Wavefront detection & modulation

Detection

- Types of photodetectors
- Digital imaging
- Color

Modulation

- Photographic film
- Spatial light modulators
- Binary optics

Imaging: detection of light

a) photothermal (pyroelectric)
b) photoconductivity

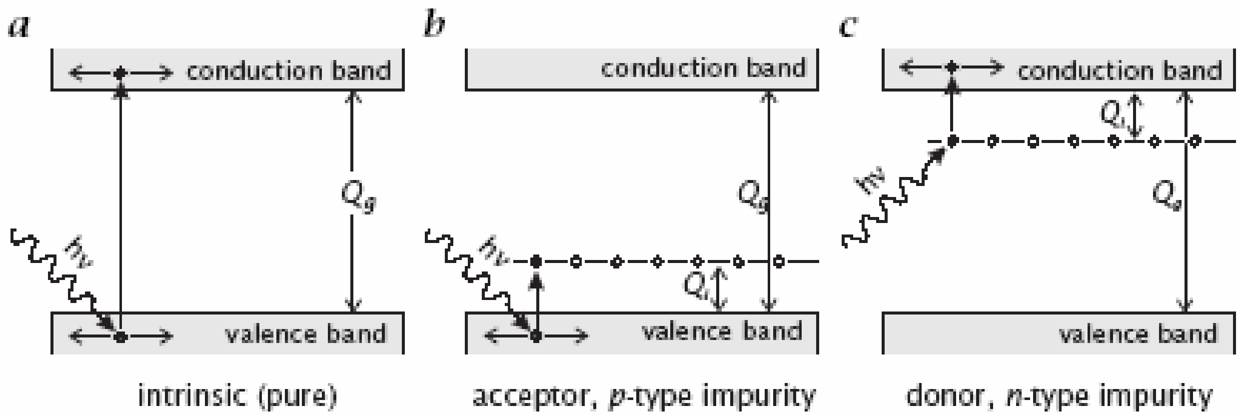


Figure 4.6: Energy-band diagrams for a intrinsic photoconductors; b extrinsic p-type photoconductors; and c extrinsic n-type photoconductors.

c) photoresistivity (bolometers)
d) photomechanical

B. Jähne & H. Haußecker,
"Computer Vision and Applications,"
Academic Press 2000

Digital imaging

Charge Coupled Devices (CCDs)

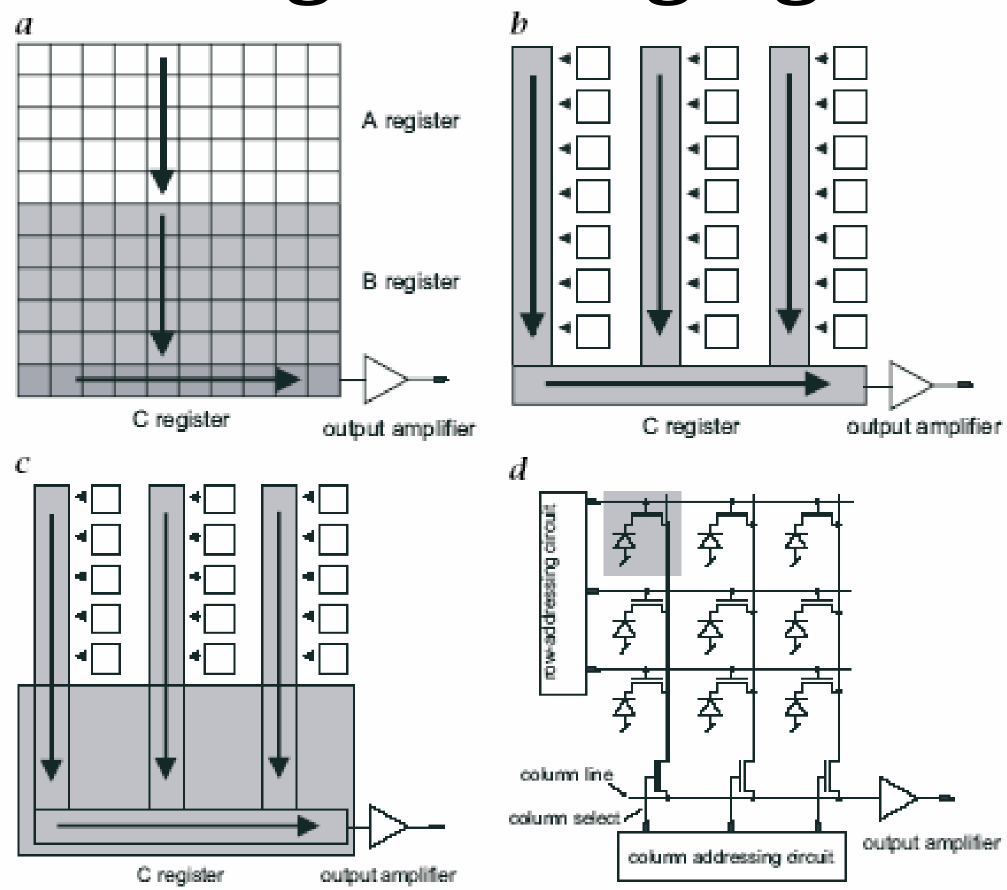


Figure 5.16: The four most important architectures of solid-state image sensors: a frame-transfer (FT) CCD with its three registers; b interline-transfer (IT) CCD with column light shields for vertical charge transfer; c field-interline-transfer (FIT) CCD, combining FT-CCD and IT-CCD principles for studio and broadcast applications; d traditional photodiode array image sensor with one photodiode and one selection transistor per pixel.

B. Jähne & H. Haußecker, "Computer Vision and Applications," Academic Press 2000

Digital imaging

CMOS

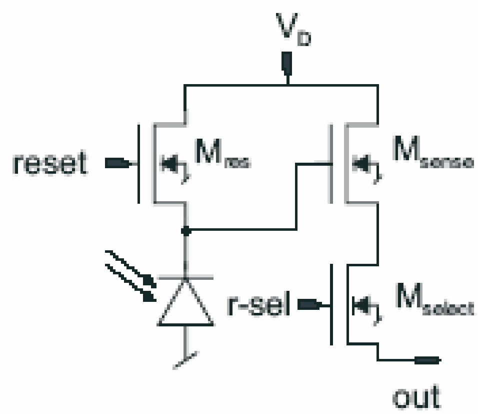
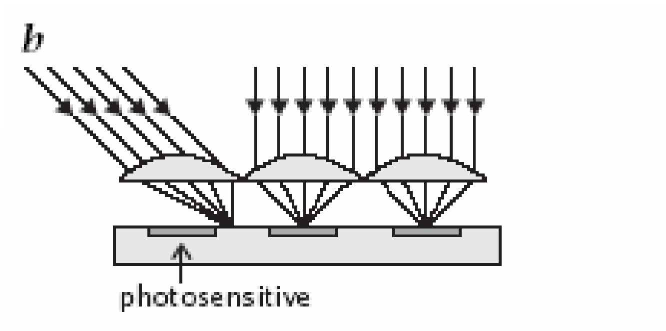


Figure 5.17: Schematic diagram of an APS pixel, consisting of a photodiode, a reset transistor, a sense transistor, and a row-select transistor. The active load transistor that completes the source-follower circuit is shared by all pixels in a column, and it is therefore needed only once per column.



microlens arrays improve sensitivity

APS=active pixel sensor

B. Jähne & H. Haußecker, "Computer Vision and Applications," Academic Press 2000

Color

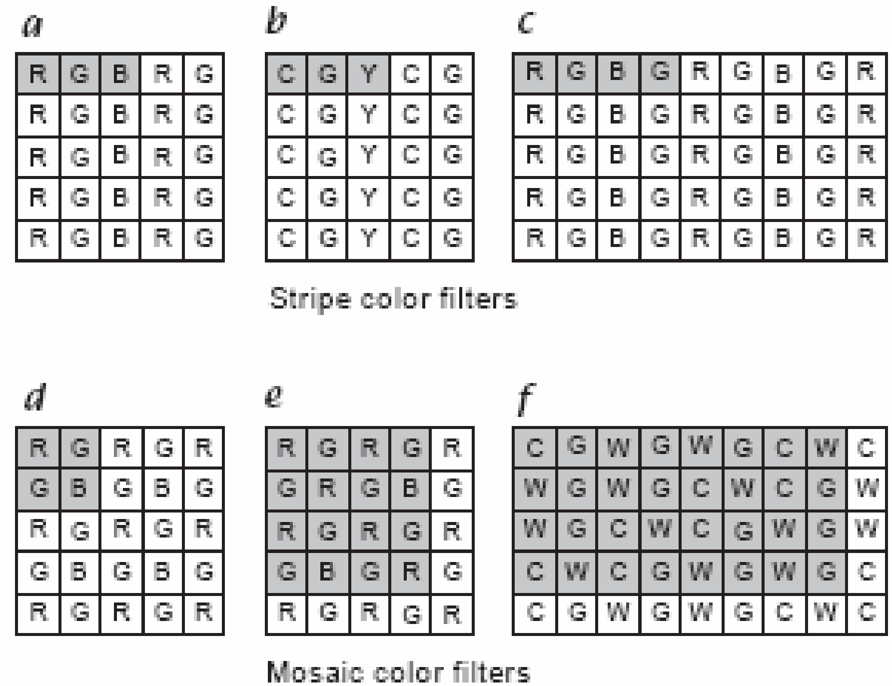
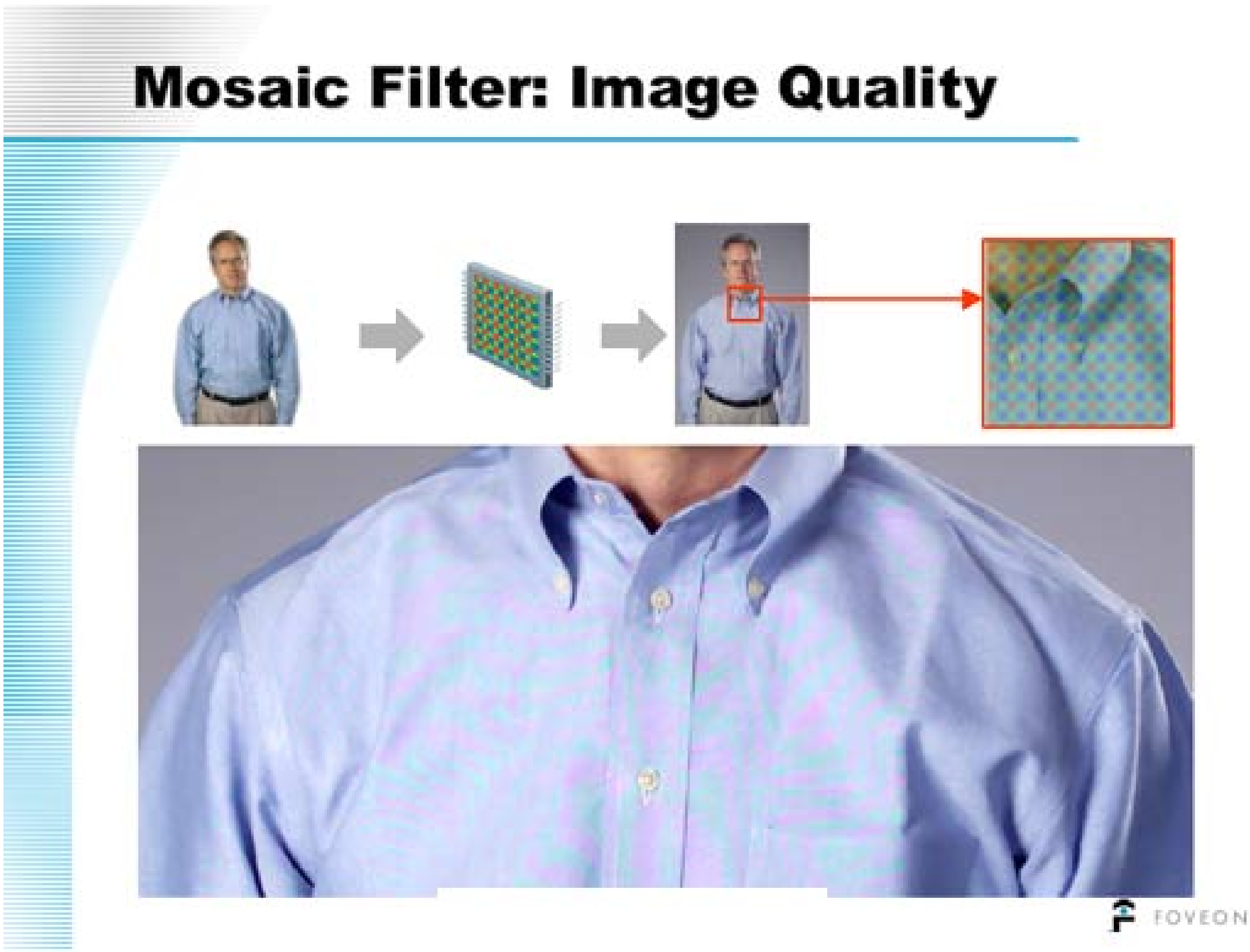


