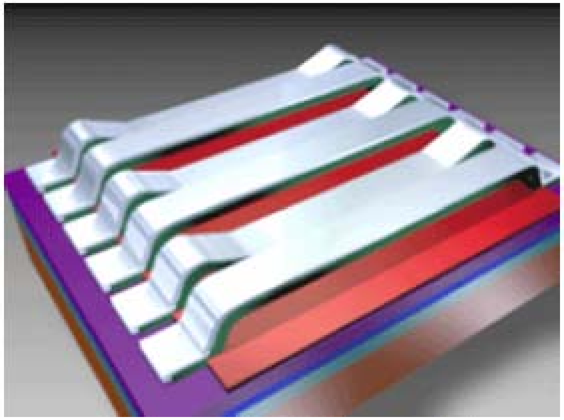
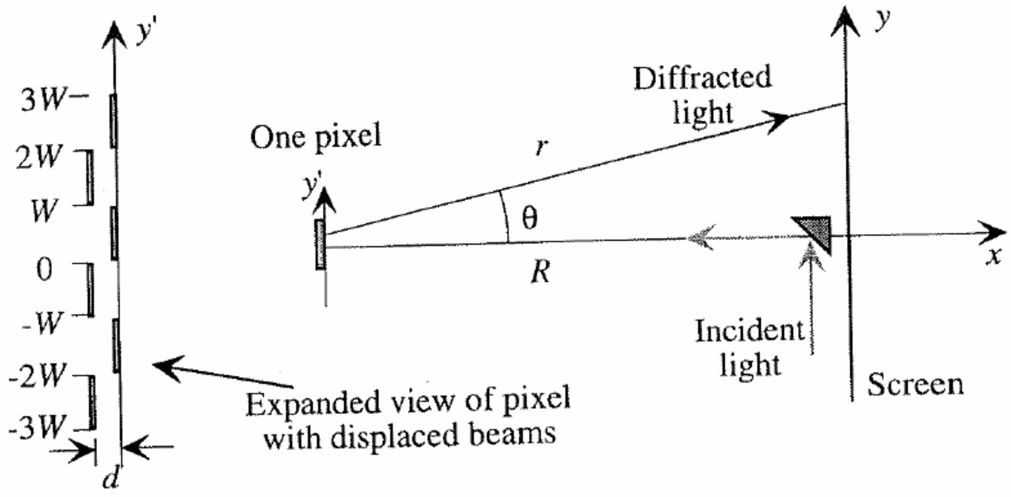
The Optics of Grating Light Valve Displays





Contents

- Crash course in diffraction theory
- How to measure the width of a hair with a laser pointer
- How to design a grating light valve (GLV) display
- Questions and answers (hopefully)

Diffraction of Light

Maxwell's equations may be reduced to the scalar wave equation.

$$\begin{aligned}
\nabla \times \vec{H} &= \epsilon \frac{\partial \vec{E}}{\partial t} \\
\nabla \times \vec{E} &= -\mu_0 \frac{\partial \vec{H}}{\partial t} \\
\nabla \cdot \vec{E} &= 0 \\
\nabla \cdot \vec{H} &= 0,
\end{aligned}$$

$$\Longrightarrow$$

$$\nabla^2 U = \frac{1}{c^2}\frac{\partial^2 U}{\partial t^2}$$

U may be any component of vectors H and E

Diffraction of light

$$\nabla^2 U = \frac{1}{c^2}\frac{\partial^2 U}{\partial t^2}$$

Example solutions of the wave equation are the plane wave and spherical wave:

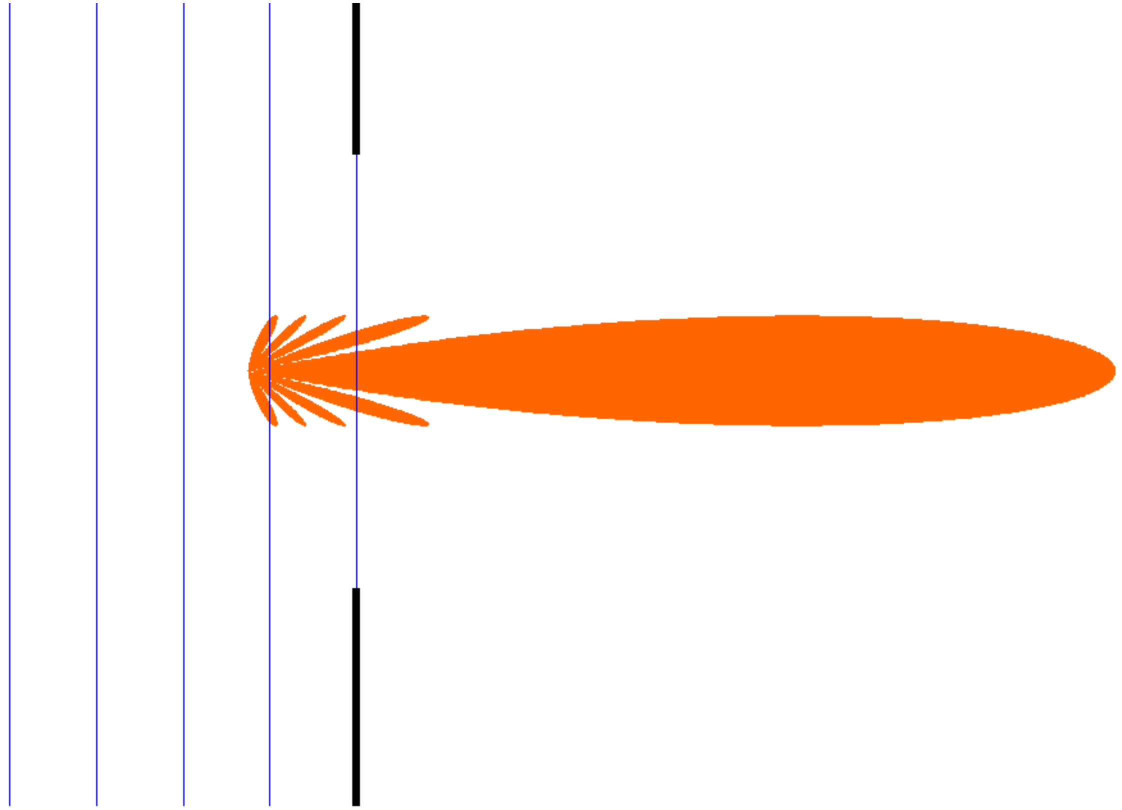
$$U = U_0 \exp(i\vec{k}\vec{r} - \omega t - \phi)$$

$$|\vec{k}| = k = \omega/c$$

$$U = \frac{U_0}{r}\exp(ikr - \omega t - \phi)$$

Diffraction of light

Light bends or diffracts around edges, and shrinking the size of an aperture will increase diffraction.



