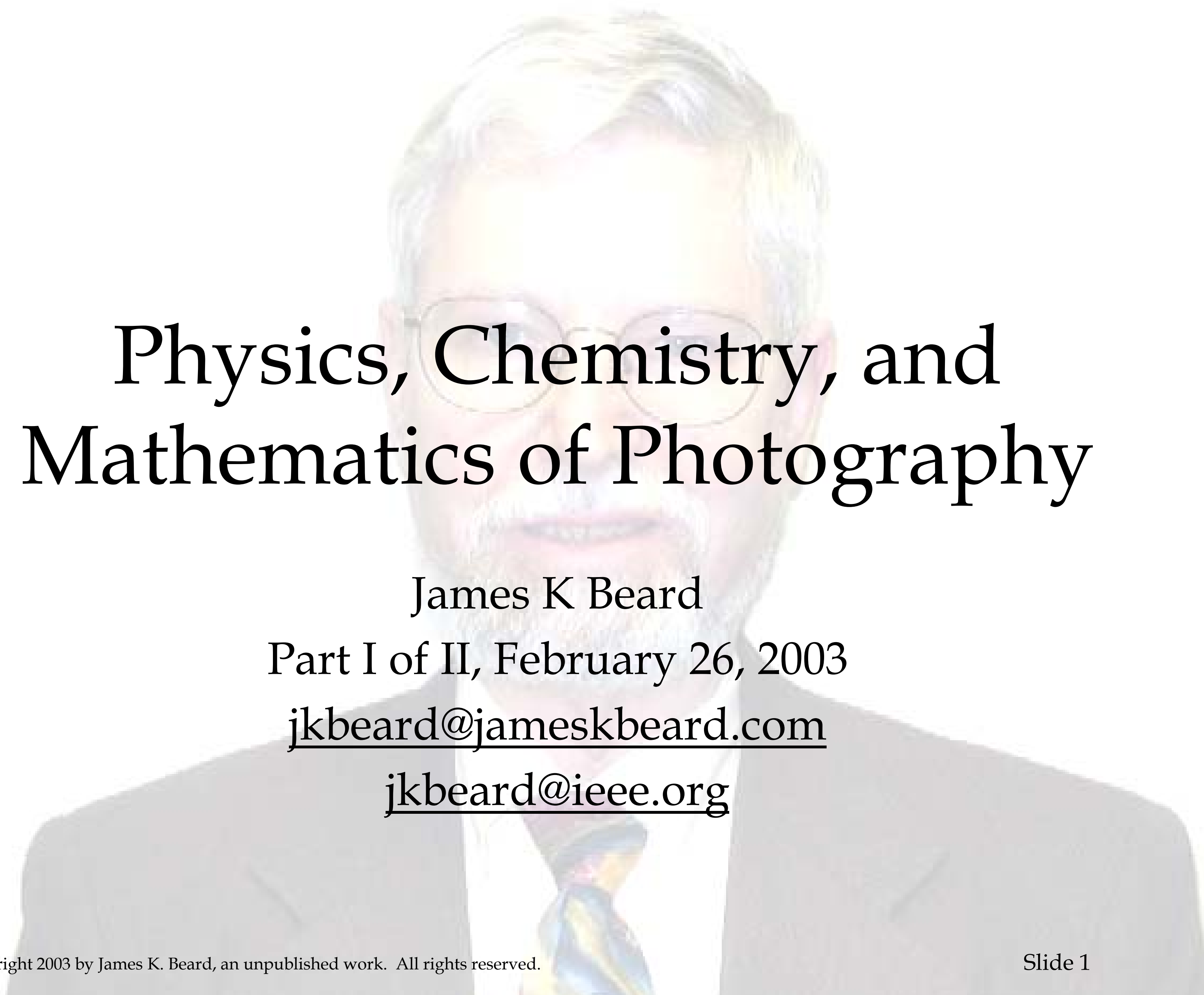

Physics, Chemistry, and Mathematics of Photography

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Part I of II, February 26, 2003

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Topics

- Part I: Resolution
  - On the film
  - On the print
  - On the slides
  - In television
- Part II: Color, shading, and prints
  - Contrast, color, and the Zone System
  - Lens design
  - Digital and conventional photography
  - The portal: scanning and scanners