Figure 5.21: Illustration of different color filter types for single-chip color sensors. The unit cell (basic arrangement of color filter patches that is periodically repeated on the image sensor) is shown as shaded rectangle: a primary color (RGB) stripe filter with 3 × 1 unit cell; b complementary color (CGY) stripe filter with 3 × 1 unit cell; c primary color (RGB) stripe filter with 4 × 1 unit cell; d Bayer color mosaic filter with 2 × 2 unit cell; e Bayer color mosaic filter with 4 × 4 unit cell; f shift-8 color mosaic filter using complementary colors in an 8 × 4 unit cell.

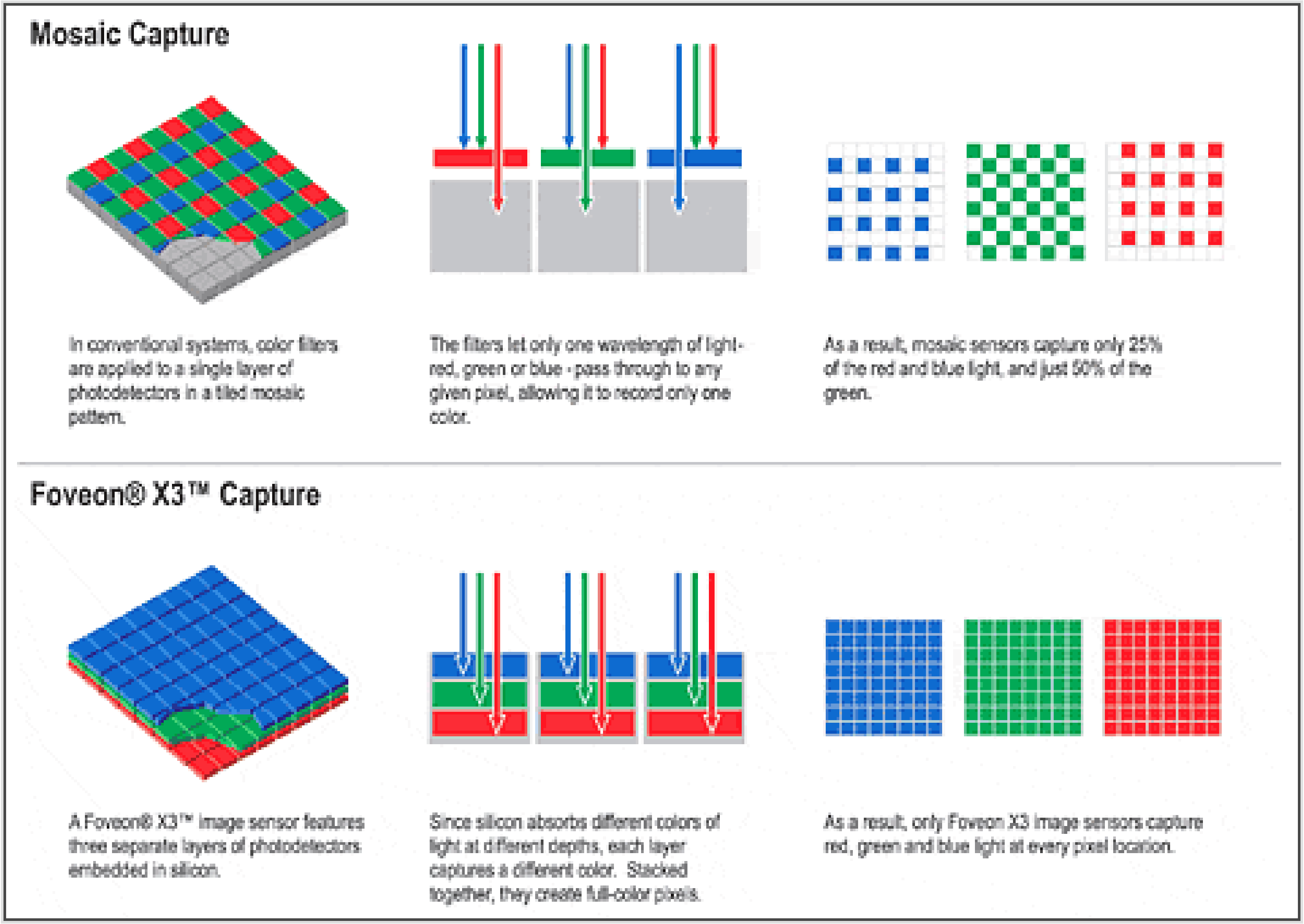
B. Jähne & H. Haußecker,
"Computer Vision and Applications,"
Academic Press 2000

Color



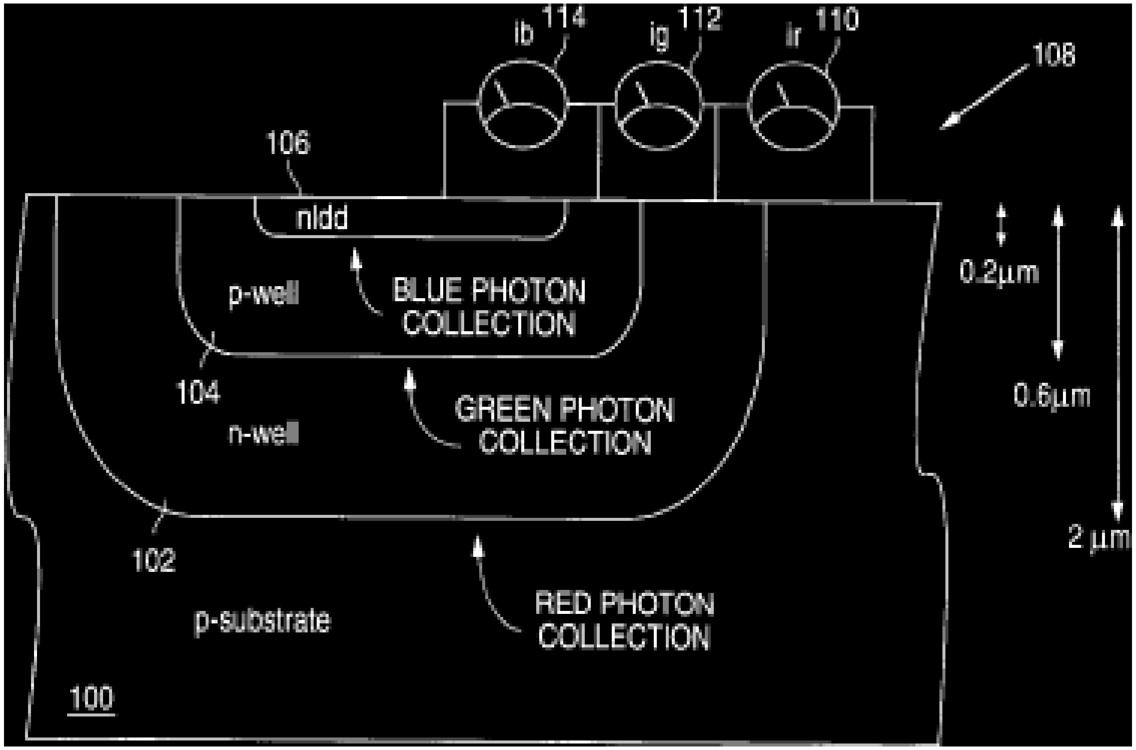
http://www.dpreview.com/news/0202/02021102foveonx3tech.asp