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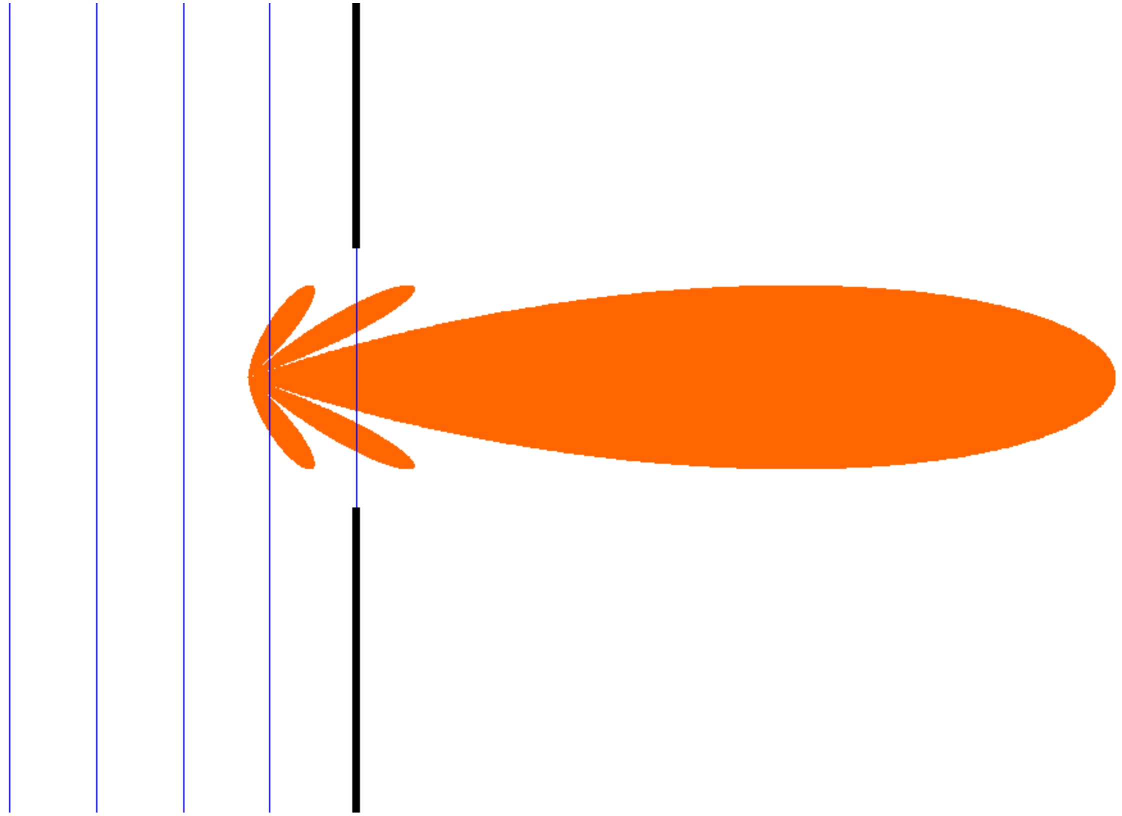

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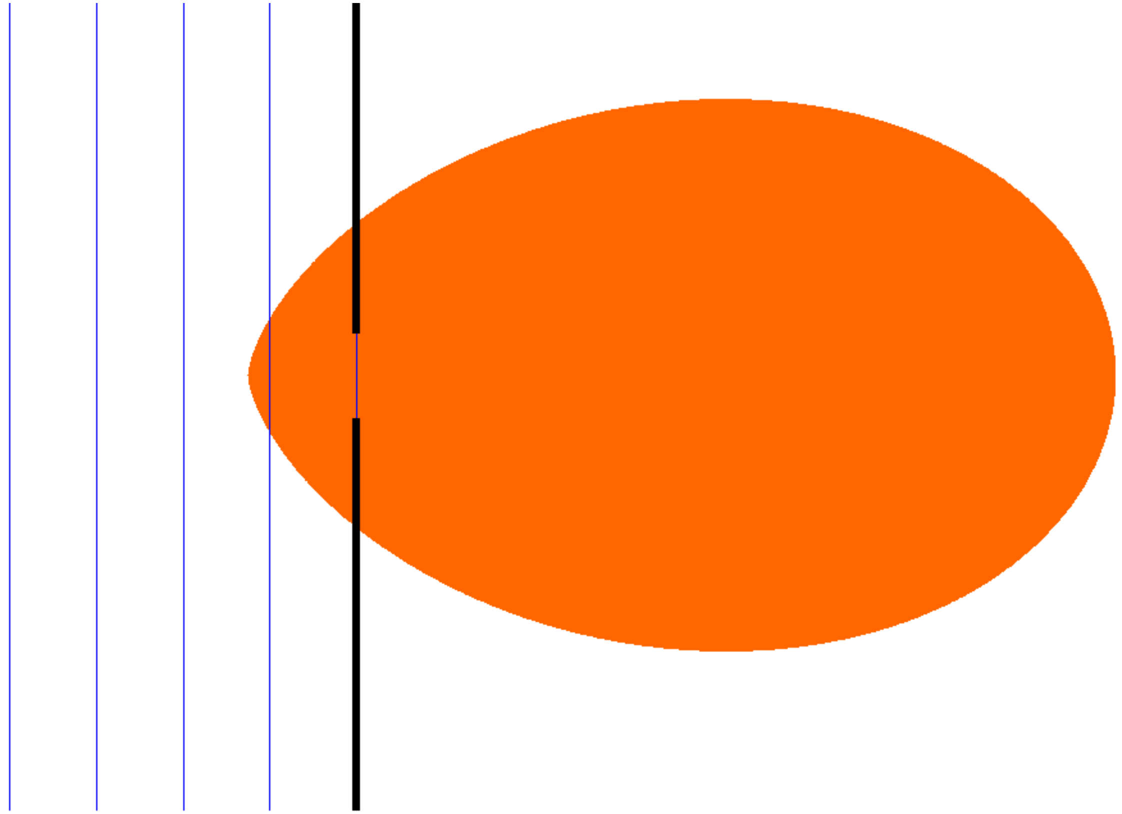
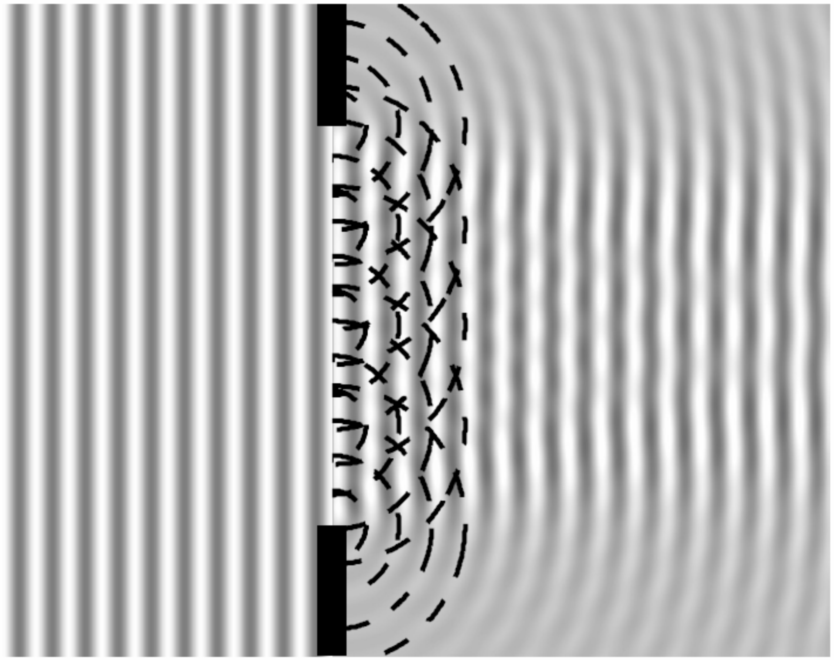


The *Huygens-Fresnel principle* says:

”The light disturbance at a point P arises from the superposition of secondary waves that proceed from a surface situated between this point and the light source.”