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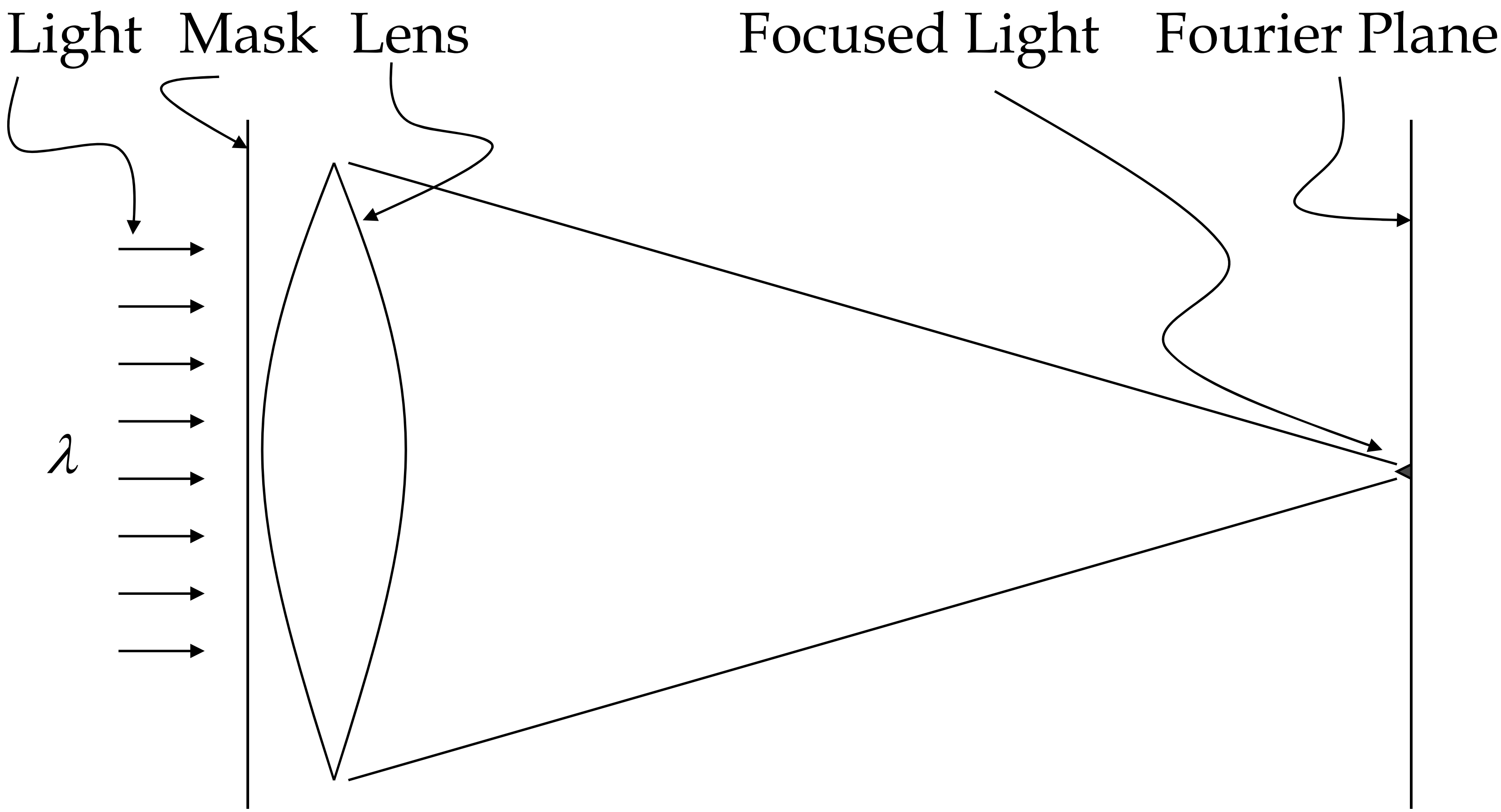
Optical Fourier Transform



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Optical Fourier Transform

- Collimated monochromatic impinging light
- Mask modulates light intensity
- Lens makes all effective path lengths to focal point equal
- Light at focal point is

"Electro-Optical Systems Analysis," K. Seyrafi, p 174-177

$$a(\rho,\varphi)=\int_{0}^{\frac{D_0}{2}}\int_{-\pi}^{\pi} m(r,\theta)\cdot\exp\left(-j\cdot\frac{2\pi}{\lambda}\cdot r\cdot\rho\cdot\cos(\theta-\varphi)\right)\cdot r\cdot dr\cdot d\theta$$