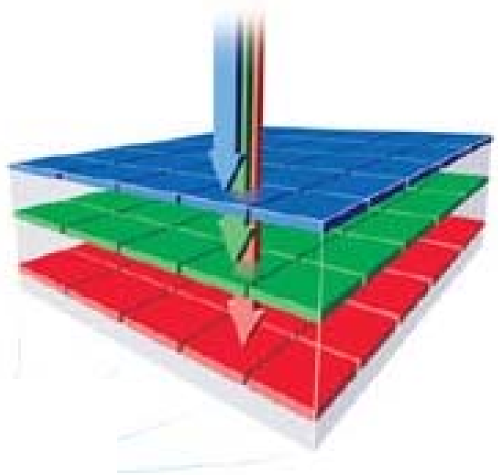
Improved color: the Foveon



http://www.dpreview.com/news/0202/02021101foveonx3.asp

Improved color: the Foveon

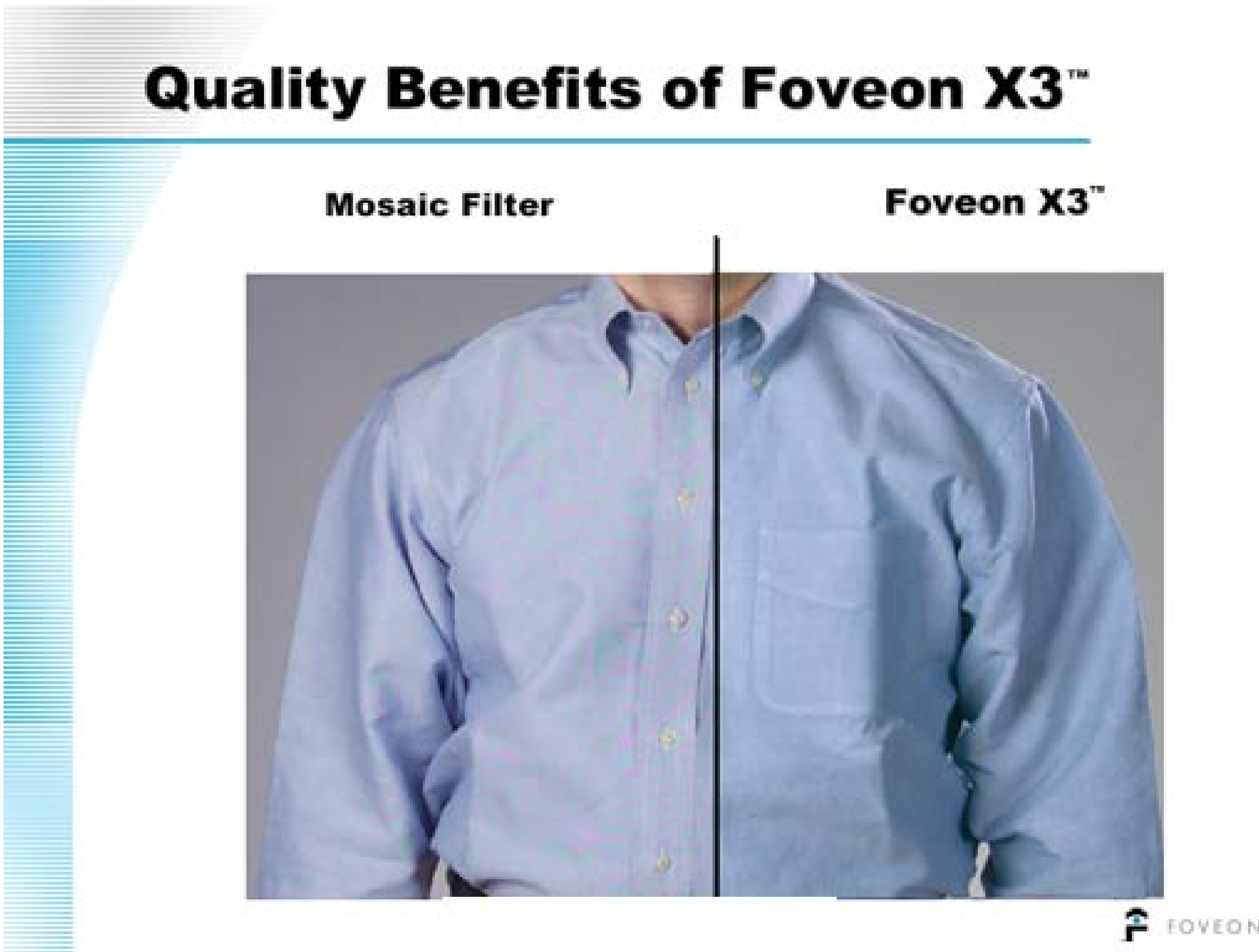




US Patent 5,965,875

http://www.dpreview.com/news/0202/02021102foveonx3tech.asp

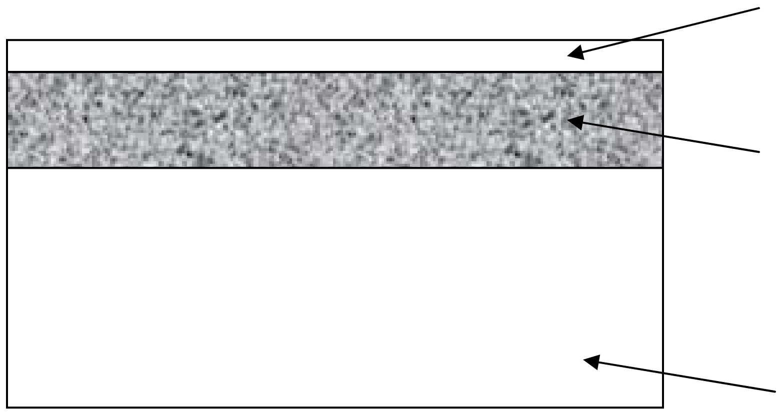
Improved color: the Foveon



http://www.dpreview.com/news/0202/02021102foveonx3tech.asp

Light modulation

Photographic films / plates



Exposure: $Ag^+ + e^- \rightarrow Ag$ (or $2Ag^+ + 2e^- \rightarrow Ag_2$)

development speck

Collection of development specks = ***latent image***

Development (1st chemical bath): converts specks to metallic silver

Fixing the emulsion (2nd chemical bath): removal of unexposed silver halide

Photographic film / plates

- Exposure (energy) : energy incident per unit area on a photographic emulsion during the exposure process (units: mJ/cm^2)

  Exposure = incident intensity × exposure time $E = I_{\text{expose}} \times T$

- Intensity transmittance : average ratio of intensity transmitted over intensity incident after development

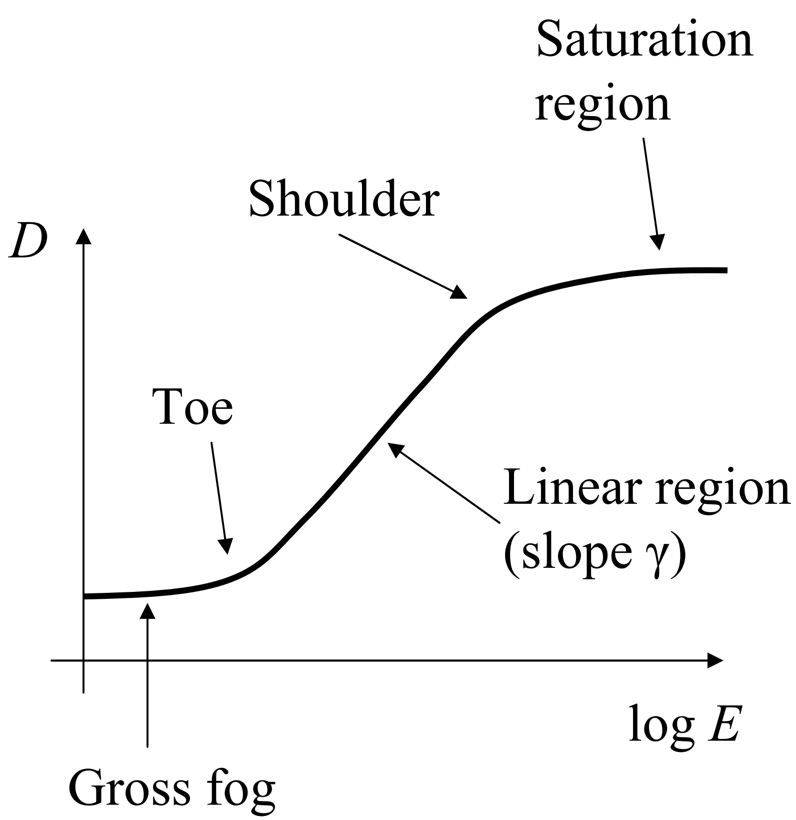
$$\tau(x,y) = \underset{\text{average}}{\text{local}} \left\{ \frac{I \text{ transmitted at } x, y}{I \text{ incident at } x, y} \right\}$$

- Photographic density

$$D = \log_{10}\left(\frac{1}{\tau}\right) \quad \Leftrightarrow \quad \tau = 10^{-D}$$