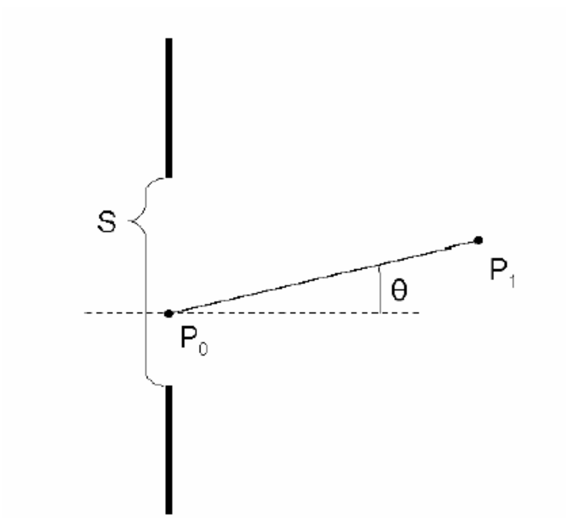
Christiaan Huygens



Augustin-Jean Fresnel

Diffraction of Light

A mathematical representation of the Huygens-Fresnel principle:



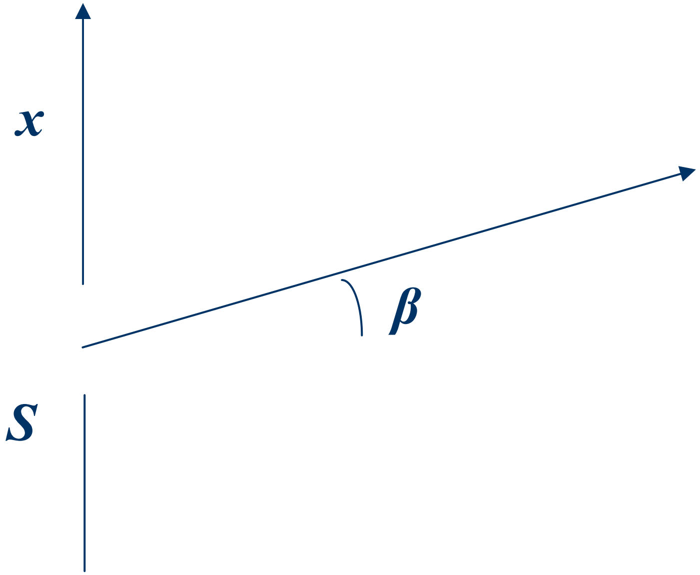
$$U(P_1) = \frac{1}{\mathrm{i}\lambda} \iint_S U(P_0) \frac{\exp(\mathrm{i}kr_{01})}{r_{01}} \cos\theta \, \mathrm{d}s$$

Spherical wave

Diffraction of Light

Far away from the aperture, and for small diffraction angles we may use the Fraunhofer approximation.

$$U(\beta) = C\int_S U(x)\exp(ik\beta x)\mathrm{d}x$$



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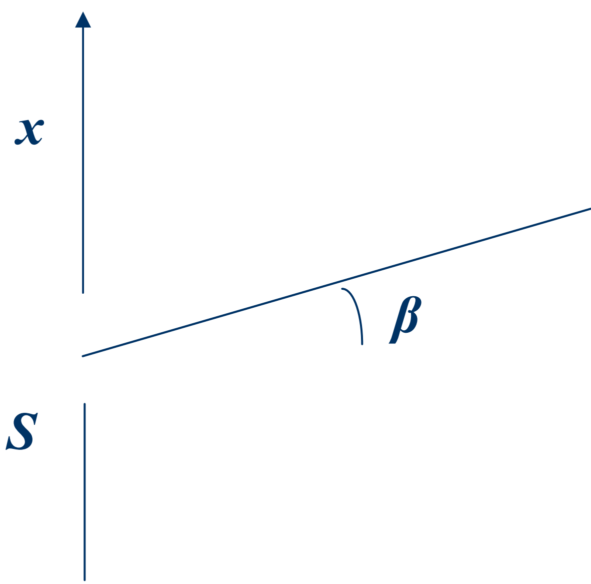


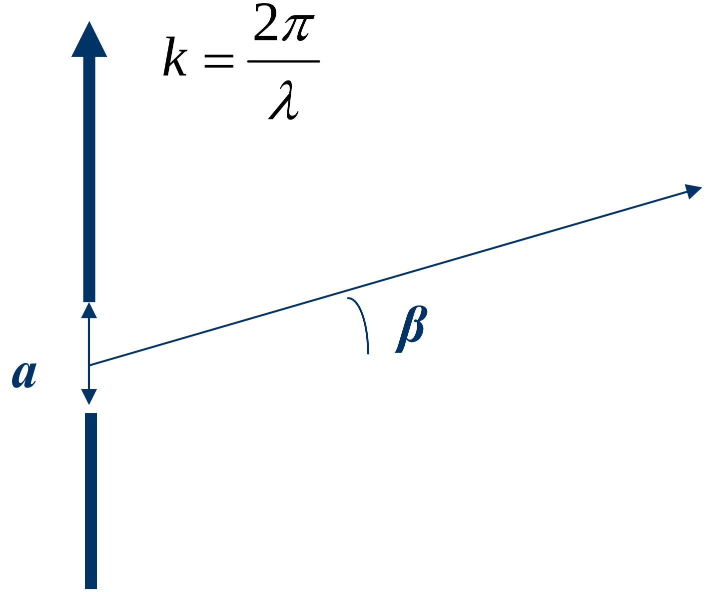
Fourier transform!

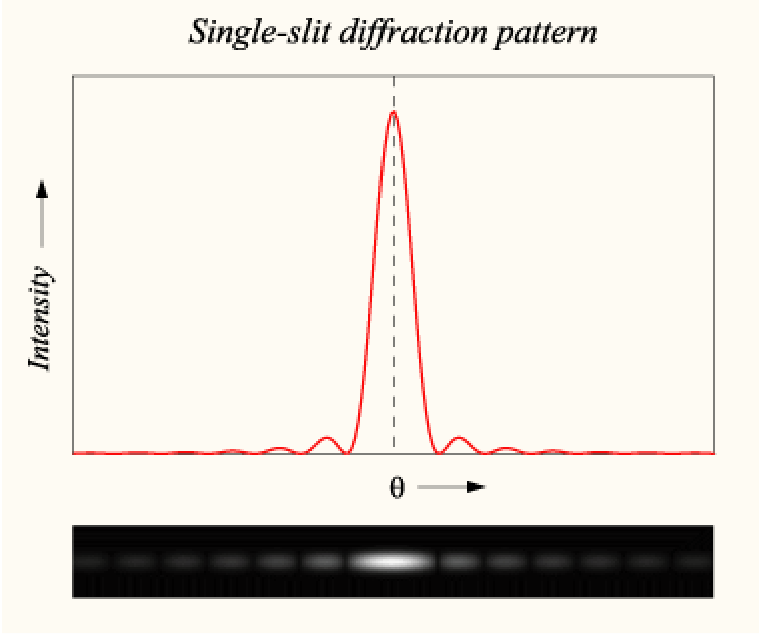
Diffraction of Light

We may now calculate the diffraction from a slit:

$$U = \frac{\sin\left(\frac{k\beta a}{2}\right)}{\left(\frac{k\beta a}{2}\right)}, I = \left[\frac{\sin\left(\frac{k\beta a}{2}\right)}{\left(\frac{k\beta a}{2}\right)}\right]^2$$

