Programmable Liquid Crystal Apertures and Filters for Photographic Lenses

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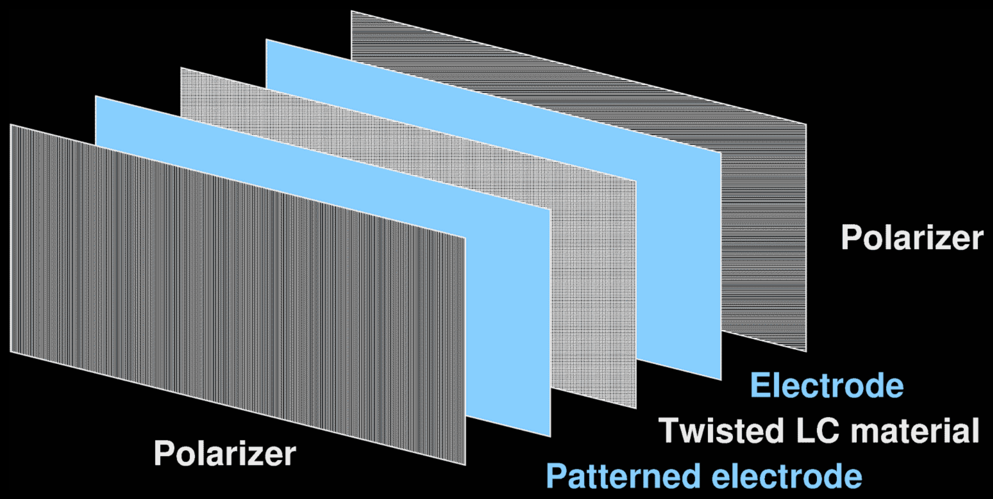
Liquid Crystal



- Liquid Crystal (LC)
  - LC physically changes polarization when a charge is applied
  - LC molecules "untwisted" $\propto$ voltage
  - Active refresh or passive hold
  - Can wear out; AC drive outlasts DC
- Combine with sheet polarizers to make a continuously-variable transmissivity filter

So Many Questions...

- LC is a well-established technology, but usually isn't used for photographic filters
- Commodity LC components as filters?
  - Contrast ratio
  - Timing & refresh issues
  - Translucent vs. transparent
  - Polarization effects on the camera
  - LCD pixelization effects
  - Color LCD RGB subpixels

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Liquid Crystal Light Valves (LCLV)

- Transmissive, usually clear ⇄ black
- Usually single element (pixel), can be large
- Very low power; unpowered holds state
- Adafruit sells two:
  - Both transmissive TN, black @ 4-5V
  - 31 x 33 x 2mm, #3627, @ $2.95
  - 96.5 x 38 x 2mm, #3330, @ $7.50

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Front-Mounted LCLV Filter

- An electronic/molecular shutter
- A variable Neutral Density (ND) filter
- Controller (digital or analog)
  – Applies voltage to twist/untwist
  – Ideally driven as +/- ⇄ -/+