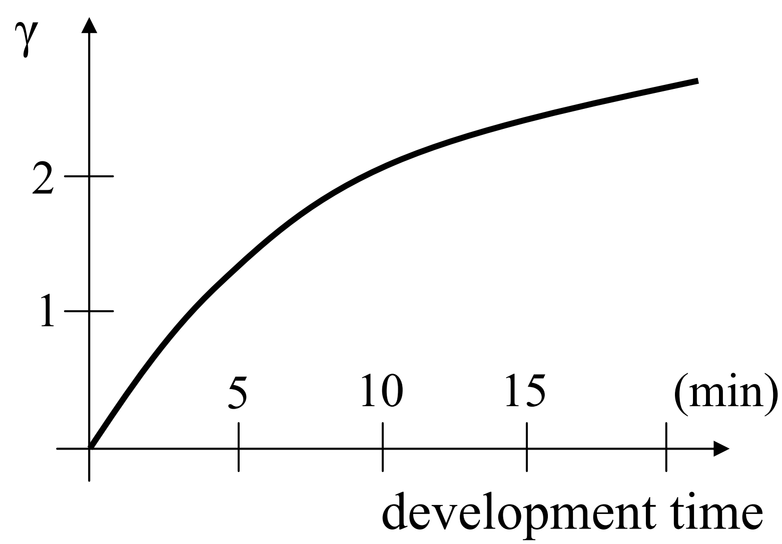
Photographic film / plates

- Hurter-Driffield curve



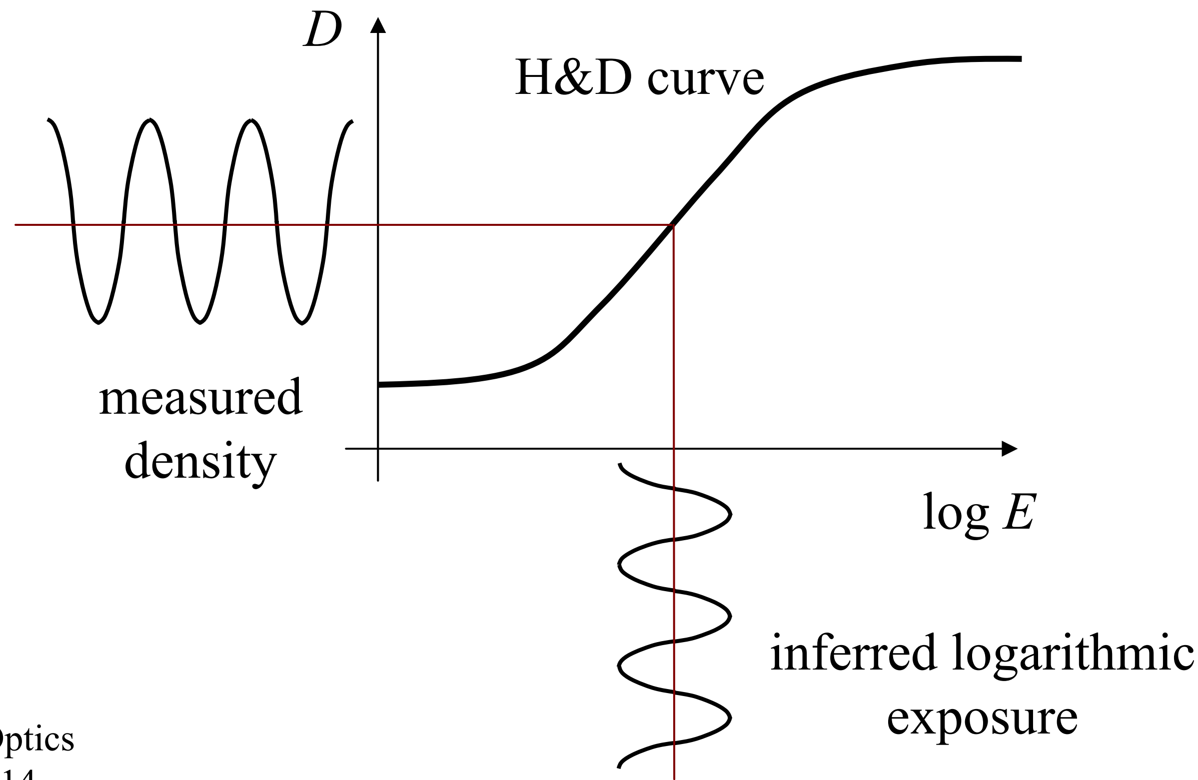
- Gamma curve

γ high/low : high/low contrast film

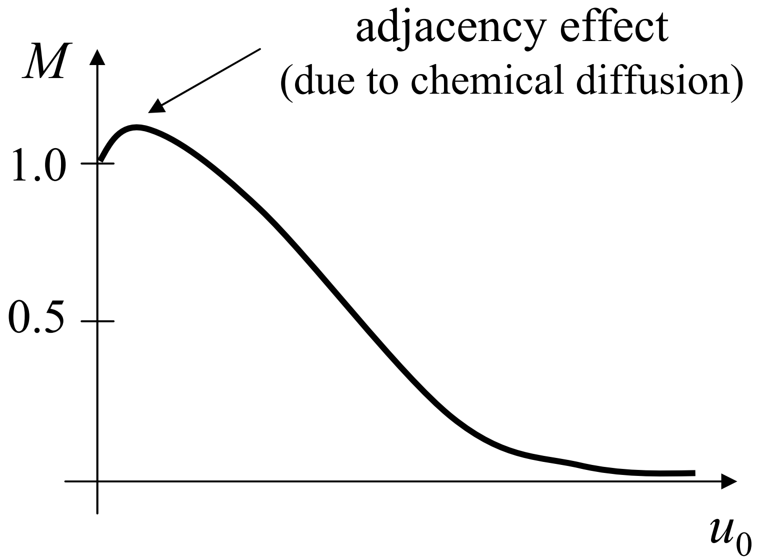


Kelley model of photographic process

Optical imaging during exposure (linear)	→	H&D curve (nonlinear)	→	additional blur due to chemical diffusion (linear)



The Modulation Transfer Function



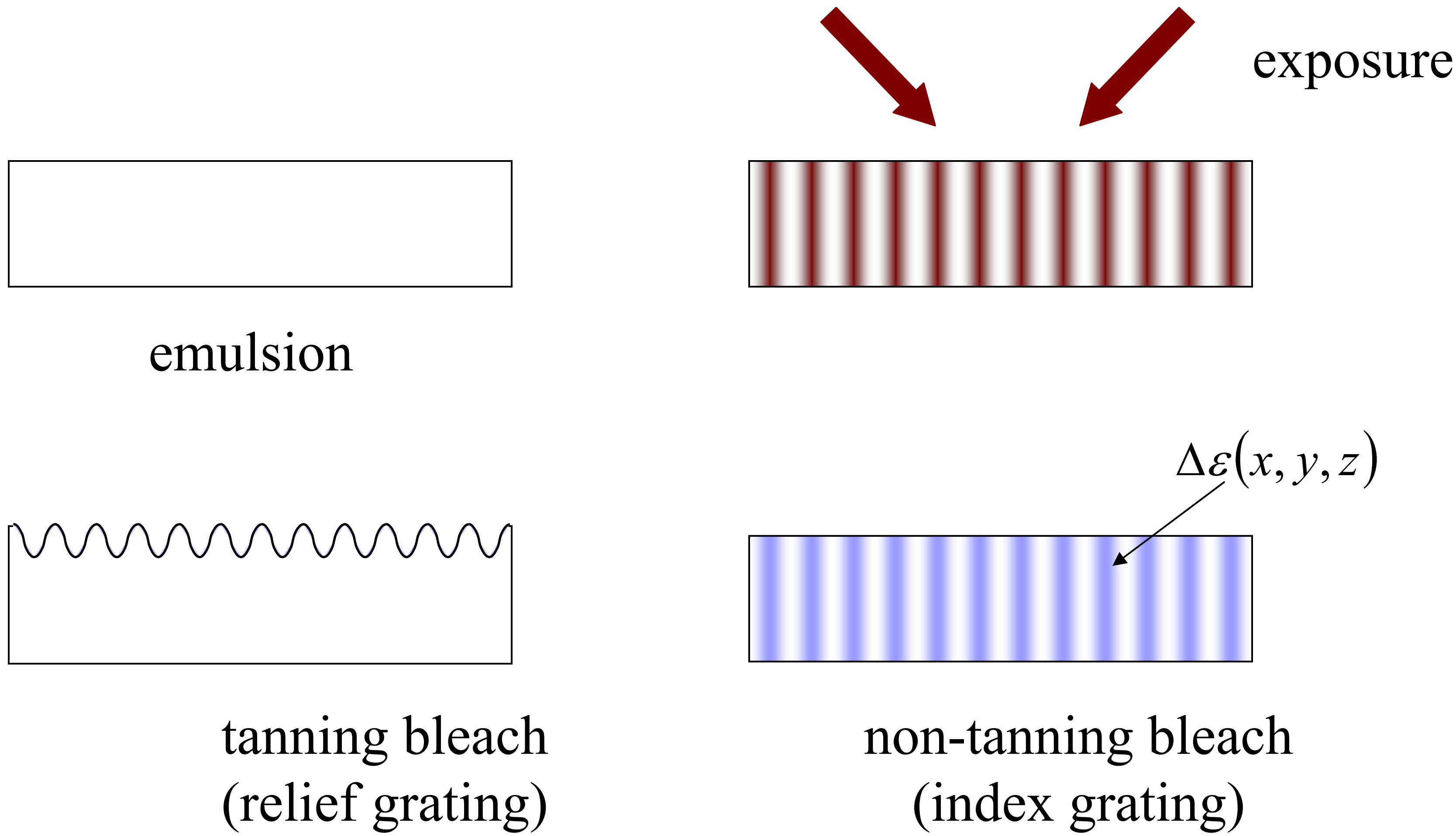
Exposure:

$$E = E_0 + E_1 \cos 2\pi u_0 x$$

"Effective exposure":

$$E' = E_0 + M(u_0) E_1 \cos 2\pi u_0 x$$

Bleaching / phase modulation

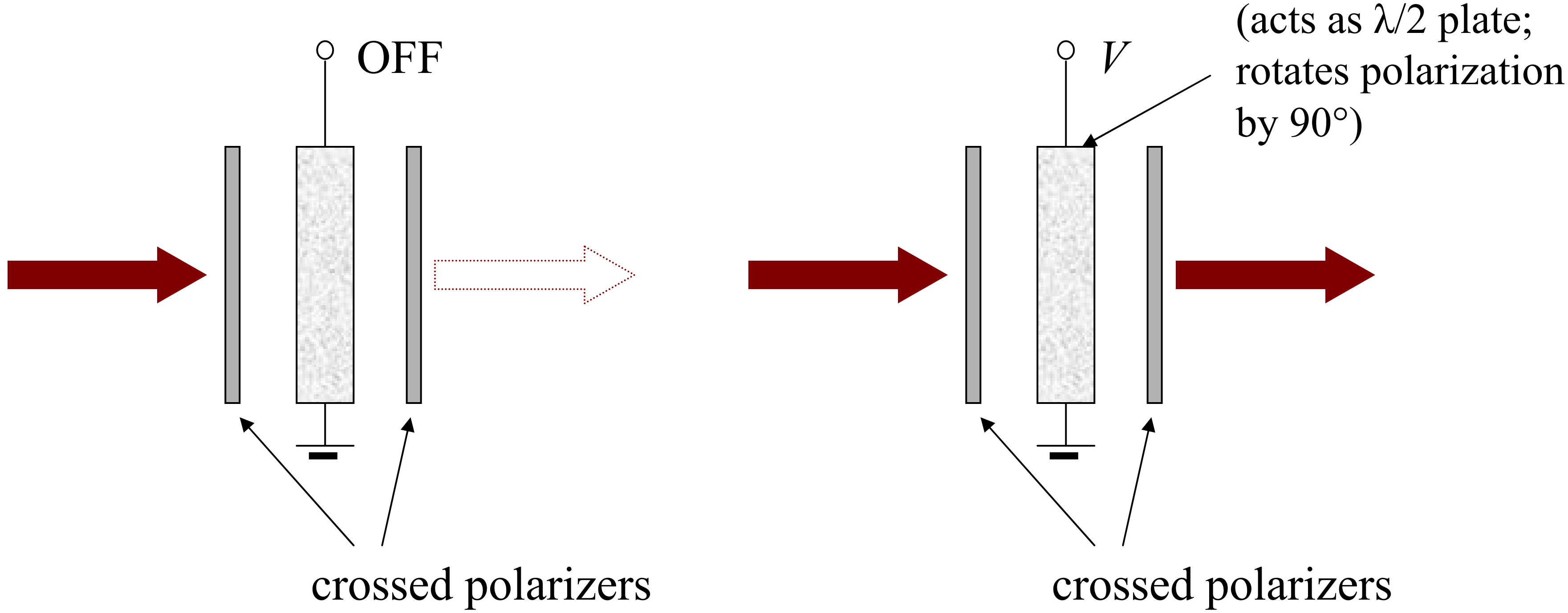


Spatial Light Modulators

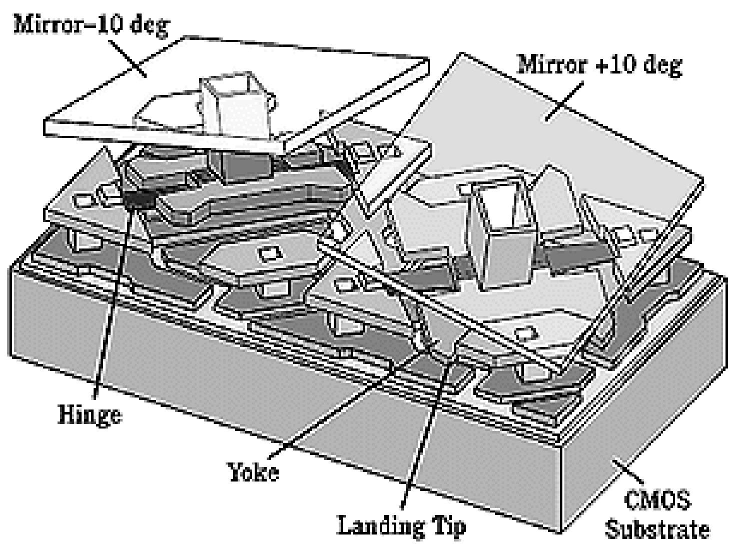
- Liquid crystals
- Magneto-Optic
- Micro-mirror
- Grating Light Valve
- Multiple Quantum Well
- Acousto-Optic