$r,\theta \leftrightarrow$ Lens Plane; r is distance

$\rho,\varphi \leftrightarrow$ Fourier Plane; ρ is half-cone angle

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The Airy Disk

- An open, uniformly weighted circular aperture of diameter D_0
- Intensity on the Fourier plane is

$$a(\rho) = \frac{\pi \cdot D_0^2}{4} \cdot \frac{2 \cdot J_1\left(\dfrac{\pi \cdot D_0 \cdot \rho}{\lambda}\right)}{\dfrac{\pi \cdot D_0 \cdot \rho}{\lambda}}$$

"Electro-Optical Systems Analysis," K. Seyrafi, p 174-177

- Resolution is peak-to-null distance

$$\Delta\rho = \frac{1.22 \cdot \lambda}{D_0}$$

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The Diffraction Limit on the Focal Plane

- The f/stop or f-number is

$$\left(f/no \right) = \frac{f}{D_0}$$

- The numerical aperture for a lens is

$$NA = n' \cdot \sin\left(u'\right) = \frac{1}{2 \cdot \left(f/no \right)}$$

n' = refractive index

u' = half-cone angle

- Resolution distance is

$$\Delta\rho \cdot f = 1.22 \cdot \left(f/no \right) \cdot \lambda = \frac{0.61 \cdot \lambda}{NA}$$

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Lines per Millimeter

- A resolvable line is two resolution elements
  - Two lines must have a resolvable space between them
  - The distance between the line and the resolvable space is a resolvable element
- The number of lines per millimeter is

$$lpmm = \frac{1}{2 \cdot \Delta\rho \cdot f} = \frac{1}{2.44 \cdot \left(f / no \right) \cdot \lambda} = \frac{NA}{1.22 \cdot \lambda}$$

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Resolution on 35 mm Film

- Film resolution is 80 to 200 lines per mm
- Optics limit
  - Diffraction limit is about 133 lines per mm at f/5.6
  - Achieved in laboratory: 80 to 100 lines per mm
  - Achieved by the photographer: 40-80 lines per mm

Practical limit is 40 – 80 lines per mm

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Resolution on 70 mm Film

- Film resolution is 80 to 200 lines per mm
- Optics limit
  - Diffraction limit is about 65 lines per mm at f/11
  - Achieved in laboratory: 45 to 80 lines per mm
  - Achieved by the photographer: 25-50 lines per mm

Practical limit is 25 – 50 lines per mm

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Number of Pixels

- In 35 mm film
  - Image is 24 mm by 36 mm
  - 4 X 3 aspect limit is 24 mm X 32 mm
  - 4.7 M at 40 lines per mm (M = 1024^2 pixels)
  - 18.75 M at 80 lines per mm
- In 70 mm film
  - Image is 6 X 7 cm
  - 22.4 M in 5.25 X 7 cm at 40 lines per mm

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Print Resolution

- Eye is about a 24 mm focal length
- F-stop of pupil is f/2.8 to f/32
  - Typical pupil is f/11 in bright light
  - Eye resolution is 0.3 milliradians for green light
- Print resolution
  - At two feet viewing distance
  - About 144 dots per inch