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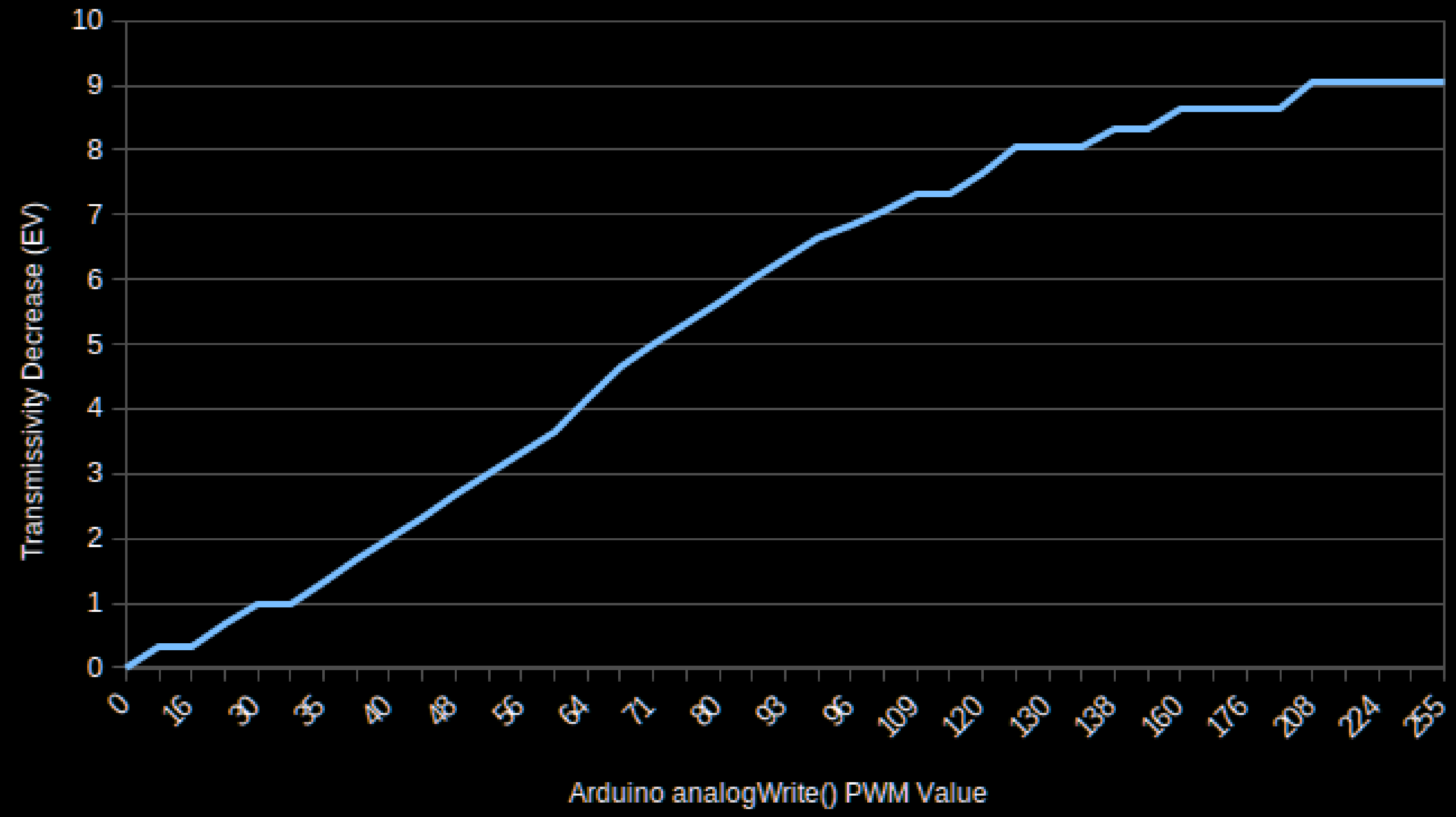
Arduino PWM Transmissivity




```
swap=(!swap);
a=pwm>>1; b=pwm-a; a=127-a; b=127+b;
analogWrite(shuta, (swap ? b : a));
analogWrite(shutb, (swap ? a : b));
```

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LCLV Filter

No filter to clear	– 2	EV	1:4
Clear to 5V black	– 9	EV	1:512

- Issues:
  - Viewing bias: often 25° from ⊥, +/-30°
  - Light passed is still polarized

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LCLV Apertures & Apodizers

- Modify the out-of-focus (OOF) point spread function (PSF) of a lens by shaping aperture
  - Impose a coded aperture pattern
  - Shape bokeh
- Definitely feasible given measured good contrast ratio and modest diffusion...
- Would want a custom patterned electrode
  - Custom costs $K, significant lead time
  - Tried laser patterning… nope.

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The Problem With Polarization

- Semi-transparent mirrors don't correctly split linearly polarized light, a problem for
  - Phase-detect autofocus (PDAF) modules
  - Some metering modules

  … not a problem for most mirrorless cameras

- Adding Quarter Wave Plate can convert the linear polarization to circular

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Sourcing A Color LCD Panel

- LCDs are widely available from < $10
  - Color, grayscale, monochrome (on/off)
  - Pixel matrix, segmented, or custom
  - TFT, PMVA, etc.; view angle choices
  - Interfaces: LVDS, MIPI, SPI, I2C…
  - Usually Backlit Transmissive, Reflective, or Backlit Transflective… + touchscreen?
- We need Transmissive without backlight
  - Remove backlight: we tried & failed
  - Peel off reflector: tends to leave residue

