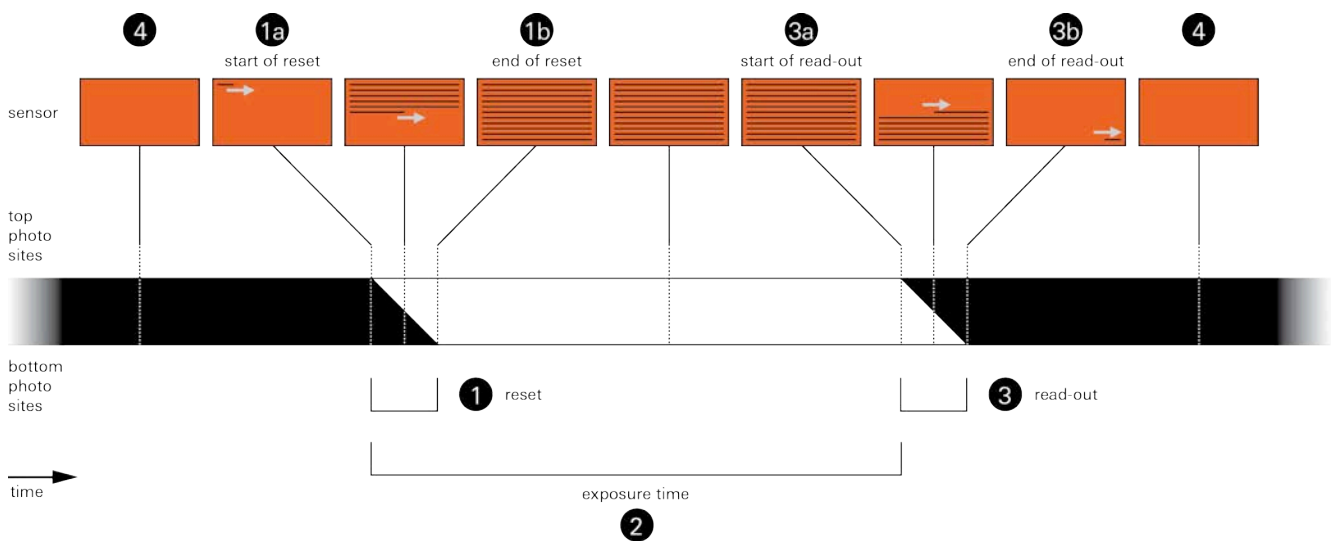
since there will be an accompanying change in motion blur and/or strobing and so this is most useful in small amounts and/or relatively static scenes.

ALEXA Electronic Shutter Timing

When the mirror shutter of the ALEXA Studio is turned off, exposure timing works just like it does with the other ALEXA cameras, using a rolling electronic shutter. In this case, nothing physically covers the sensor and light continuously falls onto the photosites and is continuously converted into an electrical charge.

The diagram below shows the state of the ALEXA sensor in the top line of rectangles and a timeline below.

1. At the beginning of each exposure the sensor resets all photosites to empty them of any charge.
 - 1a. The reset process starts with the top left photosite and then scans down line by line.
 - 1b. The reset process ends at the bottom right photosite.
2. Once reset, each photosite is being exposed, i.e. they accumulate a charge based on how much light falls on them. The more light falls on each photosite, the higher the charge.
3. Once the exposure time is over, the charge in each photosite is measured and read-out.
 - 3a. Just like the reset, the read-out starts with the top left photosite and then scans down line by line.
 - 3b. The read-out process ends at the bottom right photosite.
4. After the read-out, the photosites still convert light into a charge. However, this is ignored until the next reset (go back to 1).



Both reset and read-out happen not at the same time for all pixels, but in a scanning fashion from top left to bottom right. The duration of this scan determines how much of a rolling shutter artifact will be visible. The ALEXA sensor has a very fast reset and read-out, so while rolling shutter artifacts like skew and partially exposed frames are possible, they are greatly minimized.