$$k = \frac{2\pi}{\lambda}$$

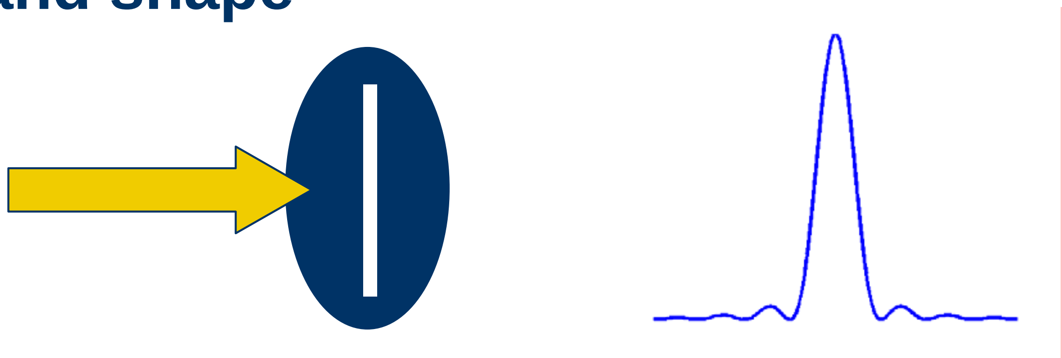




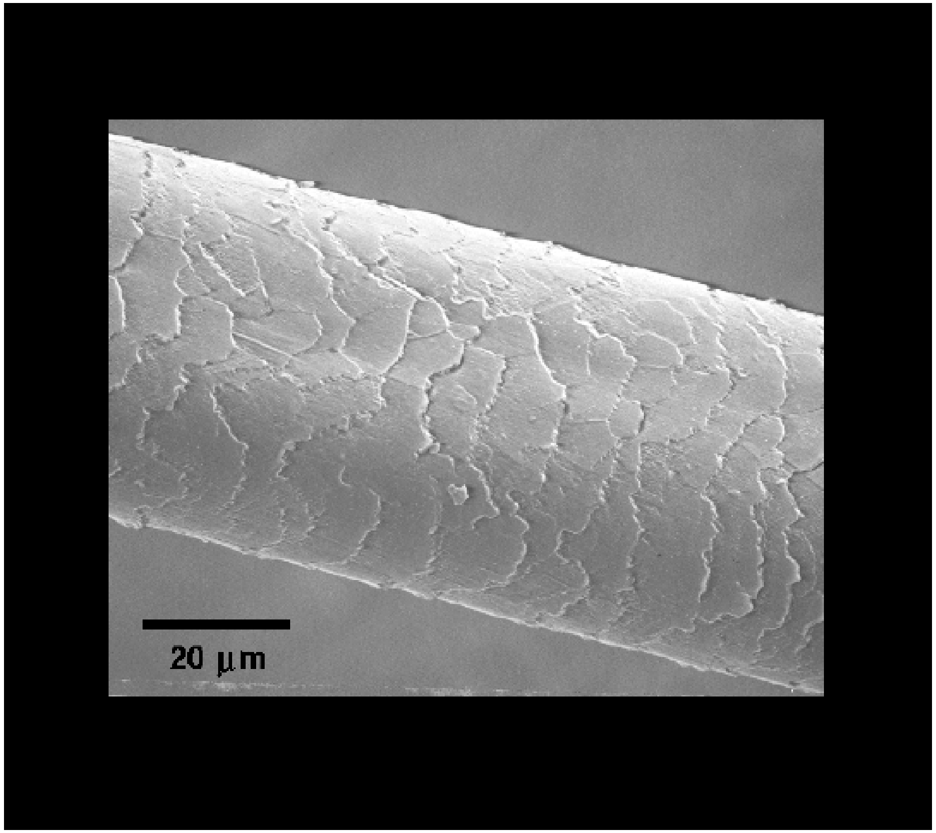
Minima for: $$\beta = m\frac{\lambda}{a}$$

Babinet's principle

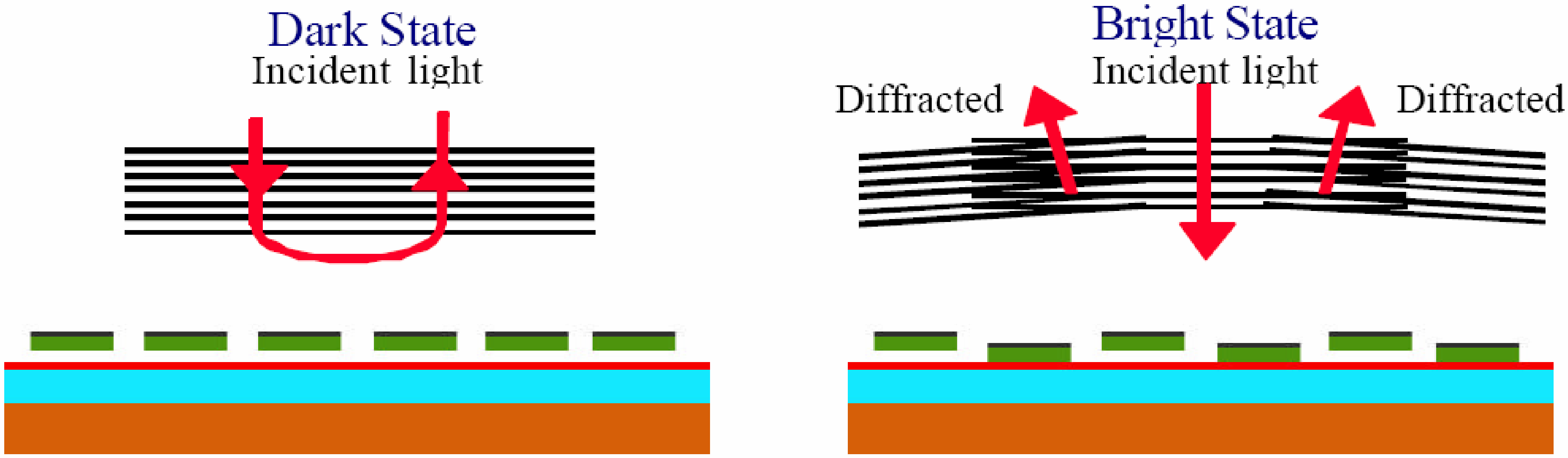
The diffracted field from an aperture is the same as from an obscuration of the same size and shape



What is the diameter of a hair?