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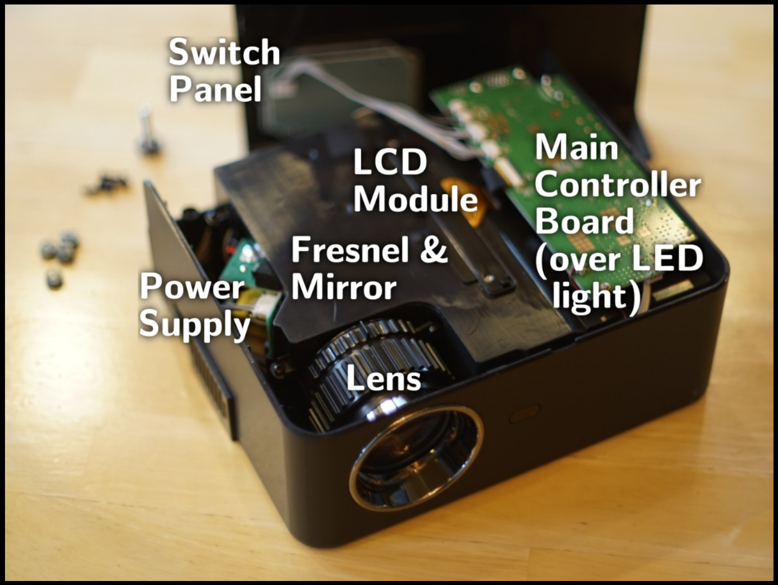
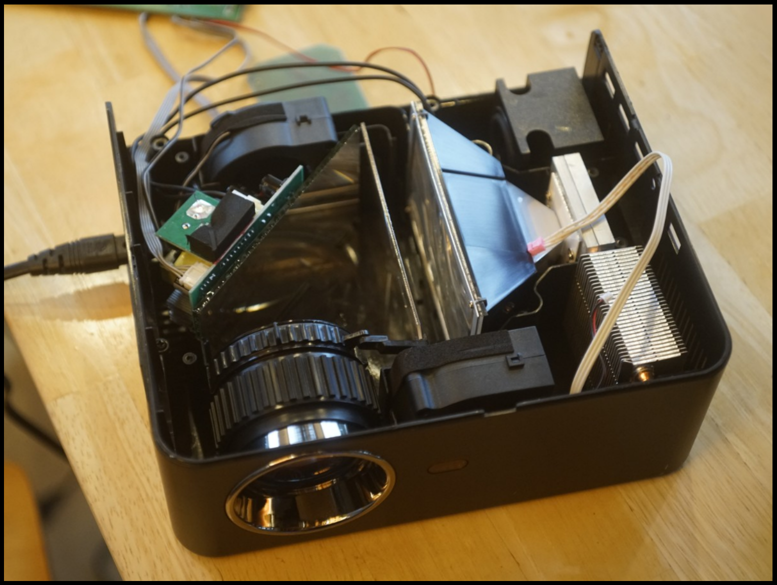
Sourcing An Unbacked Panel





- WiMiUS S2 Mini Projector – $55 with screen!
- Panel, power, and controller are usable

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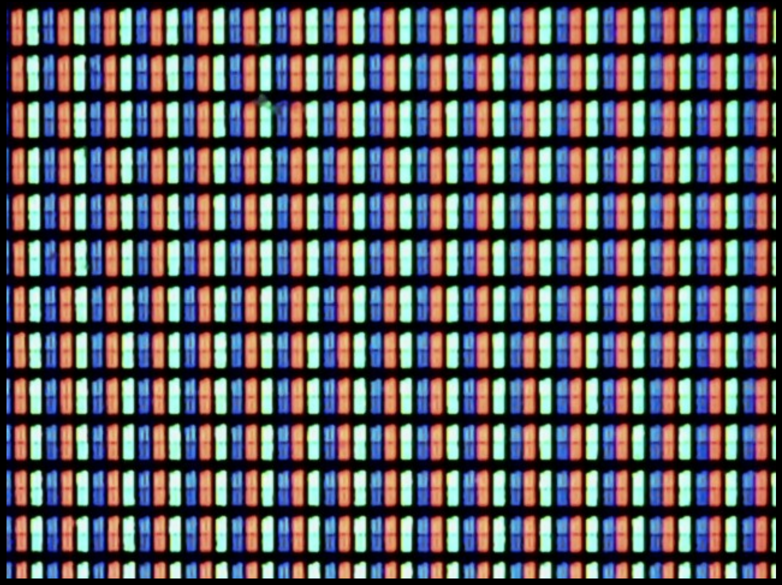
LCD Panel Specifications