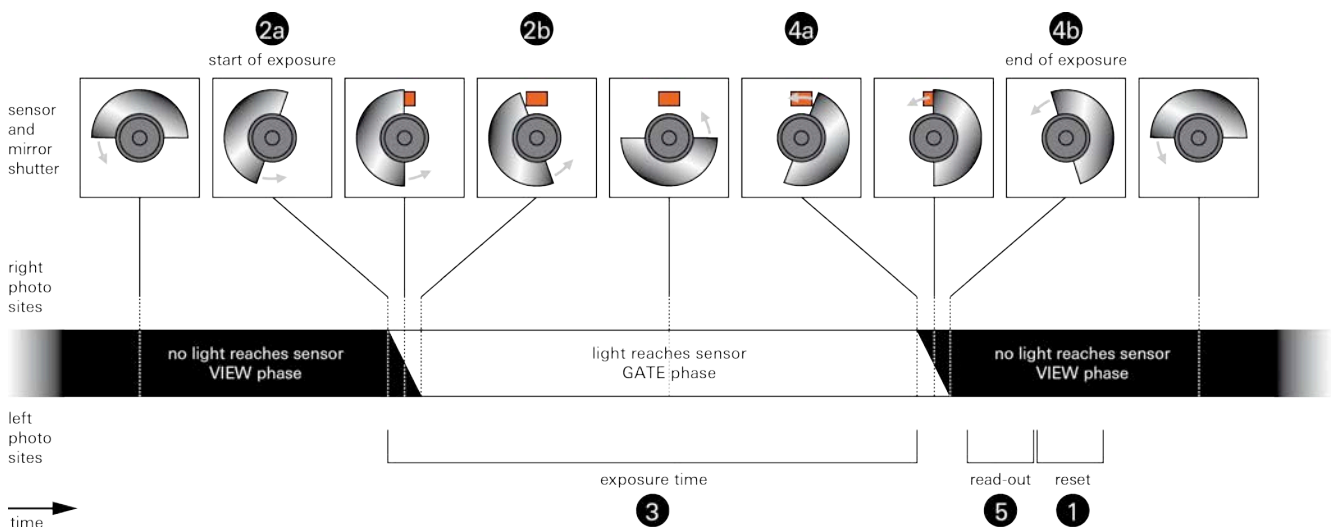
The only temporal limitation to this process is the time it takes to switch from read-out to reset. Since this time is very short for the ALEXA sensor it is possible to set electronic shutter angles from 5° up to 358° at all frame rates up to 60 fps and from 5° to 356° at frame rates from 60 to 120 fps.

ALEXA Mirror Shutter Timing

When the mirror shutter of the ALEXA Studio is turned on, exposing an image is different from using an electronic shutter. The mirror shutter physically covers and uncovers the sensor to determine exposure.

The diagram below shows the state of the ALEXA Studio sensor and mirror shutter in the top line of squares, and a timeline below. While there still is a photosite reset and a read-out, they both occur while the sensor is covered by the mirror shutter. The exposure time is determined by the physical mirror shutter sweeping across the sensor.

1. At the beginning of each exposure the sensor resets all photosites to empty them of any charge. Since this occurs during the VIEW phase, while the sensor is still completely covered by the mirror shutter, no light reaches the photosites and no charge builds up.
- 2a. Then the shutter reveals the sensor, which happens first on the sensor's right side.
- 2b. The pixels on the left side are the last to be uncovered.
3. The mirror shutter continues to rotate during the exposure time while light falls onto the photosites.
- 4a. Then the mirror shutter's leading edge starts to cover the sensor's right side again.
- 4b. Eventually it will have covered the whole sensor.
5. Once the sensor is in complete darkness, the charge that has accumulated while the photosites were exposed is read-out. Immediately after the read-out, each photosite is reset (go back to 1) to prepare for the next sweep of the mirror shutter.



Rolling vs. Sweeping Shutter

Rolling Shutter Artifacts

In contrast to a rolling electronic shutter, which scans top to bottom, a mirror shutter sweeps right to left across the sensor (left to right in the image, as the image is upside down), so we could call this a "sweeping shutter." A sweeping shutter, as used in film cameras for decades, does not exhibit the issues encountered with a rolling shutter. This is most likely based on three factors. First, even though reset and read-out of the ALEXA sensor happen extremely rapidly, the sweep of the mirror shutter across the sensor is twice as fast when compared at 24 fps. Second, in movie making there are far more pans and straight vertical lines - which would reveal a rolling shutter - than tilts and horizontal lines - which would reveal a sweeping shutter. And third, most tilts are slow but pans can be quite fast, and the rolling shutter skew artifact is more pronounced the faster the camera is moved.

Motion Portrayal

The use of an electronic top to bottom rolling shutter in contrast to the mirror shutter with its sideways sweeping motion will result in a subtly different way motion look within the shot. Since footage from ALEXAs acquired with an electronic shutter has been combined very successfully with footage from ALEXAs acquired with a mirror shutter in the past, this difference is probably too small to be noticed by most audiences.

Strobing

Strobing occurs when the individual frames of a movie are not seen as representing a continuous motion. At 24 fps/180° there is a certain amount of motion blur, since the exposure time is so long (1/48th of a second) that fast movements in the frame result in a blurred image. This actually helps the illusion of continuous motion between the frames and "glues" the frames together. If the shutter angle is reduced, say to 45°, then the exposure time is shorter, and each image has less motion blur. While theoretically 24 images with less blur sounds like a good idea, we would start seeing them as 24 individual frames, and thus experience strobing.

