OPTICAL ENGINEERING

# Picoprojector Technologies: Seeing the Big Picture

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Picoprojectors seem to offer the impossible: They are as small as a mobile phone with a screen at least as big as a laptop. This article compares four commercial devices.

Predicted to be the next big gadget, picoprojectors may soon be embedded in a wide range of products, including mobile phones, laptops and cameras. There is currently a three-horse race of competing technologies: liquid crystal on silicon (LCoS), digital light processing (DLP) and laser beam scanning (LBS). We studied four commercial picoprojectors to quantify their differences: an Aaxa P2 color-filter LCoS, Aaxa L1 color sequential LCoS, Optoma PK201 (DLP) and a Microvison Show WX+ (LBS). (The two Aaxa models have since been discontinued, but they are still representative of existing LCoS technology.)

LCoS and DLP projectors are both miniature displays in which individual pixels are switched each frame. A lens projects an enlarged image of the display. Laser scanning devices operate differently: Thin red, green and blue laser beams are combined and rapidly scanned in a raster pattern (similar to a cathode ray tube) using tiny microelectromechanical system mirrors.

Light sources are critical—whether diode lasers or LEDs. The latter are cheaper, but laser technology will be preferable once green lasers of at least 50 mW become inexpensively available. Laser coherence allows for always-in-focus projection, but image

### Aaxa P2

**Technology:** CF LCoS
**Contrast ratio:** 79
**Flux [spec]:** 22.2 lm [33 lm]
**Power consumption:**
  **White:** 19.0 W
  **Black:** 19.0 W
  **Video:** —
**Lumens per watt:** 1.2 lm/$W_e$

### Aaxa L1

**Technology:** CS LCoS
**Contrast ratio:** 175
**Flux [spec]:** 9.9 lm [20 lm]
**Power consumption:**
  **White:** 6.3 W
  **Black:** 6.3 W
  **Video:** 0.5 W
**Lumens per watt:** 1.6 lm/$W_e$

### Optoma PK201

**Technology:** DLP
**Contrast ratio:** 1,724
**Flux [spec]:** 16.8 lm [20 lm]
**Power consumption:**
  **White:** 5.7 W
  **Black:** 5.7 W
  **Video:** 1.0 W
**Lumens per watt:** 2.9 lm/$W_e$

### Microvision show WX+

**Technology:** LBS
**Contrast ratio:** 9,285
**Flux [spec]:** 12.5 lm [15 lm]
**Power consumption:**
  **White:** 4.9 W
  **Black:** 3.4 W
  **Video:** 0.4 W
**Lumens per watt:** 2.6 lm/$W_e$

(Left to right) Courtesy of Aaxa/Optoma/Wikimedia Commons speckle is a drawback. When diode lasers combine with LCDs, the linear polarization requirement of LCDs is met naturally and without loss. Laser eye safety limits the maximum power (and therefore brightness), although LCoS and DLP devices have a much higher limit than a scanner.

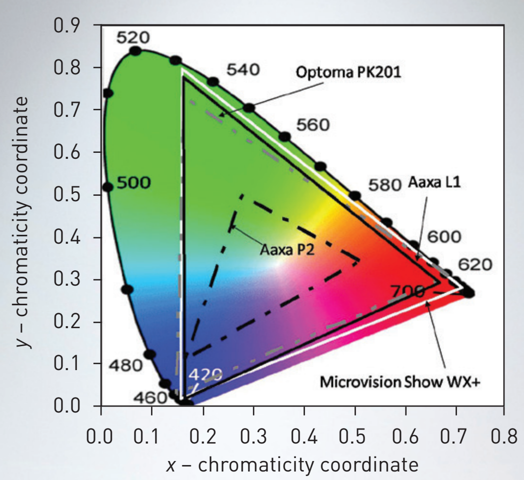
## Resolution

Picoprojectors usually have resolution specifications of video-graphics array (VGA), wide VGA (WVGA), super VGA (SVGA), or, most recently, high definition. The Aaxa P2 is an SVGA color-filter LCoS picoprojector illuminated with a white LED. In an enlarged view of the projection of one- and two-pixel–dense lines at the field center and corner, we found good resolution evident across the field. The Aaxa L1 is an SVGA color-sequential LCoS, sequentially illuminated by three lasers. White pixels require illumination of all three lasers in one frame—the eye integrates the three colors over the 60-Hz frame to perceive white. Each laser is pulsed multiple times per frame, depending on laser brightness.