- 1280x800 panel, 5000:1 contrast ratio?
- 68.7 micron “pixels”, really RGB stripe sets

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Image Quality Through LCD

- Sony A6500 + 50mm *f*/1.4 Takumar @ *f*/1.4
- Color shift: < 1% difference in RGB
- Exposure: – 4 ⅔ EV (strong polarizer!)

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Image Quality Through LCD

- Diffusion: modest loss of contrast
- Diffraction grating effects!

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Diffraction Is A Big Problem

- Pixel fill factor is about 85%
  - Rows: thick mullions, 68.7μm on center
  - Columns: thin mullions, 22.9μm on center
- Diffraction $\theta = \sin^{-1}((m * \lambda) / d)$ where:

  m : order number λ : wavelength

  d : line spacing θ : angle
- Angular displacements for m=1:

  @ 450nm: 1.13°horizontal, 0.38°vertical

  @ 530nm: 1.33°horizontal, 0.44°vertical

  @ 600nm: 1.50°horizontal, 0.50°vertical
- Measured ~ 60-90 pixels

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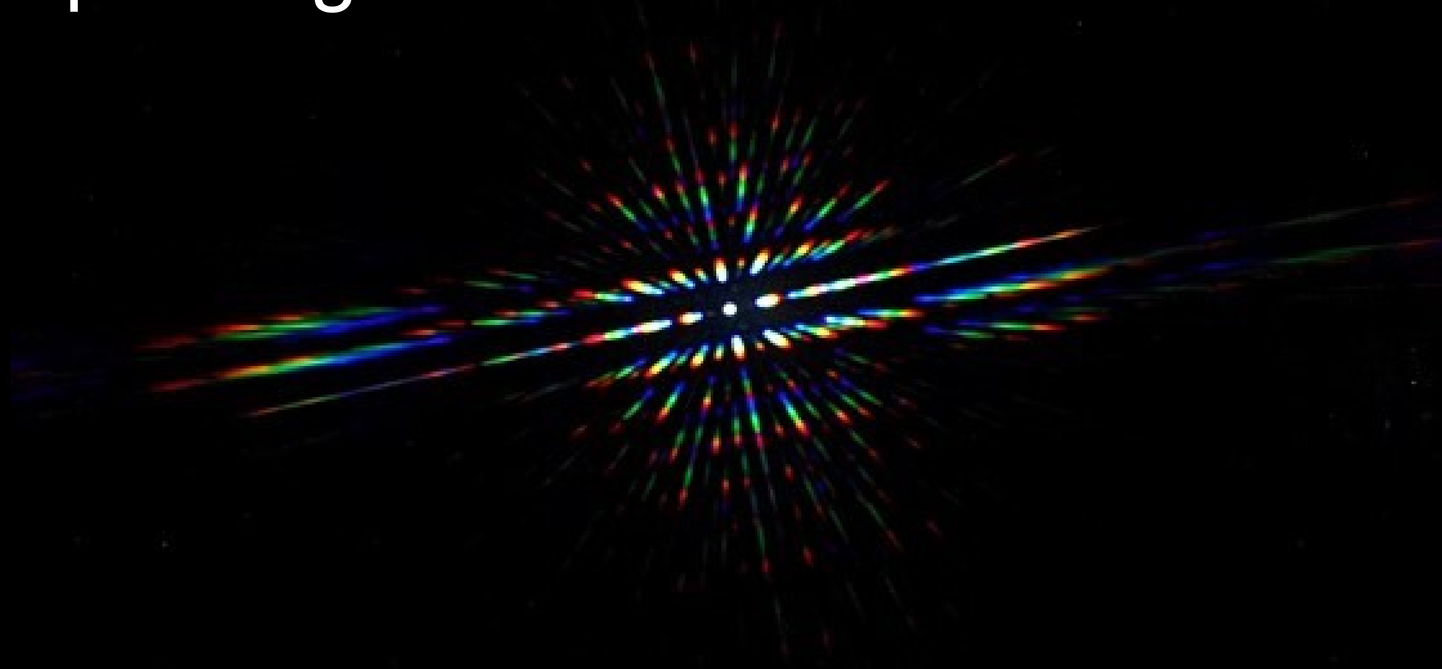
Diffraction Is A Big Problem