A large number of tests between an ARRIFLEX 435 film camera, an ALEXA Studio with the mirror shutter on and an ALEXA Studio with the mirror shutter off have shown no difference at all in the strobing behavior of an electronic shutter vs. a mirror shutter.

Strobing and Safe Panning Speeds

Strobing can also occur when the "difference" from one frame to the next is too great. With just a small change between frames there won't be much strobing; in a static shot of an immobile subject there will be no strobing, even with a 11.2° shutter. But a shot at 180° might have a lot of strobing if the pan was done too fast, since the elements in the image changed too much from frame to frame.

Existing safe panning speeds established for film cameras apply as well to all ALEXAs with an electronic shutter and to the ALEXA Studio with its mirror shutter.

Mirror Shutter Limitations

Photosite reset and subsequent readout take a finite amount of time and have to occur during that portion of the VIEW phase when the sensor is completely covered by the mirror shutter. As the frame rate of the camera is increased the time available for read-out and reset gets shorter and shorter. In 4:3 mode at 37 fps (in 16:9 mode at 47 fps) the available time is too short and artifacts could be seen. To avoid this and still allow faster frame rates, the camera will reduce the open mirror shutter angle (which increases the duration of the time the sensor is covered) to maintain the necessary time for read-out and reset.

When changing fps on the ALEXA Studio with the mirror shutter on, the SHUTTER screen will always pop up once a new fps is chosen. If the shutter needs to be reduced the camera will suggest a legal shutter angle that makes calculating exposure differences easy. This shutter angle is most likely below the maximum angle possible at the given frame rate, but can be manually set to the maximum possible angle. For instance, when changing from 24 fps/180° to 48 fps in 4:3 mode, the maximum angle possible is 139.2°, but after the FPS screen the SHUTTER screen will pop up with 135° selected. 135° is 1/2 stop less light than 180°. It is now possible to simply acknowledge the 135° or to set the shutter to the maximum possible value of 139.2°.

Of course, the appropriate exposure compensation for the reduced shutter angle must be taken into consideration. In our example at 135° the lens' iris would have to be opened up by 1.5 stops; 1 stop for the switch in fps and 1/2 stop for the change in shutter angle.

The exact frame rates and shutter angles are listed in the ALEXA Maximum Fps data sheet, which can be downloaded from the ARRI website.

Operational Notes

Viewfinder Notes

When the mirror shutter of the ALEXA Studio is on, it is possible to use either the optical viewfinder OVF-1 or to replace it with the Electronic Viewfinder EVF-1. However, when the mirror shutter is off, only the EVF-1 can be used, as there is no mirror shutter to reflect light into an optical viewfinder.

While optical viewfinders show no delay between the time an event happens in front of the camera and when it can be seen in the viewfinder, they do not show the image at the exact time when the sensor is exposed. This can be an issue for events with a duration approximately the same as the exposure time, i.e. a gun's muzzle

flash. If the muzzle flash is visible in the optical viewfinder, it did most likely not reach the sensor. If you suspect that you are dealing with such an event, always double check the recording to make sure you have captured it.

Mirror Shutter Runs During Record and Standby

When using the mirror shutter of the ALEXA Studio it will continuously rotate - while the camera is recording and while it is in standby - as indicated by having both SHUTTER PARK LEDs illuminated. This is different from the way film cameras work, where the shutter only rotates during recording. It is necessary however on a digital camera, as it is the only way to send an image both to the optical viewfinder and to the sensor (and hence to monitors, the in-camera media or recorders connected to the HD-SDI outputs of the camera).

Parking the Mirror Shutter

When using the mirror shutter there are two times when the camera operator or assistant may want to temporarily stop the shutter from rotating. This is done with the two MIRROR PARK buttons labeled VIEW and GATE. Status LEDs below the button indicate the mirror shutter's state and position.



1. When the operator wants to see through the optical viewfinder without the flicker of the rotating shutter, the MIRROR PARK/VIEW button will stop the mirror shutter in the viewing position and the LED next to the VIEW button illuminates. In that case no signal will reach the in-camera media or HD-SDI outputs anymore and connected monitors or recorders cannot show an image. Pushing MIRROR PARK/VIEW again will resume rotation.
2. To check the sensor for cleanliness the MIRROR PARK/GATE button on the left side of the camera can be pushed. The mirror shutter will stop in the GATE position, change to a 180° open angle position and the LED next to the GATE button illuminates. Since the mirror shutter does not cover the sensor, an image will reach the in-camera media, HD-SDI outputs and EVF-1, but the optical viewfinder will be dark. The mirror shutter does not determine the exposure time anymore, so an electronic shutter with the same shutter angle as was set on the mirror shutter (and thus the same exposure time) will be used by the camera. Pushing the MIRROR SHUTTER/GATE button again will reset the open shutter angle to its previous value, resume rotation and the exposure time will again be determined by the mirror shutter.