Diffraction from a grating light valve



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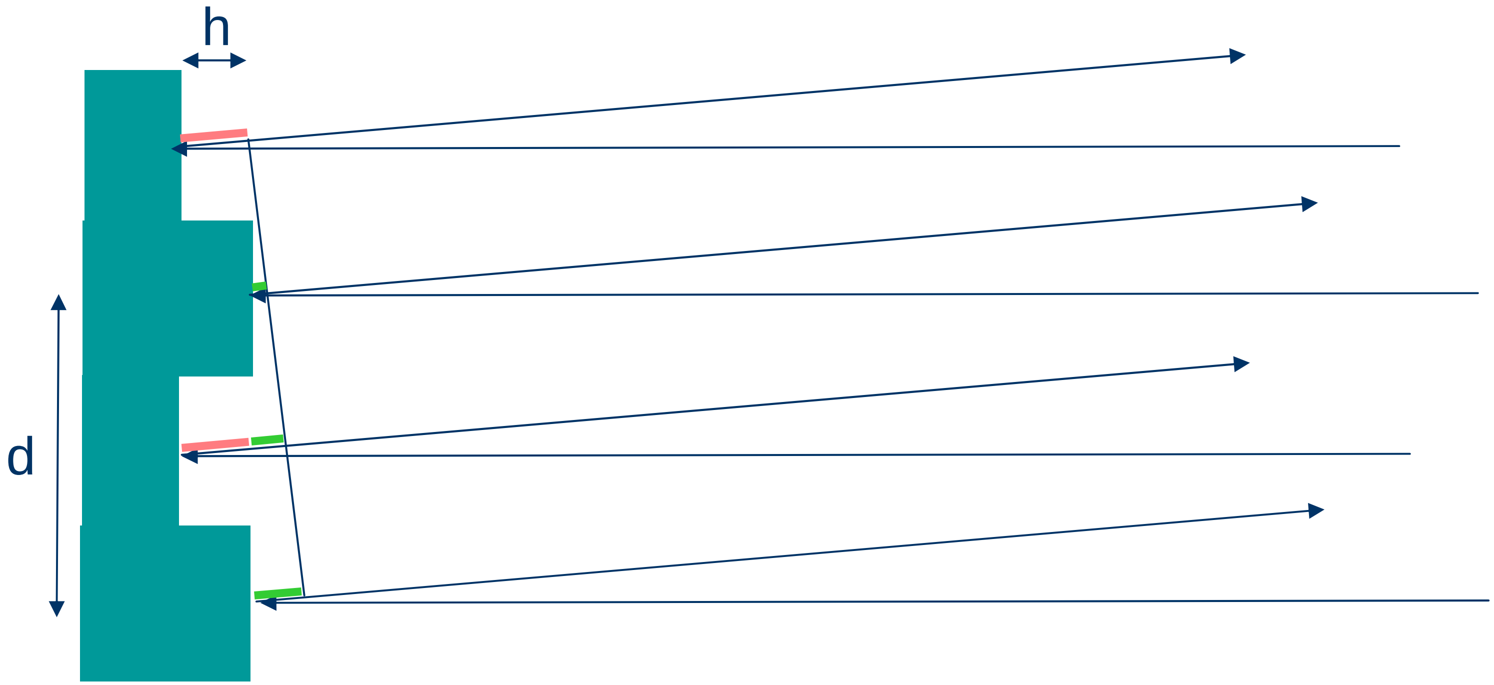
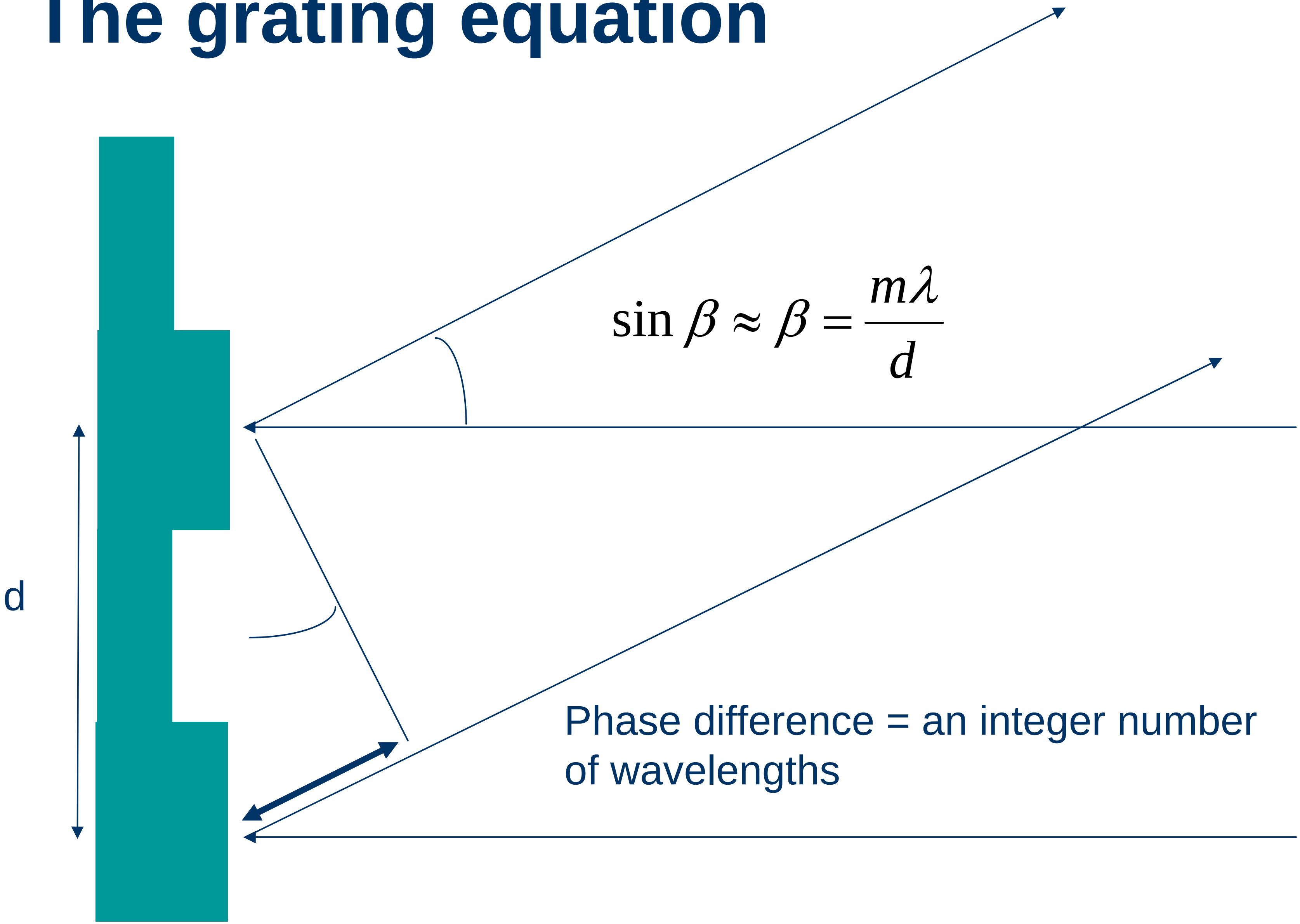


$$U = \frac{\sin\left(\frac{k\beta d}{4}\right)}{\left(\frac{k\beta d}{4}\right)} \frac{1}{N} \sum_{n=1}^{N} \left[\exp(ik\beta nd) + \exp(ik\beta(n+\tfrac{1}{2})d) \exp(2ikh) \right]$$