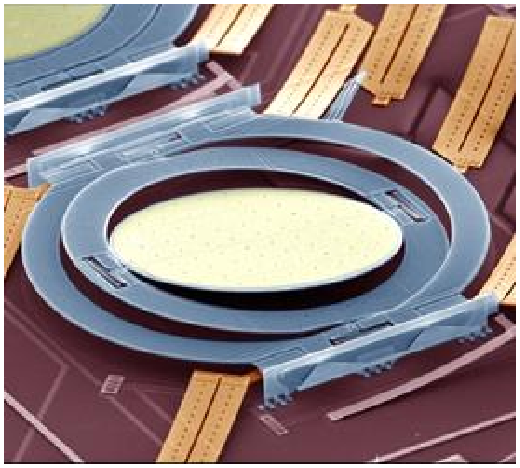
Liquid crystal modulators

- Nematic
- Smectic (smectic-C* phase: ferroelectric)
- Cholesteric



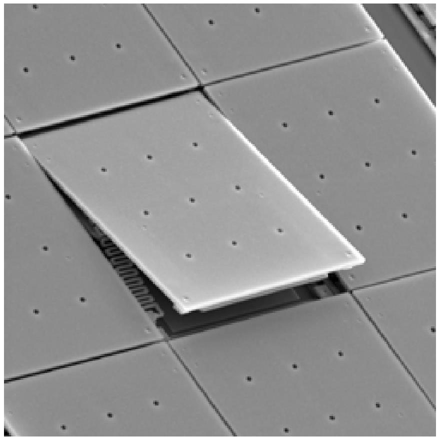
Micro-mirror technology





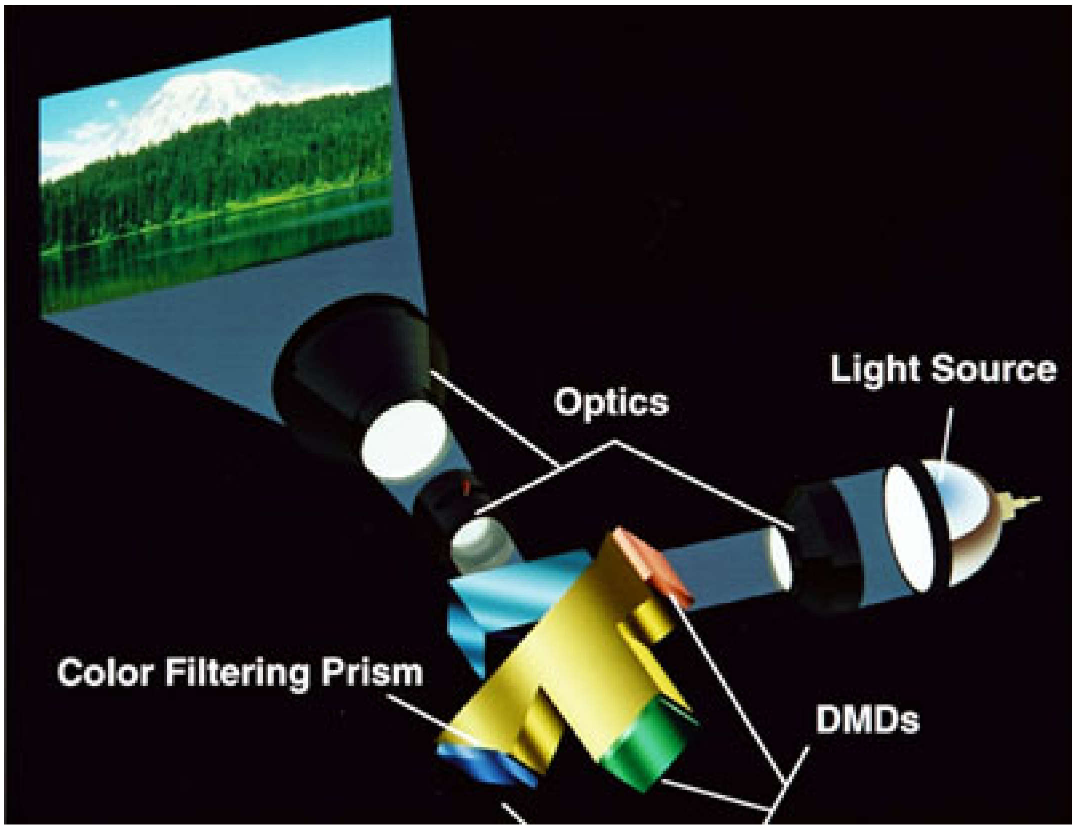
Lucent (Bell Labs)

Texas Instruments DMD/DLP



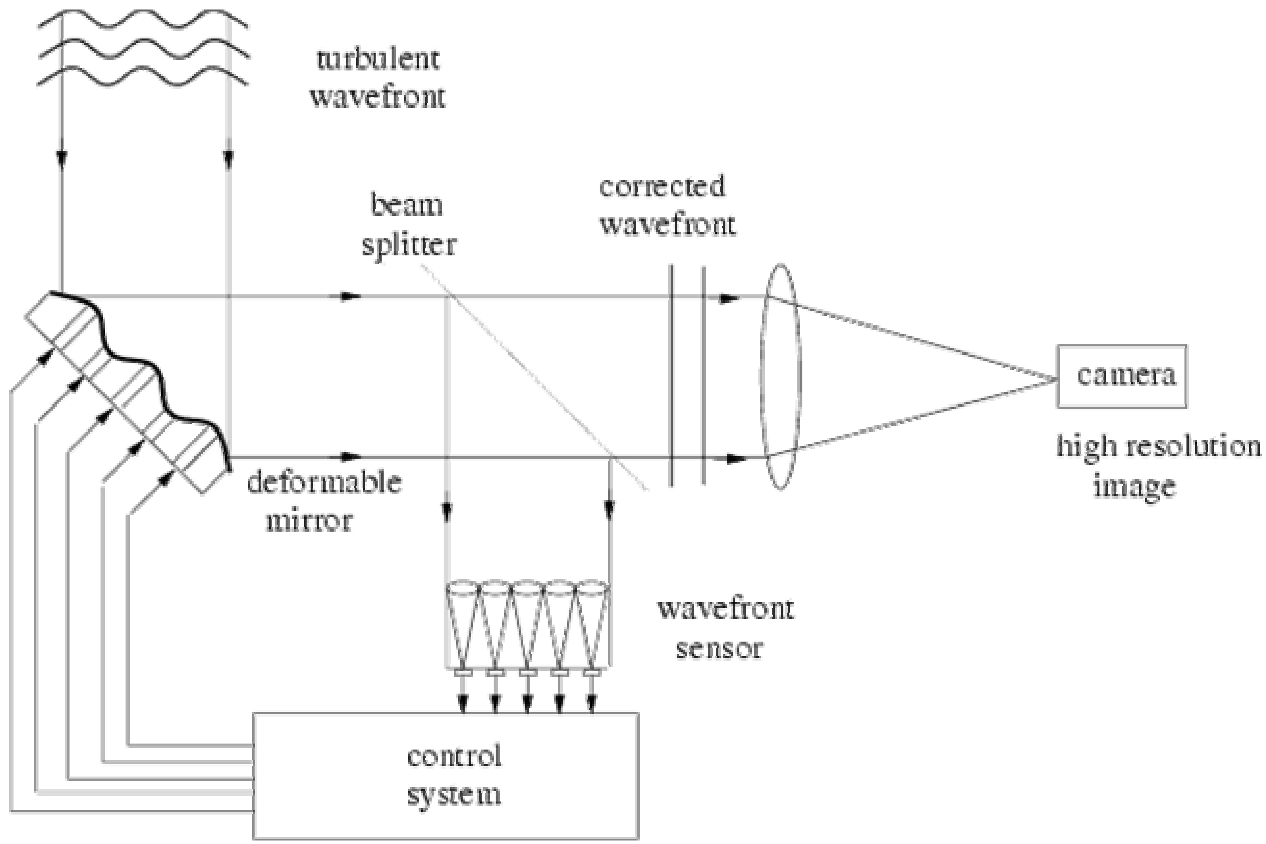
Sandia

Micro-mirror display



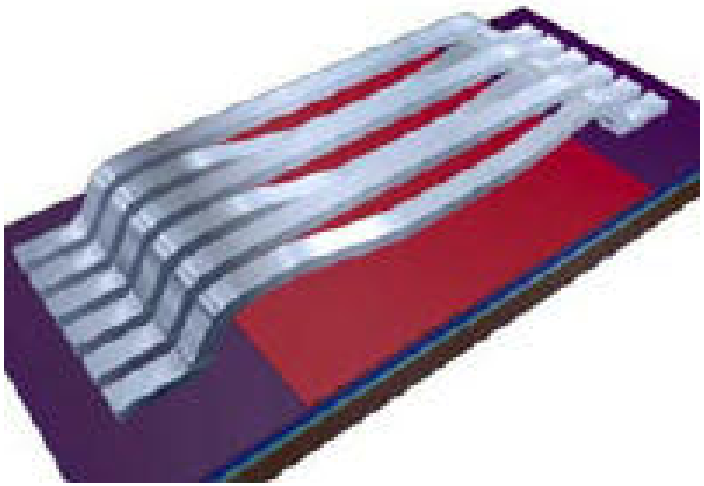
http://www.howstuffworks.com

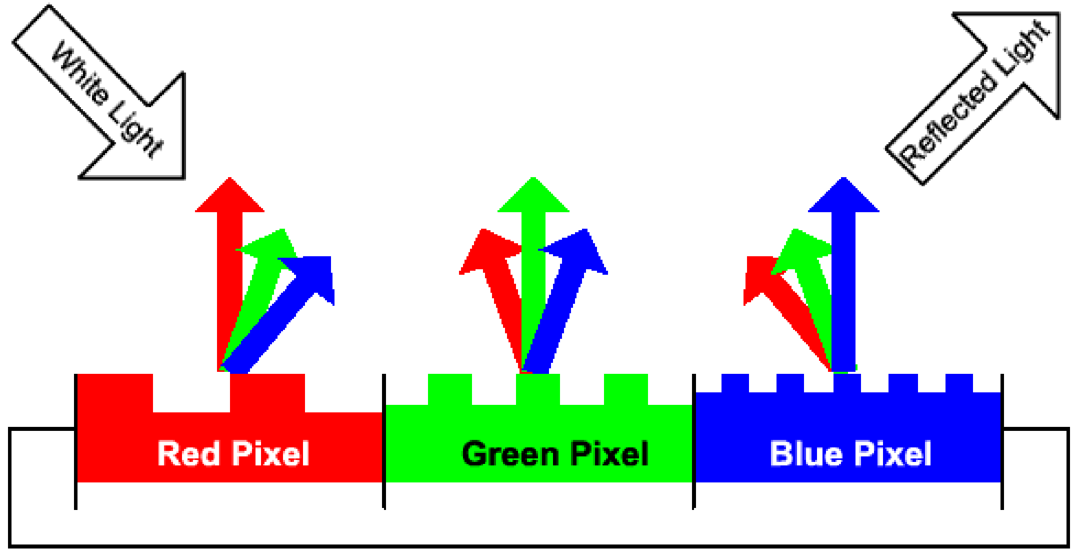
Micromirrors for adaptive optics



Véran, J.-P. & Durand, D. 2000, ASP Conf. Ser 216, 345 (2000).