Please note that checking and cleaning the sensor should always be performed with the camera switched off and disconnected from the power source to avoid an accidental rotation of the mirror shutter which could lead to injuries and damage to the camera.

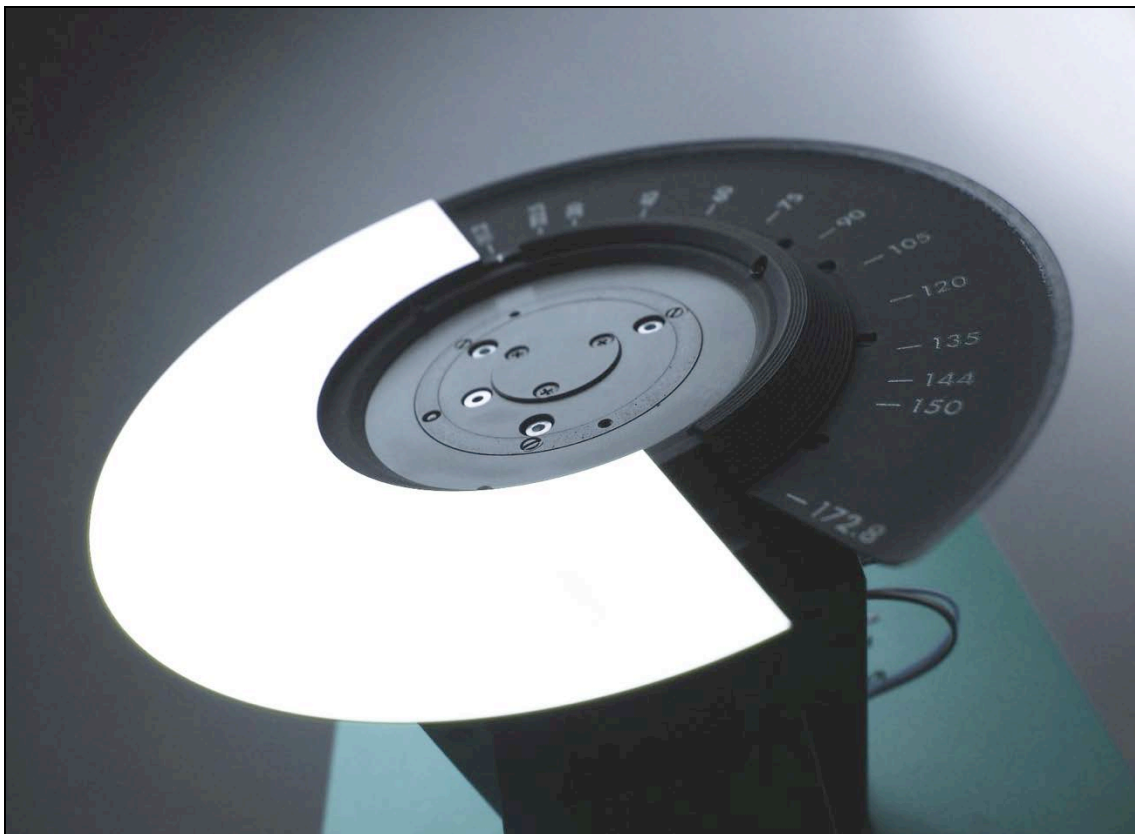
Mirror Shutter Power Requirements

We recommend to power the camera with at least 18V when running it faster than 30 fps with the mirror shutter on. If the voltage is less, ALEXA Studio will still try to run the mirror shutter, but depending on frame rate, voltage level and ambient temperature it may or may not succeed. If it does not succeed, a warning message will be given.

Power Off/On

When the ALEXA Studio is powered down while the mirror shutter rotates, the mirror will stop at a random position. To ensure that the operator can immediately look through the camera the next time it is taken out of the case, we recommend parking the mirror shutter in the VIEW position before turning the power off.

Once the camera is powered up, the shutter will rotate and park in the GATE position. As long as a human is next to the camera who wants to look through the viewfinder it is easy for them to push the MIRROR PARK/GATE button to start the shutter rotating. When the camera is on a remote head on a crane, this is the park position needed. After a power up with the camera in mirror on mode, as soon as the REC button is pushed for the first time, the shutter will start rotating.



The mirror shutter used in ARRICAM film cameras and ALEXA Studio. The mirror is on the left and a thin carbon blade imprinted with shutter angles values can be seen on the right. This blade can be used to reduce the open shutter angle, which in this image is at its minimum of 11.2°.