In our tests, the Aaxa L1 showed good monochromatic resolution. However, if a polychromatic image is viewed off-axis, transverse chromatic aberration becomes apparent. In the field corners, red and blue projections are shifted a whole pixel from the green. This is a limitation of the projection lens and not the display technology, but clearly the stated resolution is not achieved in practice.

Optoma's DLP projector also operates in a 60-Hz sequential mode, but uses RGB LED sources, not lasers. Again, color sequencing is complex: There are four green, four red and two blue pulses per frame, as required by the power of the LED sources to make white. The square micromirrors are aligned at 45°, and even though resolution is specified as WVGA (854 × 480 pixels), single-pixel lines are not well resolved. As with the Aaxa L1, this is an issue with the projection lens, not the DLP chip.

Resolution in LBS picoprojectors is complicated by the nature of line scanning. Currently, only Microvision has marketed an LBS device, though others are in development, including Lemoptix and ST Microelectronics (via bTendo). The line scan is resonant in one or both directions, so the pattern is a Lissajous figure, which causes inconsistent separations between adjacent scan lines. Resolution cannot be traditionally defined.




**Color gamuts of the four projectors on a CIE 1931 chromaticity diagram**

LBS picoprojectors are without projection lenses, but chromatic issues exist. Three < 1-mm–diameter laser beams must be aligned and synchronized to a fraction of a pixel. Our tests show that this is not the case in commercial LBS picoprojectors.

## Contrast ratio

This is measured as the ratio of illuminance between white and black projections. In practice, this ratio is very dependent on background illumination, which we subtracted in our tests. Our measurements showed large variation across the products. The differences stemmed from light "leaking" into black projections. Black regions are "projected" by blocking light with crossed polarizers (LCoS) or diverting via micromirrors (DLP). Light leakage can be caused by internal scattering; it may be better extinguished in devices with laser sources that are highly polarized or can be turned off.

## Color gamut

Although lasers should have the largest gamut (since they use primary wavelengths), our measurements tell a different story. Microvision's device has the widest gamut, while the Aaxa L1 uses the same laser wavelengths but has a smaller gamut: Light leakage that causes the low contrast also pulls in the gamut's corners. The complementary case helps the Optoma PK201 device: It uses broadband LEDs, so it should be worse than the Aaxa L1, but its higher contrast ratio maintains its gamut.

The Aaxa P2 gamut is noticeably small; this is due to a low contrast ratio and inefficient performance of color filters in each sub-pixel. These filters are much broader band than a colored LED or laser. This is a design compromise: narrowband filters sacrifice transmission for a larger gamut. The Aaxa P2 is the brightest picoprojector tested, but the lesson learned from its color gamut is clear: Create color in the source, not by filtering white light.

## Emitted luminous flux and power consumption

Using a goniometric system to measure each picoprojector, we collected the total emitted flux of a completely white projection. By comparing this value to its power consumption, we generated a lumens-per-watt$_{elec}$ ratio.

For all four projectors, the measured flux emission was short of the specified values. The Aaxa P2 consumes an enormous 19 W, and, although it produces the highest flux (22.2 lm), it is the least efficient.

LCoS and DLP projectors consume the same power for black and white projection because the light sources are always on. The Microvision device consumes 3.4 W for idle black and 1.5 W more for full white output. Video processing consumes additional power, even if it is done on a connected computer or mobile device, because videos require conversion from a standard rectilinear pixel array to a projector's format.

## Summing up

There was no clear picoprojector standout, but the color-filter LCoS device trails the others tested. Costs have not been covered here, but integrators want about $1 per lumen to embed a picoprojector. Another rule of thumb: The projected image must be at least three times larger than the internal display, requiring a picoprojector in a laptop to be 15 times more powerful than one in a smartphone. All told, it may be a case of "horses for courses," with all three technologies prevailing in their own niches. OPN

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