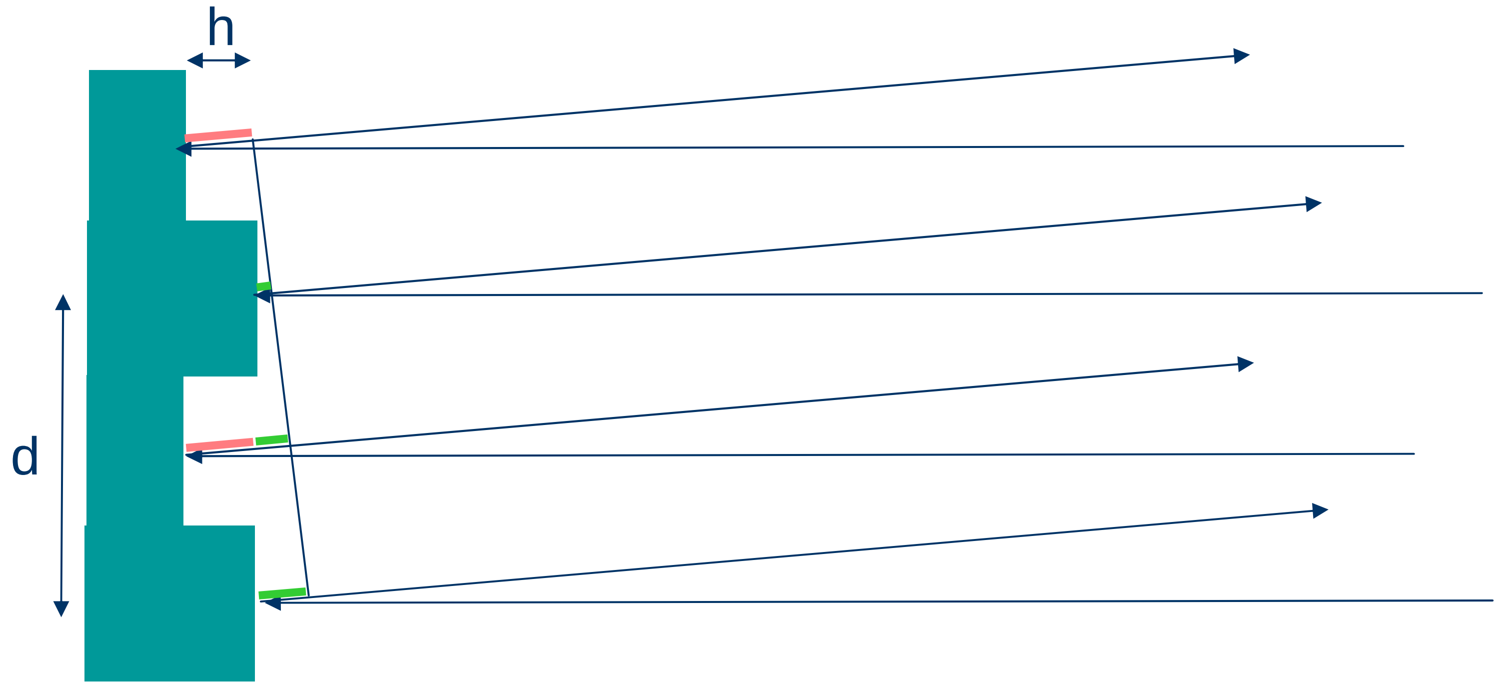
The grating equation



$$\sin\beta \approx \beta = \frac{m\lambda}{d}$$

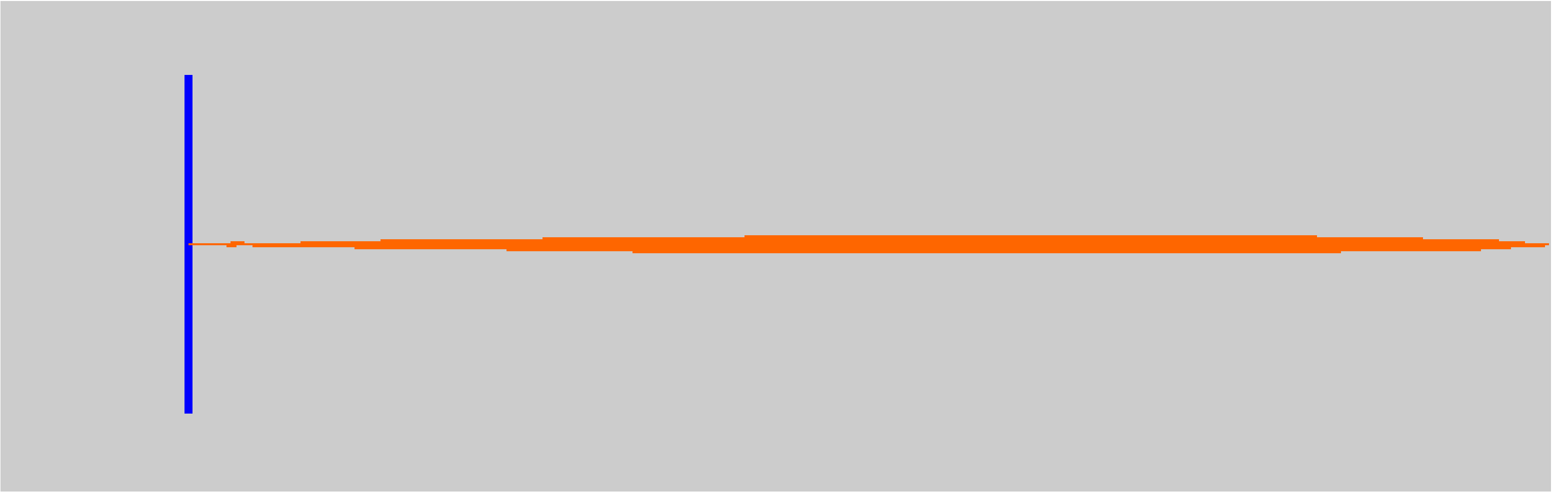
Phase difference = an integer number of wavelengths

Diffraction from a grating light valve



$$\frac{I}{I_0} = \left| \frac{U}{U_0} \right|^2 = \frac{4}{\pi^2} \sin^2(kh)$$

Diffraction from a grating light valve



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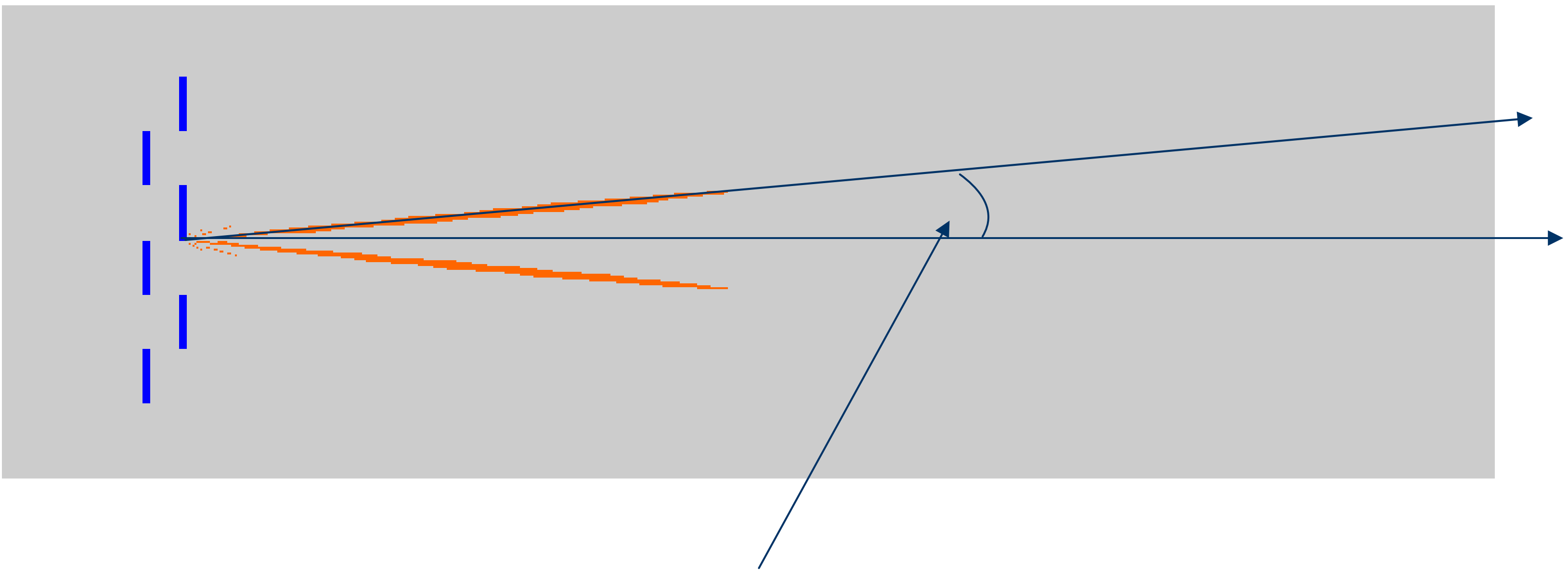
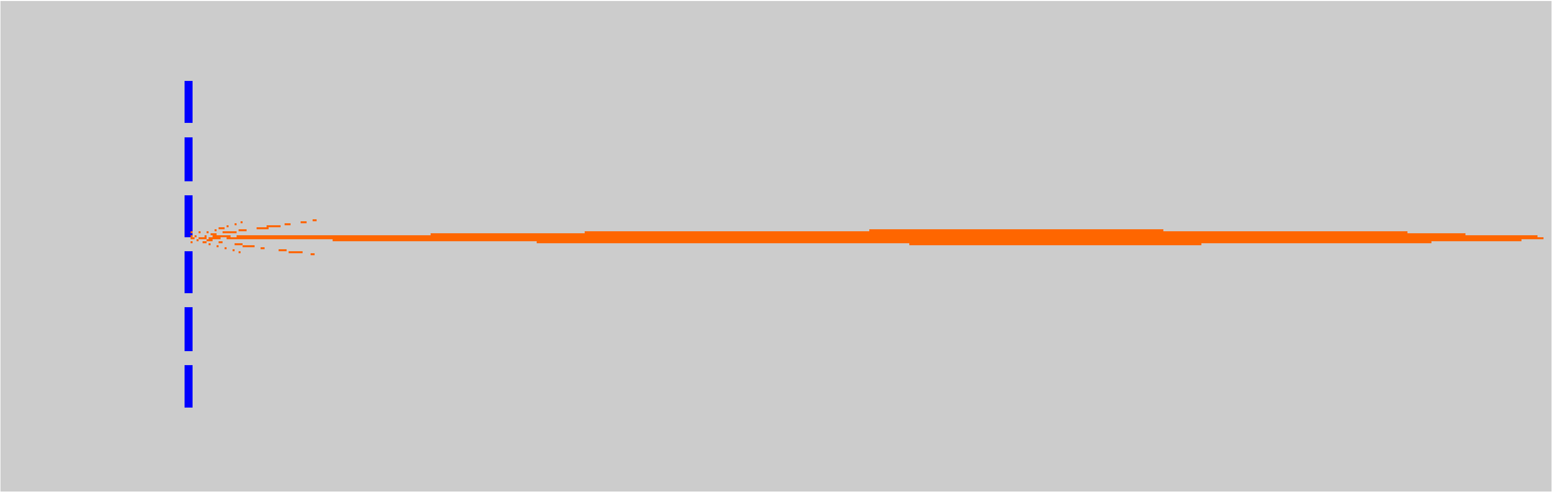