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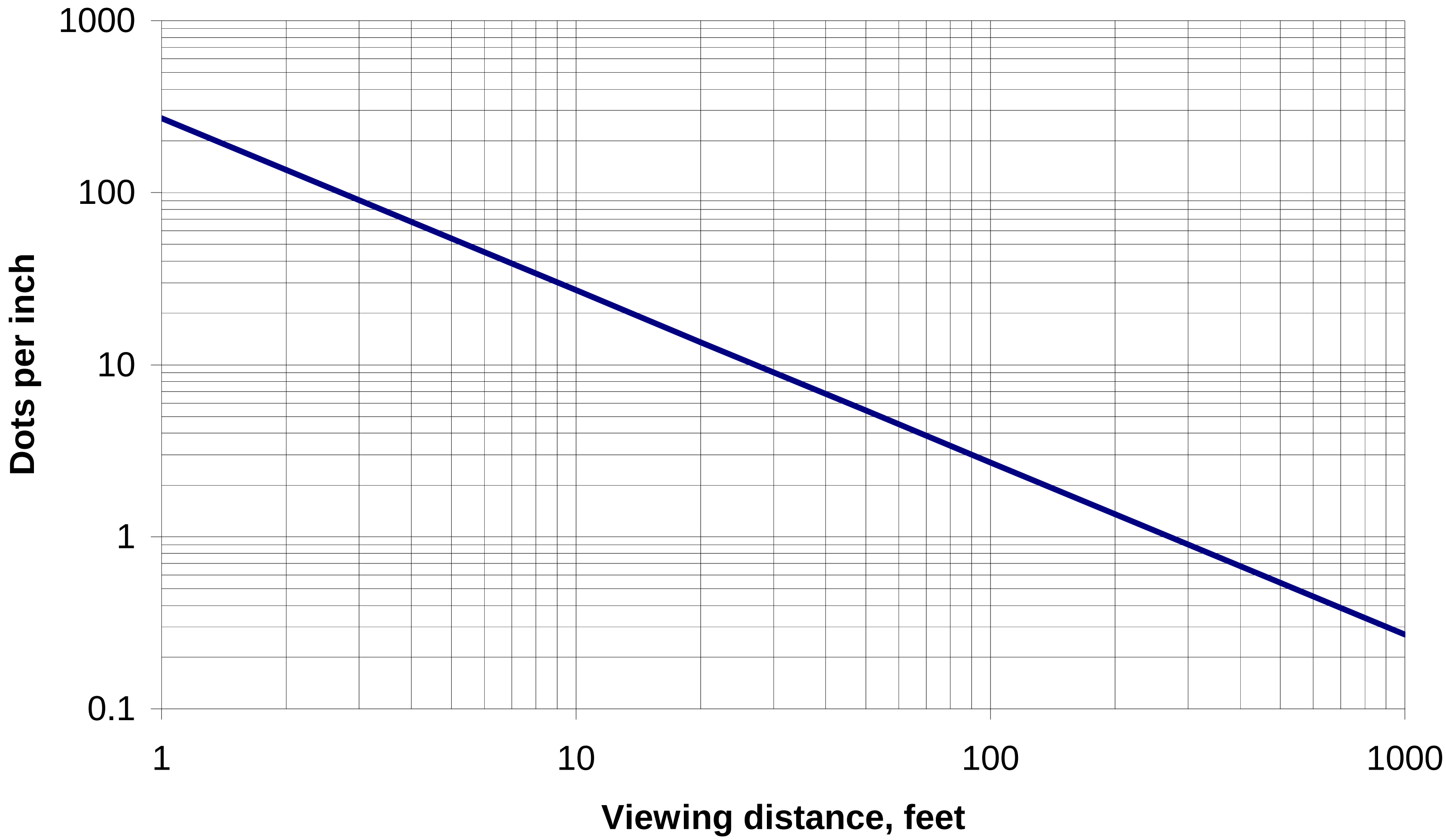
Print Resolution vs. Distance



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Scanning Slides and Negatives

- Resolution
  - Scale factor from lines per mm to DPI

$$25.4\frac{mm}{in}\cdot 2\frac{dots}{line}=50.8\frac{dots/in}{line/mm}$$

  - 80 line per mm is 4000 DPI
- Vendors of slide/negative scanners
  - SmartDisk: 2700 or 3600 DPI
  - Nikon Coolscan, Canoscan, Microtek, Polaroid: 4000 DPI
  - Minolta Dimage: 2820, 4800 DPI

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NTSC Color TV

- RGB is encoded for transmission
  - Illuminance, weighted combination
  - I and Q channels to carry color
  - Signal is compatible with pre-color TV
- Resolution
  - Limited by channel bandwidth to 220 lines
  - Color is less; relationship is complex

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The Encoding Matrix

$$
\begin{array}{c} E_Y' \\ E_I' \\ E_Q' \end{array}
\quad
\begin{array}{ccc} E_R' & E_G' & E_B' \\ \end{array}
$$

$$
\begin{bmatrix} 0.30 & 0.59 & 0.11 \\ 0.60 & -0.28 & -0.32 \\ 0.21 & -0.52 & 0.31 \end{bmatrix}
$$