Grating Light Valve (GLV) display



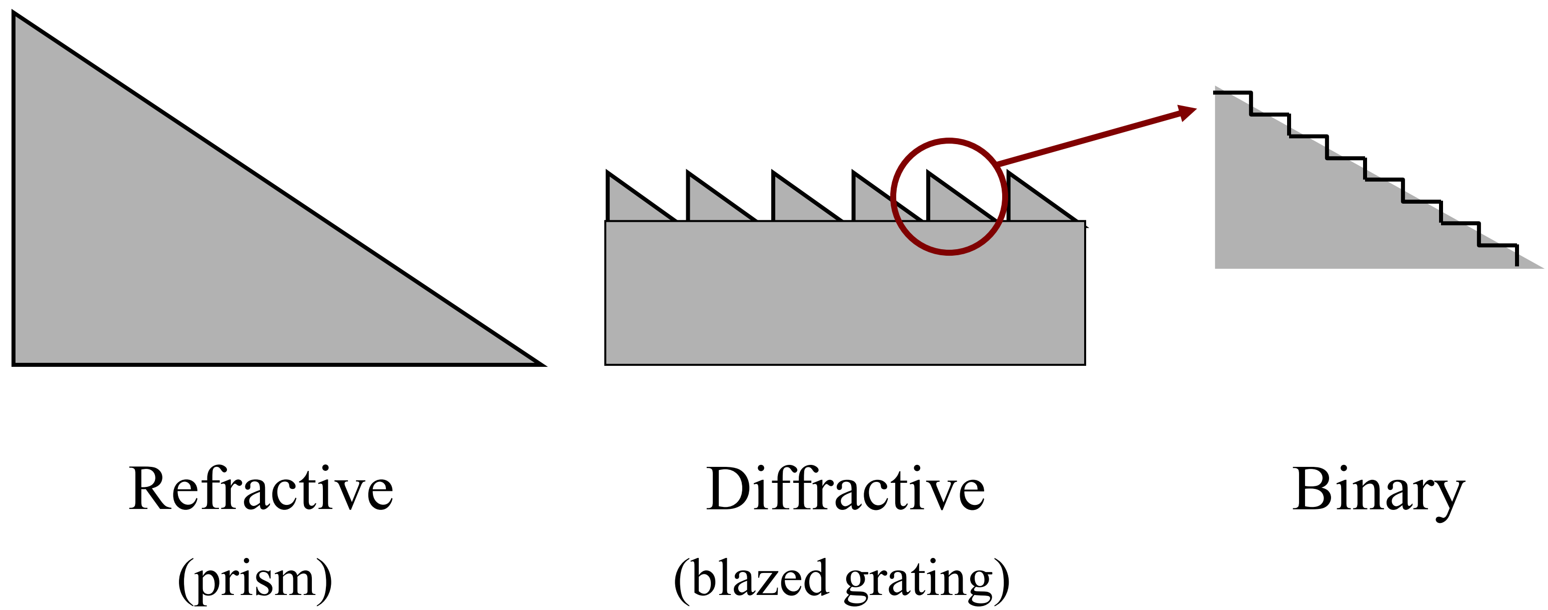


With all ribbons in a pixel in the rest position, light striking the pixel is reflected away from the optical path. When alternate ribbons are pulled down, the diffraction grating is formed and the light's component frequencies spread out. Varying the width and spacing of the ribbons "tunes" pixels to send a single colour into the projector's light path.

www.meko.co.uk

Silicon Light Machines, www.siliconlight.com

Binary Optics

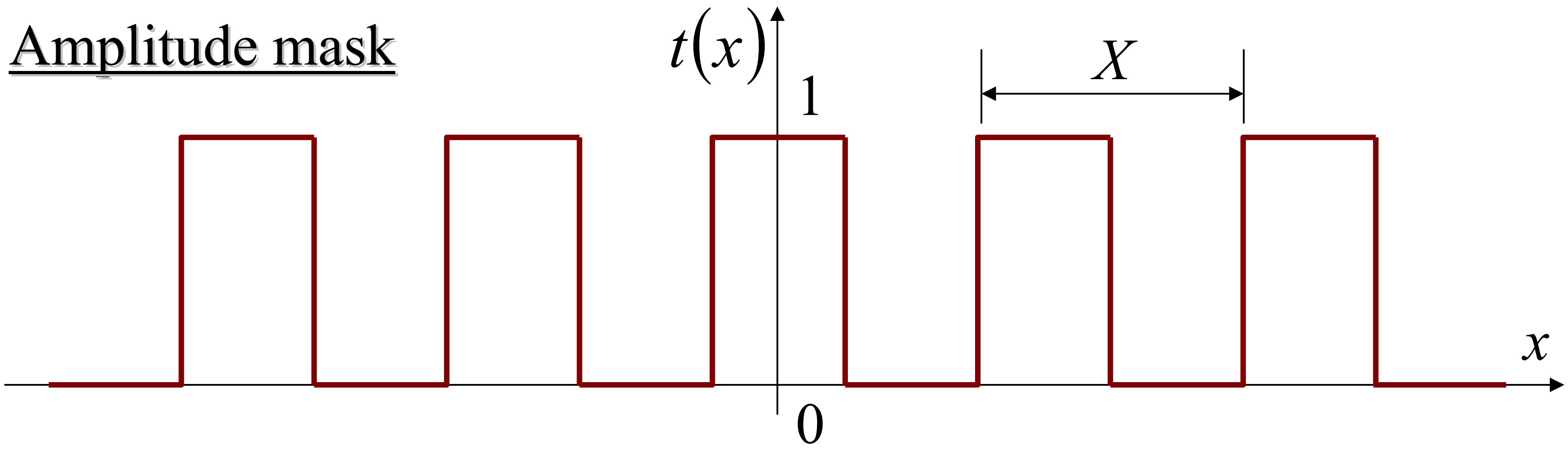


$$\eta_1 = \text{sinc}^2\left(\frac{1}{2^N}\right)$$

efficiency of 1st diffracted order from step-wise (binary) approximation to blazed grating with N steps over 2π range