Angle given by the grating equation

Diffraction from a grating light valve



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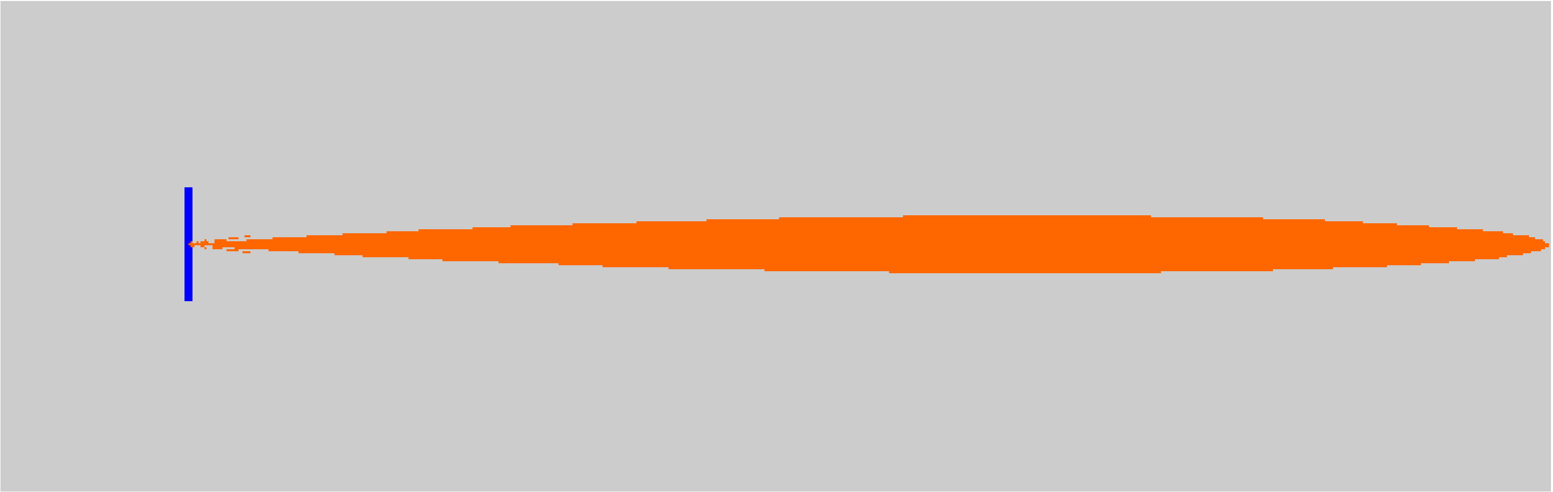
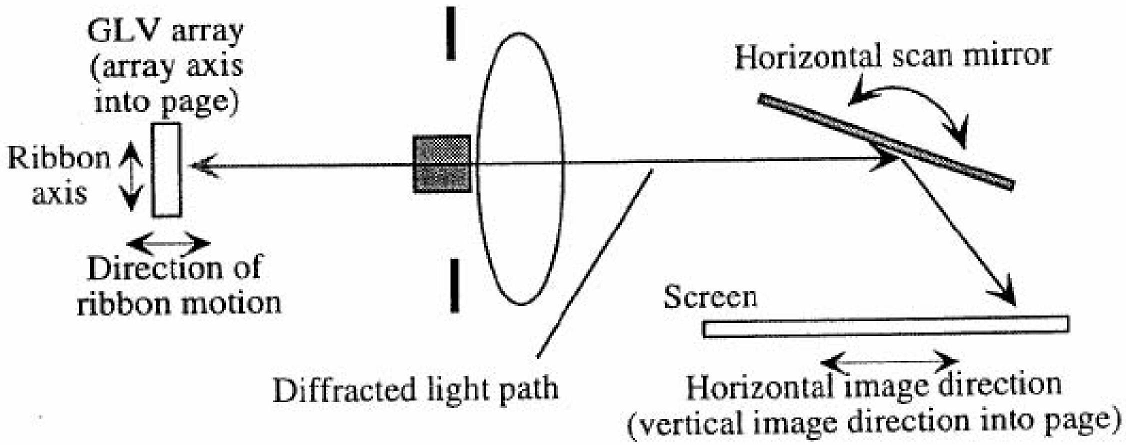
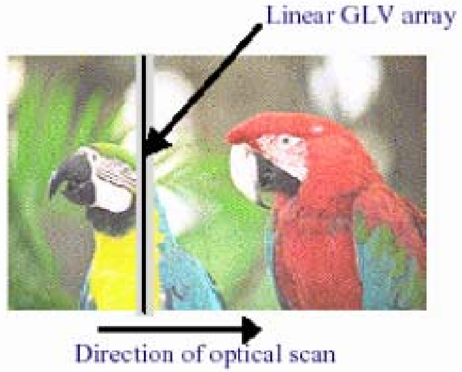


