A NEW “ANGLE” ON PROJECTION

THE FUJIFILM FP-Z5000
Ever since the first lantern slide shows of centuries long ago, we’ve relied on projectors to create large, bright, and immersive images for entertainment, education, and enterprise. Video projection, once an expensive and exotic presentation platform, has become an affordable and essential tool for visual communication, thanks to the development of solid-state imaging technologies, lamp-free light engines, and specialized software for blending and mapping projected images to a wide range of surfaces.

As projector resolution and brightness increased, lenses became more sophisticated in design, making it possible to mount projectors very close to the screen for front and rear projection. Mechanical lens offset enabled installation of projectors above, below, and behind presenters and viewers to prevent blocking and shadowing of the viewing screen. And increasing the light output from projectors eliminated the need for high-gain projection screens, doing away with “hot spots” and narrow viewing angles.

In many ways, projectors have evolved into something more resembling a theatrical lighting instrument. They can be mounted horizontally, vertically, aimed up and down, and combined in arrays to fill the width or height of a wall, stage, or scenic backdrop of any shape or size. Projectors have been used to create images on every conceivable surface – water, stone, fog, buildings, airplanes, cars, roads, hockey rinks and basketball courts, and even on people.

**RE-WRITING THE RULES**

Today’s projectors share very little in common with those dim, clunky models from a quarter-century ago, except for their basic design. The housing may be streamlined; the light engine is state-of-the-art, and the connectors have evolved from analog to digital. But the projection lens still sits at the front as it always has, locked into place. And that has always presented a bit of a problem for certain installations.

Mechanical lens shift in both horizontal and vertical axes can compensate for off-center projector placement, to a degree. This technique works best when the plane of the projector lens is parallel to the plane of the imaging surface, minimizing geometric distortion and maintaining sharp, edge-to-edge focus. But if the projection angle becomes sufficiently acute, the only remaining remedy is to add some form of digital image offset. This approach is a classic trade-off: while digital pixel mapping can correct image geometry, it typically results in diminished image resolution.

The ideal solution would be to free the lens to move independently of the projector housing, no matter how the projector is placed or installed, at any angle and in any orientation. But conventional wisdom has been that it wasn’t possible to design a high-performance projector with a lens that could rotate independently of the projector’s placement.

Now, FUJIFILM Corporation (“Fujifilm”) has done just that, with a snorkel-like projector design that can rotate 360 degrees horizontally and 180 degrees vertically. This unique lens design makes it possible to mount a projector in just about any location imaginable and fill the imaging area with bright, contrasty, and sharp pictures and video.

To be sure, designing such a projector lens is not without its technical challenges. A high degree of precision is required to ensure there is no loss in image quality, regardless of the lens position. The focal length is purposely short to maximize installation options, creating additional lens design challenges. And essential tools like mechanical lens shifting must be incorporated, along with digital keystone correction for particularly difficult angles and projects.
Fujifilm, an industry leader in camera and lens design, has taken on this challenge. The result of its efforts is the FP-Z5000 ultra-short-throw projector, the world’s first projector to incorporate a biaxial, rotatable lens with lens shift. It offers a multitude of projector/lens alignment options, combined with 1-chip DLP technology and a solid-state, laser-phosphor light engine for near instant on/off operation. In effect, the FP-Z5000 is a sophisticated lighting instrument that can also show video, graphics, and photos.

Designing a projector lens like that of the FP-Z5000 isn’t easy, particularly given the very short varifocal length of 5 to 5.5 millimeters and the need for a wide lens aperture for bright images. Fujifilm’s goal was to illuminate a 100-inch screen or surface from a projection distance of just 30 inches with the rotatable lens set in any position. In addition, the lens plane can be shifted by a maximum of ±82 percent vertically and ±35 percent horizontally, with the FP-Z5000 “remembering” those shift settings when the lens is rotated to a new position.

The lens assembly of the FP-Z5000 can rotate in two sections. By itself, the main lens can be set to any of four positions within 360 degrees. The lens support arm – which is also part of the optical path – rotates up to 180 degrees. Combined, these settings provide 22 different lens and projector placement choices, opening the door to all kinds of projection capabilities on walls, floors, and even on ceilings, all while the projector is mounted in an unobtrusive location.
The front lens of the FP-Z5000 is a large-diameter, aspheric type with a diameter of 87 millimeters. To manufacture it, Fujifilm had to develop advanced, high-precision manufacturing processes, ensuring that surface accuracy on the aspheric lens varied by no more than 0.1µm, or .0001 millimeters. The entire lens assembly has 18 separate elements and bends light four times on its way to the screen, including two 90-degree angles in the lens arm. This advanced design grew out of Fujifilm’s continuing research and development into lenses for 4K and 8K video cameras.

Figure 2.
The FP-Z5000’s unique, biaxial, rotatable projection lens has multiple precision elements.

Figure 3.
The main lens can rotate 360 degrees in four positions, while the lens arm can rotate 180 degrees.

Figure 4. The FP-Z5000 offers image shifting with memory if projector orientation and lens position change.
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PERFORMANCE METRICS

It’s one thing to be able to build a high-performance, rotatable, snorkel projection lens, but it’s quite another to bring it to market. One of the challenges in ultra-short-throw lens design is to minimize chromatic aberrations; that is, misalignment of light rays at different wavelengths. This phenomenon, not completely unavoidable, typically manifests as red and/or blue fringing along the edges of lines and sharply-defined objects in the image. In addition, poor focus uniformity exaggerates the fringing effect.

The aspheric lens design of the FP-Z5000 exhibits excellent focus uniformity across the projected image, with virtually no color fringing, as tested on a 92-inch, 1.0 gain screen while using a 32x32 grid pattern. That level of performance is the result of high-quality lens manufacturing, and while it would be difficult to attain in a conventional projection lens, it represents a major breakthrough in a multi-angle lens of this type.