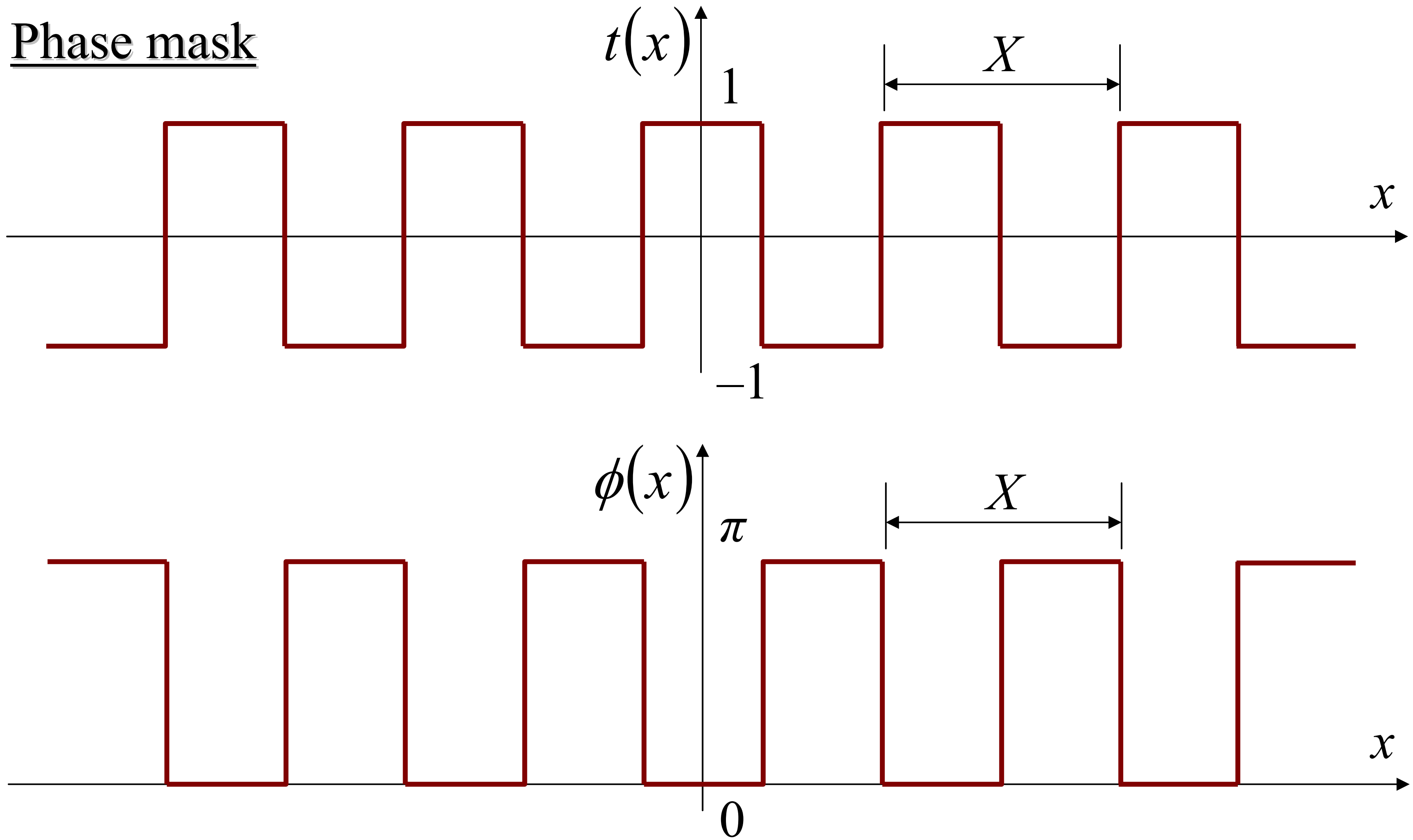
Binary Optics: binary grating

Amplitude mask



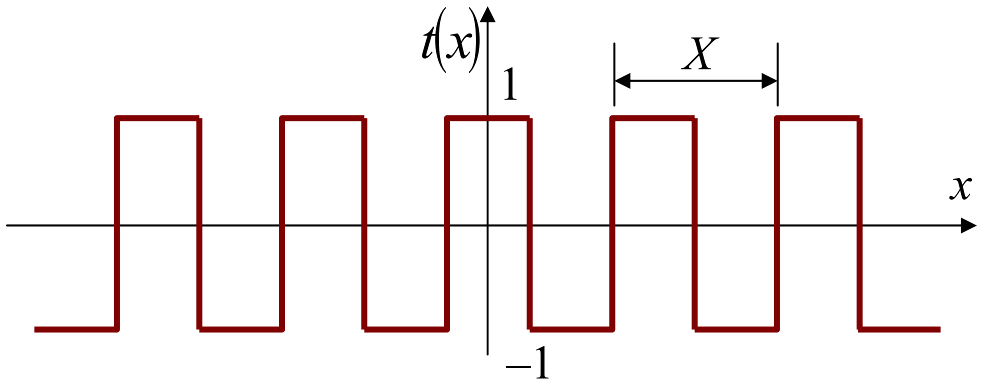
Binary Optics: binary grating

Phase mask



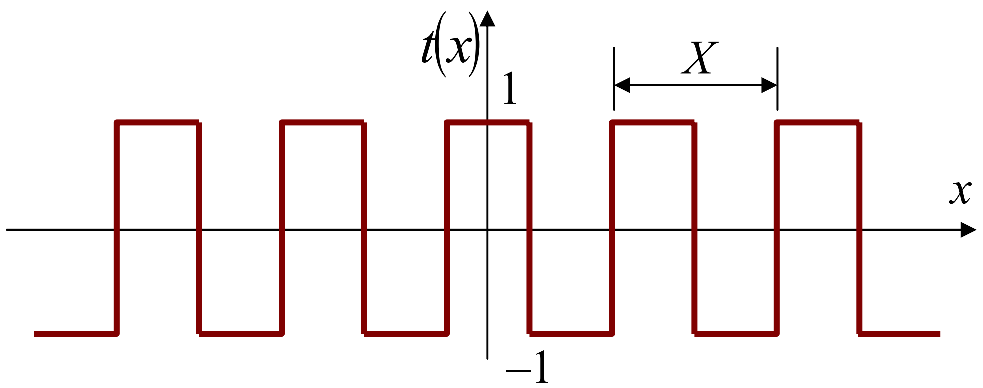
$$t(x) = \exp[i\,\phi(x)]$$

Fourier series for binary phase grating



$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$

Fourier series for binary phase grating



$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \mathrm{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$

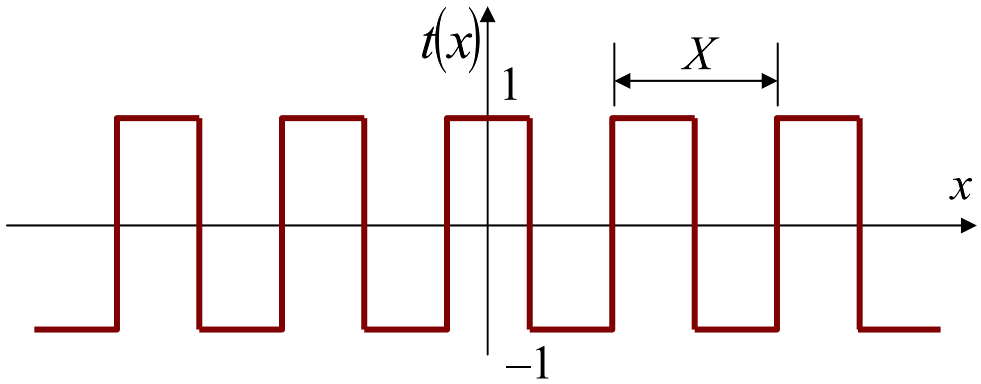
identify physical meaning:

- plane waves
- orientation of n^{th} plane wave:

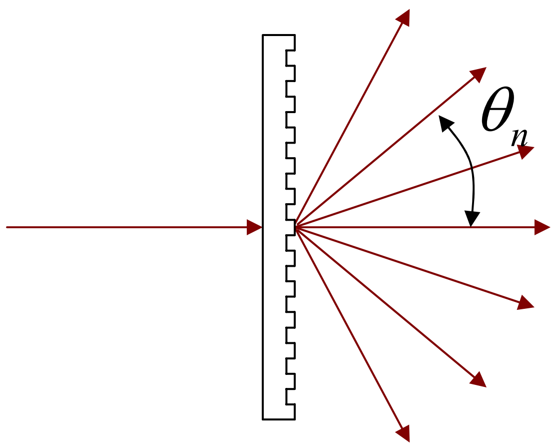
  $\sin\theta_n = n\lambda / X$

- ***diffracted orders***

Fourier series for binary phase grating



$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$



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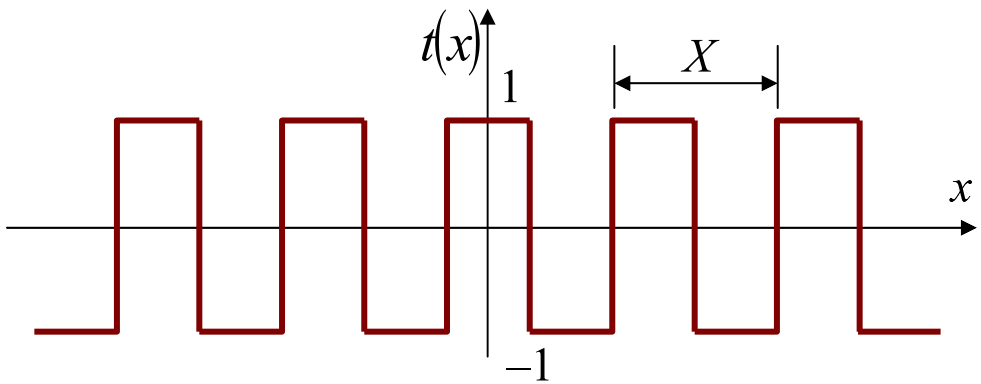
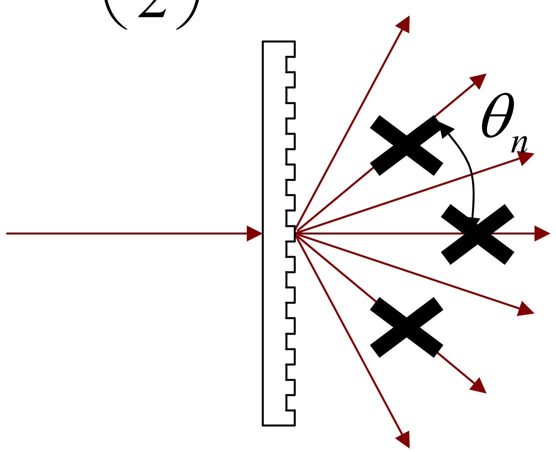
Fourier series for binary phase grating



$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$

$\operatorname{sinc}\left(\frac{n}{2}\right) \Rightarrow$ odd orders only!



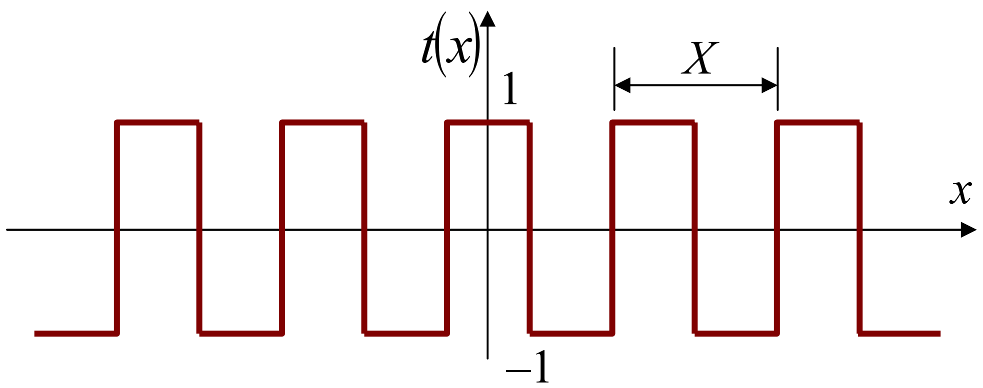
identify physical meaning:

- plane waves
- orientation of n^{th} plane wave:

  $\sin\theta_n = n\lambda / X$

- ***diffracted orders***

Fourier series for binary phase grating



$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$

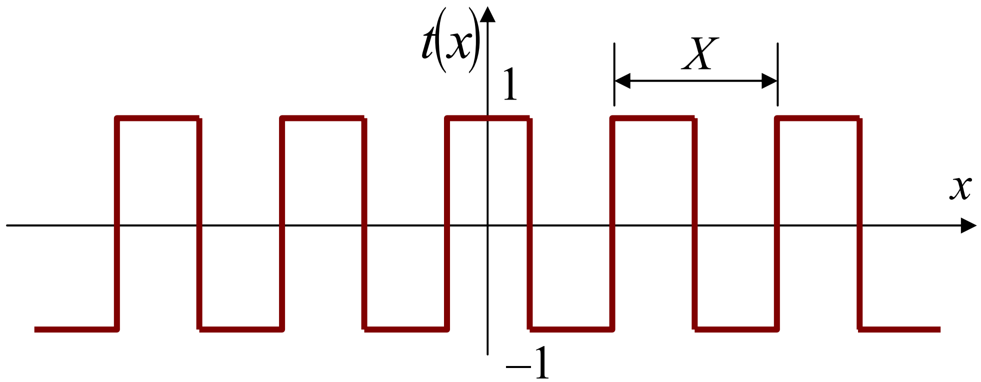
Fourier transform:

- $\exp(i2\pi u_0 x) \leftrightarrow \delta(u - u_0)$

- result is

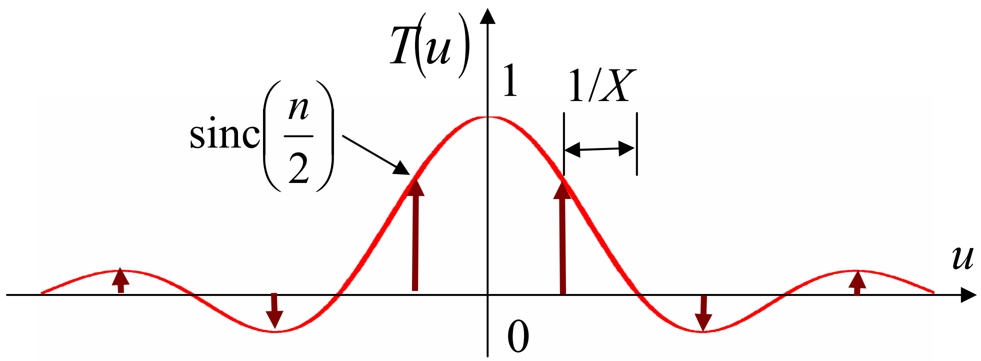
$$\sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \delta\left(u - \frac{n}{X}\right)$$ (Fourier series)