How to design a GLV display device

- One line of mirror elements only





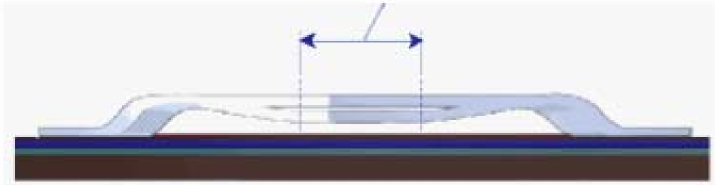
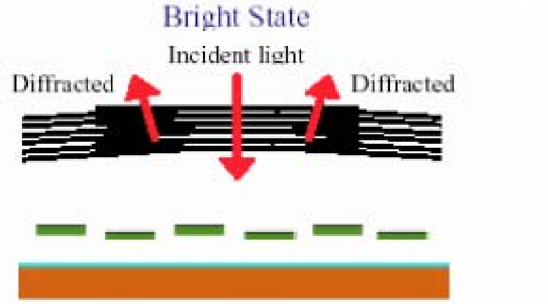


Figure 1: A GLV pixel with alternate reflecting ribbons electrostatically deflected to produce a square-well diffraction grating (vertical deflection greatly exaggerated)



How to design a GLV display device:

Design targets

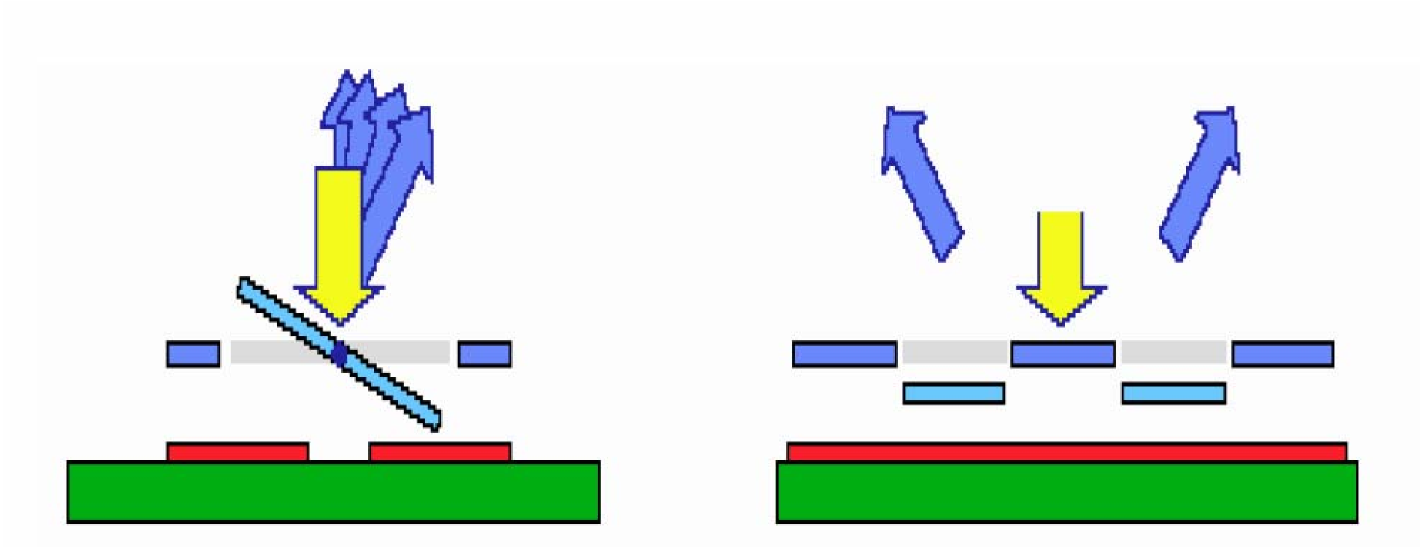
- 1000 pixels, 2000 horizontal resolution
- 10000 lumen total = 10 lumen per pixel
- 96 Hz refresh rate => 4 microsecond pixel time

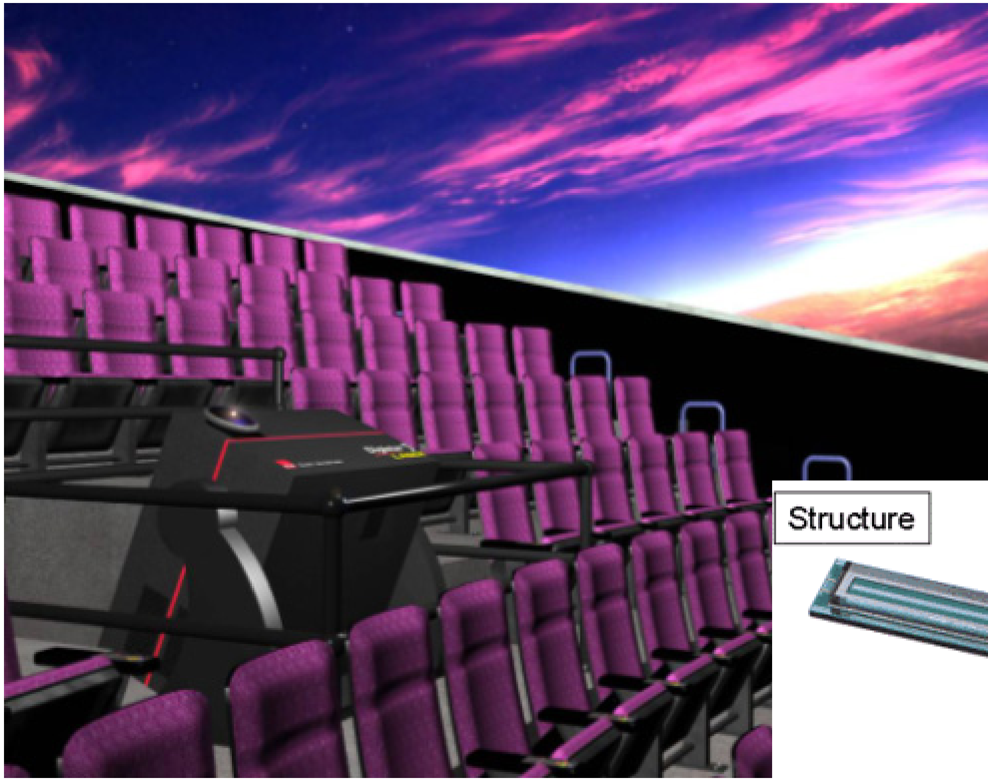
How to design a GLV display device:

Design constraints

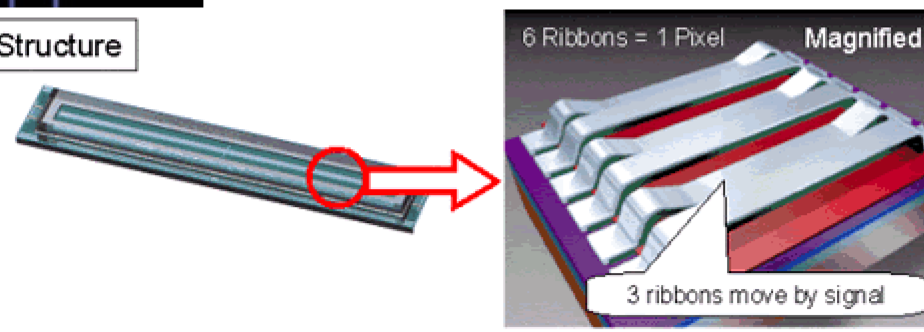
- Minimum feature size (gaps between ribbons) 0.6 µm
- Minimum ribbon distance 3 µm gives maximum diffraction angle and maximum throughput
- Required yield -> Maximum chip size
- Available laser light source (Xenon lamp is not powerful enough)

Two display principles





Structure



Principle of GLV Display