Sharp focus is maintained even when projecting onto surfaces with moderate concave or convex curves. And while it’s considered good practice to align the planes of the lens and projection surfaces in parallel, such alignment is not critical to achieving acceptable focus.

Focus uniformity is just one of many metrics applied to projectors. Color accuracy, brightness and uniformity are also critical, particularly for edge blending two or more projectors. In lab testing, average brightness uniformity (four corner brightness measurements averaged to a center brightness reading) for the FP-Z5000 was 82% and 85% over a nine-screen measurement, while color temperature varied by a maximum of ±280 Kelvin or 8.5% across the full screen.
These numbers are consistent with single-chip DLP™ projector performance using a conventional projection lens, meaning that no sacrifices have been made in the design of the rotating lens assembly and aspheric front lens. These high levels of brightness and color uniformity facilitate edge blending in any axis, even when the FP-Z5000 is mounted at an extreme angle and position relative to the screen.

The mechanical image offset function, common in many medium- to high-brightness projectors, provides a powerful installation tool here. Let’s assume the initial position of the FP-Z5000 is with the projector housing in a horizontal position and with the rotating lens raised and swiveled to a 90-degree position, relative to the projector body. In addition, the projected image is elevated by 40% vertically and shifted to the right by 10%. These image offset positions are stored in the projector’s memory after setting.

Now, we find out that the projector housing must instead be mounted vertically, to accommodate space limitations or physical constraints. The projector is re-aligned correspondingly, the lens is rotated to maintain the desired orientation (portrait or landscape), and the FP-Z5000 image-shift memory automatically restores the +40% V / +10% H shift settings, bringing the image back to its previous position with minimal alignment time and labor.

As mentioned earlier, maintaining parallel alignment between the projector lens and imaging surface is always good practice. However, there may be instances where that is not possible, and the FP-Z5000 will need to be positioned at an acute angle to the screen. An additional tool, digital keystone correction, is provided to adjust image geometry to match the dimensions of the projection screen or imaging surface.

Combined with the rotatable lens and best-in-class mechanical image shifting, the projector permits image geometry consistency even when the projector housing is placed at one corner of the screen.

The advantage of a solid-state, light engine becomes apparent when choosing projector installation positions. Conventional projectors that use short-arc lamps have limitations on placement due to air flow and other mechanical requirements. In contrast, the FP-Z5000 can be mounted anywhere with nearly any alignment – horizontal, vertical, angled, and tilted up or down – without constraints – much the same way a contemporary lighting instrument can be positioned on a stage.

### Table of Horizontal Projection Distances

<table>
<thead>
<tr>
<th>Size (in)</th>
<th>Width x Height (cm)</th>
<th>Projection Distance (cm)</th>
<th>Lens Shift (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>155 x 87</td>
<td>52 – 57</td>
<td>-115 – 28</td>
</tr>
<tr>
<td>80</td>
<td>177 x 100</td>
<td>59 – 65</td>
<td>-131 – 32</td>
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<tr>
<td>90</td>
<td>199 x 112</td>
<td>67 – 74</td>
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<td>332 x 187</td>
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<td>250</td>
<td>553 x 311</td>
<td>189 – 208</td>
<td>-411 – 100</td>
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<tr>
<td>300</td>
<td>664 x 374</td>
<td>227 – 250</td>
<td>-493 – 120</td>
</tr>
</tbody>
</table>

Table 1. The FP-Z5000 can create an image measuring 100 diagonal inches with a throw distance starting from 30 inches.
Let’s take a closer look at the projection design possibilities created by the FP-Z5000.

**Figures 6a and 6b** below perfectly illustrate the advantage of a rotatable lens. The designer has created a virtual garden with a large goldfish pond, underneath blue skies. One projector is mounted on and parallel to the ceiling, with the lens rotated 90 degrees to the housing and aimed down, creating the video images of the pond. The other projector sits on the floor unobtrusively and projects upward onto the ceiling. Both images are shifted mechanically to offset the projectors comfortably out of the field of view.

*Figure 6a. Projecting a virtual goldfish pond on the floor.*

*Figure 6b. Projecting a virtual sky on the ceiling.*
In Figure 7, the FP-Z5000 sits hidden away under a reception desk at an upscale hotel. The rotating lens and mechanical lens shift are combined to illuminate a large, curved projection screen behind the desk, and the offset lens ensures images won’t be blocked by anyone standing at the desk. Image mapping software is used to conform the projected images to the concave screen surface. As a bonus, the laser-phosphor light engine enables instant on-off operation with minimal required maintenance.

In Figure 8, a single projector is set up on the ceiling of an art gallery to create a vertical projection of approximately 90 inches. Once again, the FP-Z5000 is mounted with its housing parallel to the ceiling. The lens is then rotated below the projector and positioned orthogonally to it, creating a vertical (portrait) image orientation. Mechanical lens shift finishes the image offset. Viewers can stand close to the projected video and view it without obstructing the projected image and casting a shadow.

CONCLUSION

Fujifilm’s FP-Z5000 represents a novel approach to projection. Equipping the projector with a bi-axial rotatable lens and mechanical lens shift enables a wide range of installation and throw options that were previously difficult, if not impossible, to accomplish with a traditional fixed lens design. This unique combination of features, plus automatic memory of shifted images as the lens rotates to a new position, creates a powerful tool for projection designers.

No compromises in lens design were necessary to achieve high performance in this ultra-short-throw projector, which projects Full HD (1920x1080) images with excellent focus, high brightness, impressive color uniformity, and minimal geometric distortion. The solid-state laser/phosphor light engine and DLP™ imaging technology provide high reliability and long hours of lamp-free operation, ideal for complex projector installations.