Diffracted spectrum from binary phase grating



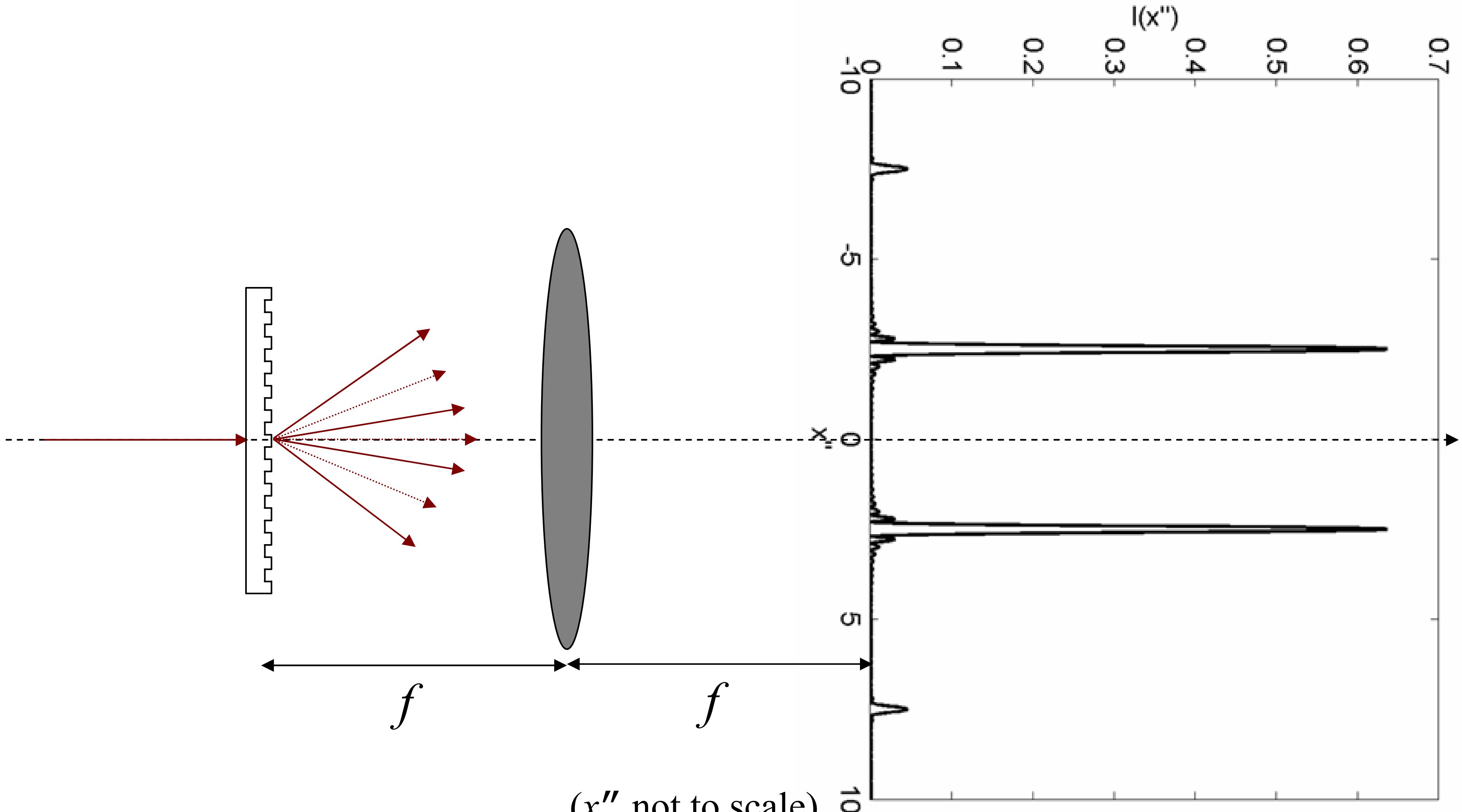
$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \exp\left(i2\pi \frac{nx}{X}\right)$$

$\mathfrak{I}$ $\qquad$ $\mathfrak{I}$



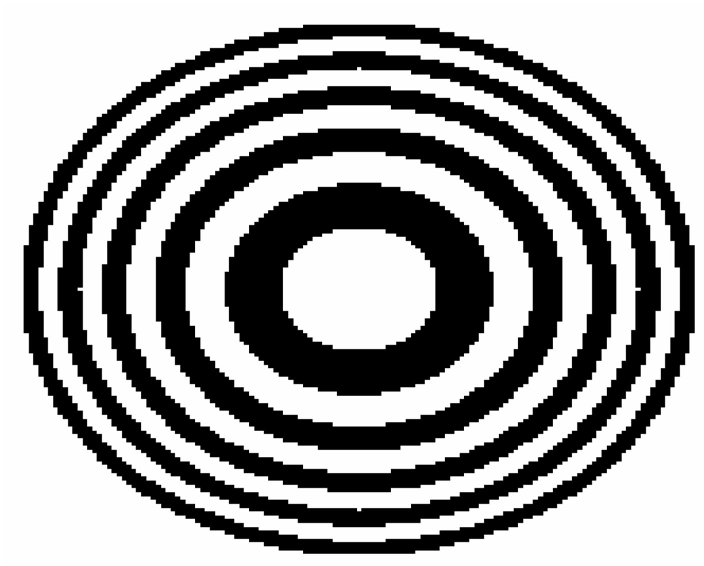
$$= \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \operatorname{sinc}\left(\frac{n}{2}\right) \delta\left(u - \frac{n}{X}\right)$$

Fourier-plane diffraction from finite binary phase grating



(x'' not to scale)

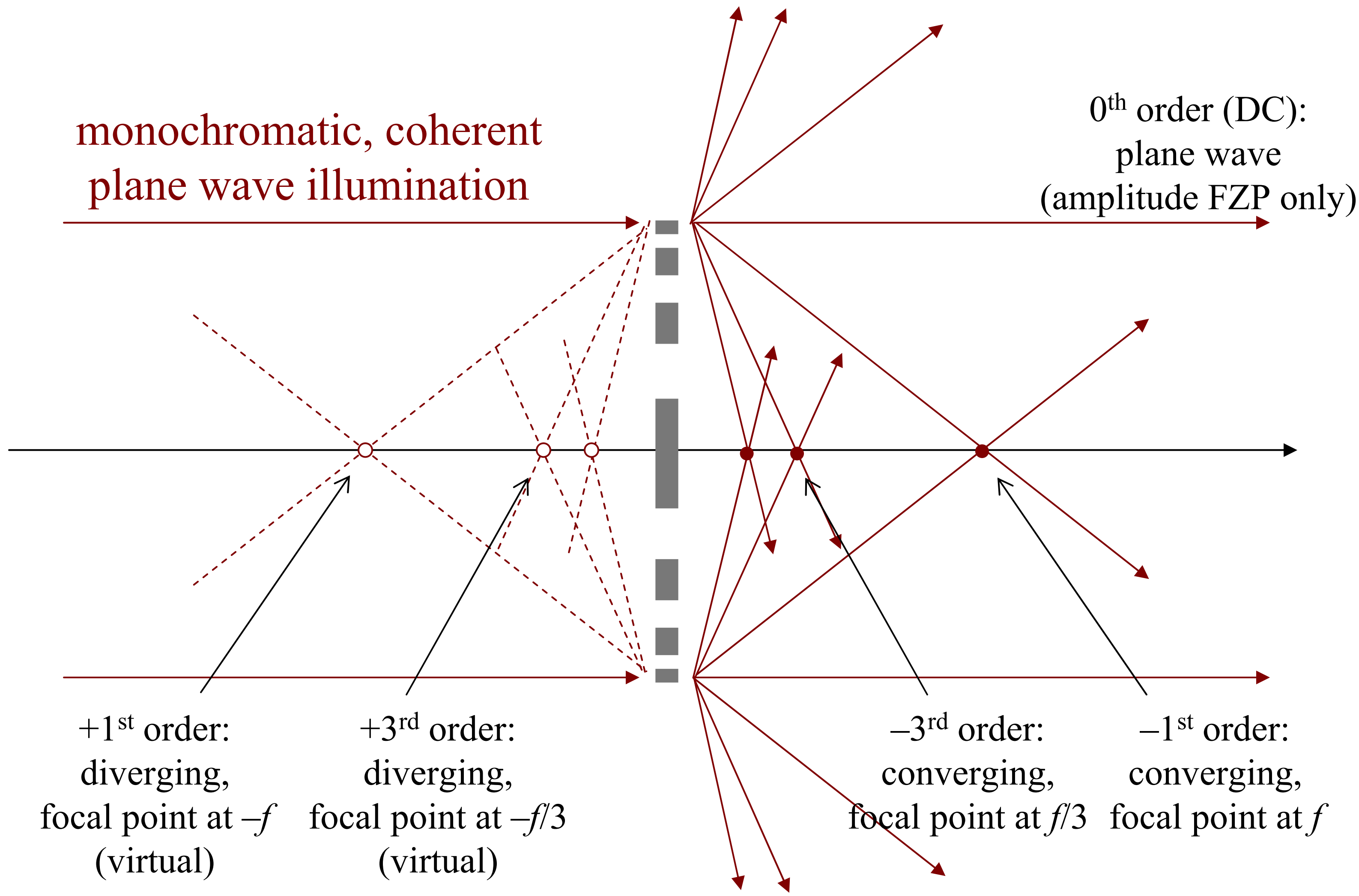
The Fresnel Zone Plate (FZP)



amplitude FZP: $g(x,y)=\frac{1}{2}\left[1+\operatorname{sgn}\left(\cos\left(\pi\frac{r^2}{\lambda f}\right)\right)\right]$ $\qquad r=\sqrt{x^2+y^2}$

phase FZP: $g(x,y)=\operatorname{sgn}\left(\cos\left(\pi\frac{r^2}{\lambda f}\right)\right)$

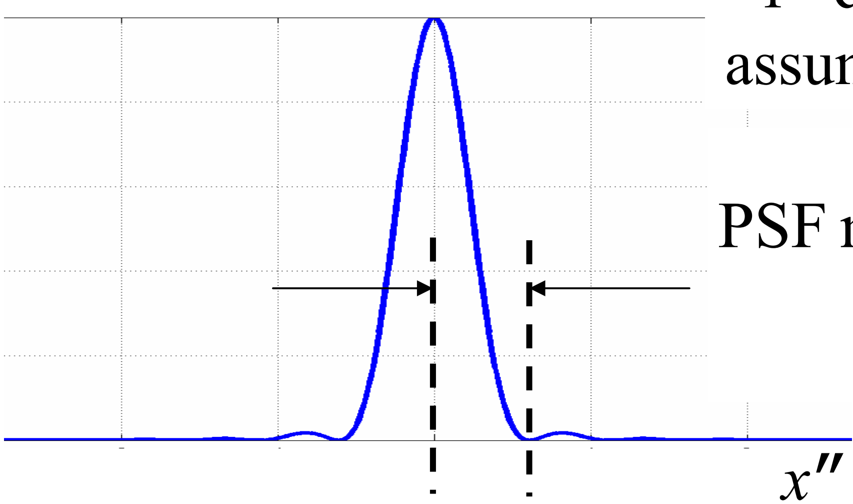
Field diffracted from the FZP



FZP relationships

$$r_m = \sqrt{\frac{m\lambda f}{2}}$$ m^{th} zone radius

$$\delta_m \equiv r_m - r_{m-2} \approx \sqrt{\frac{\lambda f}{2m}}$$ m^{th} zone width



-1^{st} diffraction order, assuming FZP radius = r_M:

$$\text{PSF main lobe half-width} \approx 1.22\sqrt{\frac{\lambda f}{M}}$$

$\propto$ width of last zone