White point light source



LCD panel tilted relative to sensor pixels

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Diffraction Solutions

- Only *m*=1 horizontal shifts are severe
  - Vertical shifts give minor ghosting
  - Horizontal artifacts amplified by RGB?
- Computational repair: ISS-067 ISS-068
- Change the diffraction grating
  - Larger pixels; Monochrome? Square?
  - Custom segment (pixel) layouts
  - Translucent conductors (as in OLEDs?)
- Grating as part of lens design?

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RGB Filtering Through LCD

- All three color filters work,
  but R is purer than B, which is purer than G
- Mixing colors works as expected,
  with good control

Is LCD Contrast Really 1:5000?

No filter to all black	– 14	EV	1:16384
No filter to all white	– 4 ⅔	EV	1:25
All white to all black	– 9 ⅓	EV	1:645

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So Many Answers...

- Contrast ratio: more than good enough
- Timing & refresh issues: dealt with
- Translucent vs. transparent: minor diffusion
- Polarization effects on the camera:
  - OK on mirrorless
  - DSLRs need circular polarization
- LCD pixelization effects: horrific **diffraction**!
- Color LCD RGB subpixels: OK

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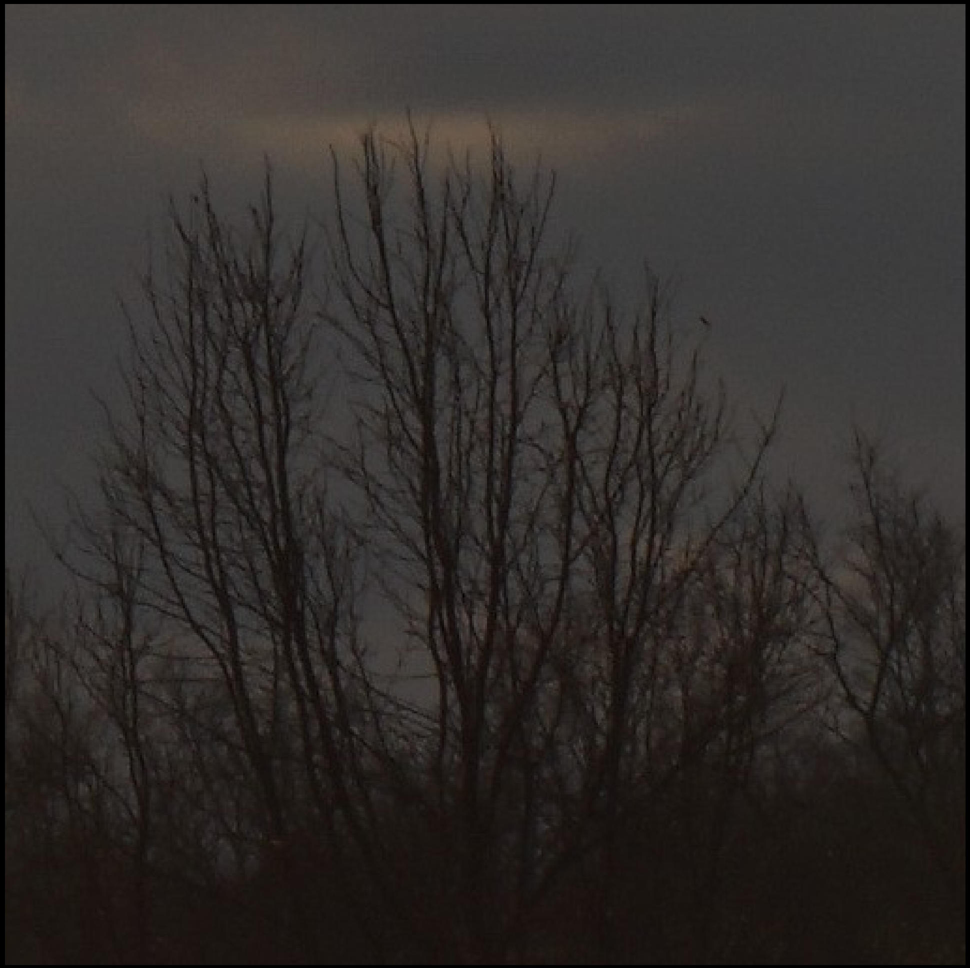
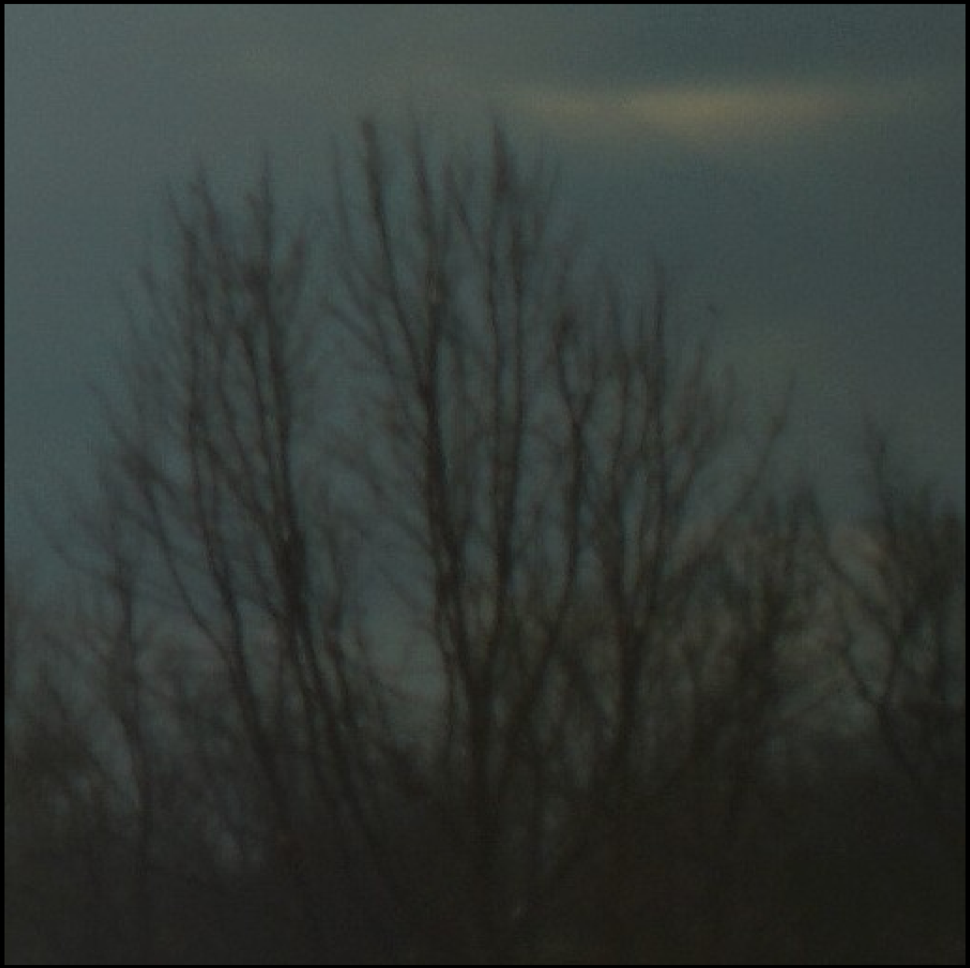
Conclusions

- Programmable Liquid Crystal Apertures and Filters for Photographic Lenses?
  - Simple LCLV usable for both
  - LCD technology is viable for both
  - LCD **pixels act as a diffraction grating**; fixing LCD likely not economically viable
- Future work
  - Custom LCLV apertures (not laser mod)
  - Use of color LCD as single-pixel modulator

Diffusion Effect (42MP)





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