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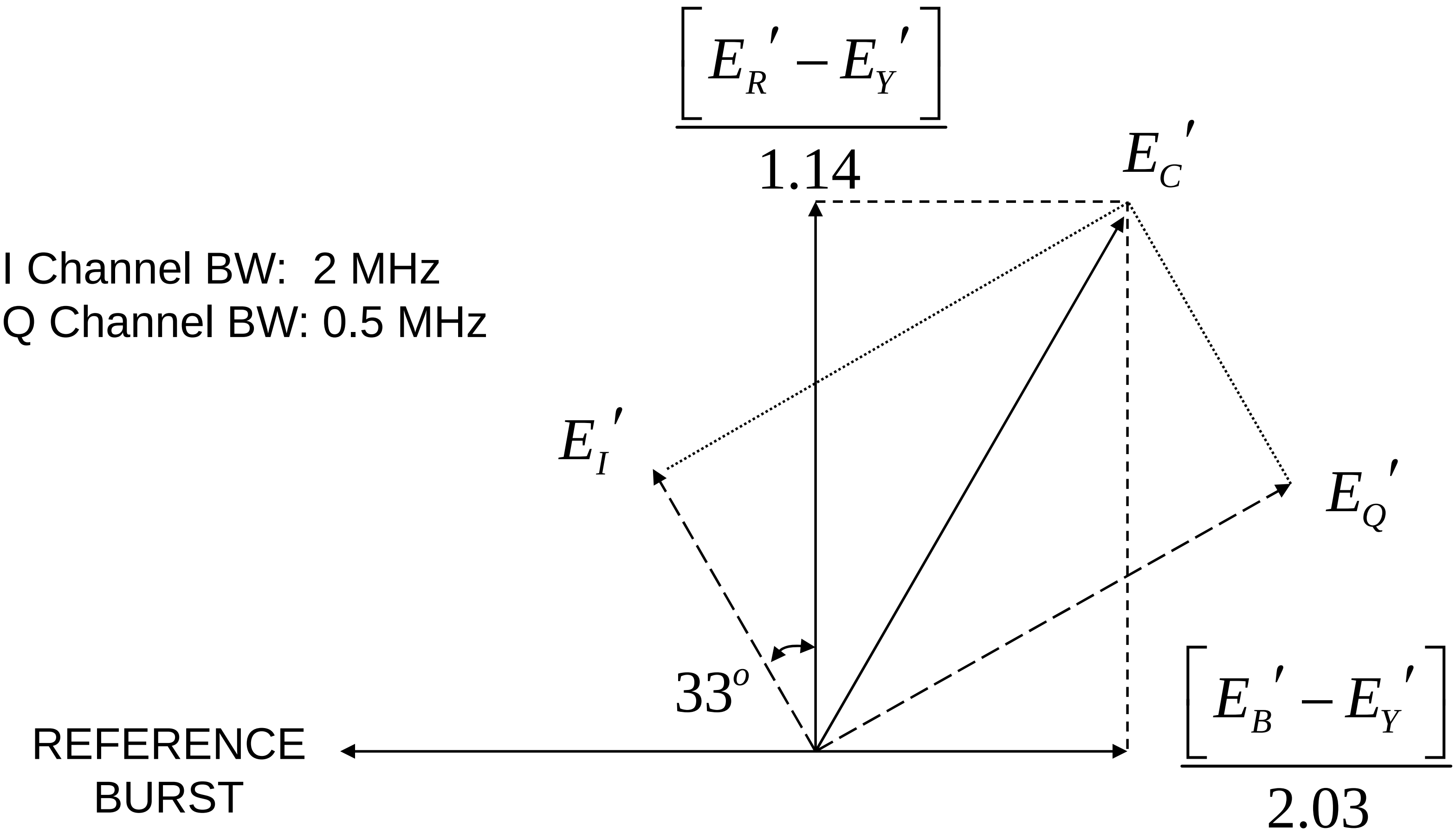
NTSC Color Encoding

I Channel BW: 2 MHz
Q Channel BW: 0.5 MHz



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NTSC Summary

- Resolution
  - Limited by TV channel bandwidth
  - About 200 by 480
  - Color is less bandwidth – complex relationship
  - Eye sees 200 by 480
  - Frame averaging with motion enhances perception
- Color
  - Purity and quality are not a problem
  - Blue is lower resolution than red, green

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HDTV

- Information given here is from
  - http://www.ee.washington.edu/conselec/CE/kuhn/hdtv/95x5.htm
- Aspect ratio remains 16:9
- Resolution – either of
  - 1280 X 720 (1 MPX)
  - 1920 X 1080 (2 MPX)

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Field of View

Format	*Field of View, Degrees*
TV	6.5
HDTV 1	20
HDTV 2	30
35 mm	104

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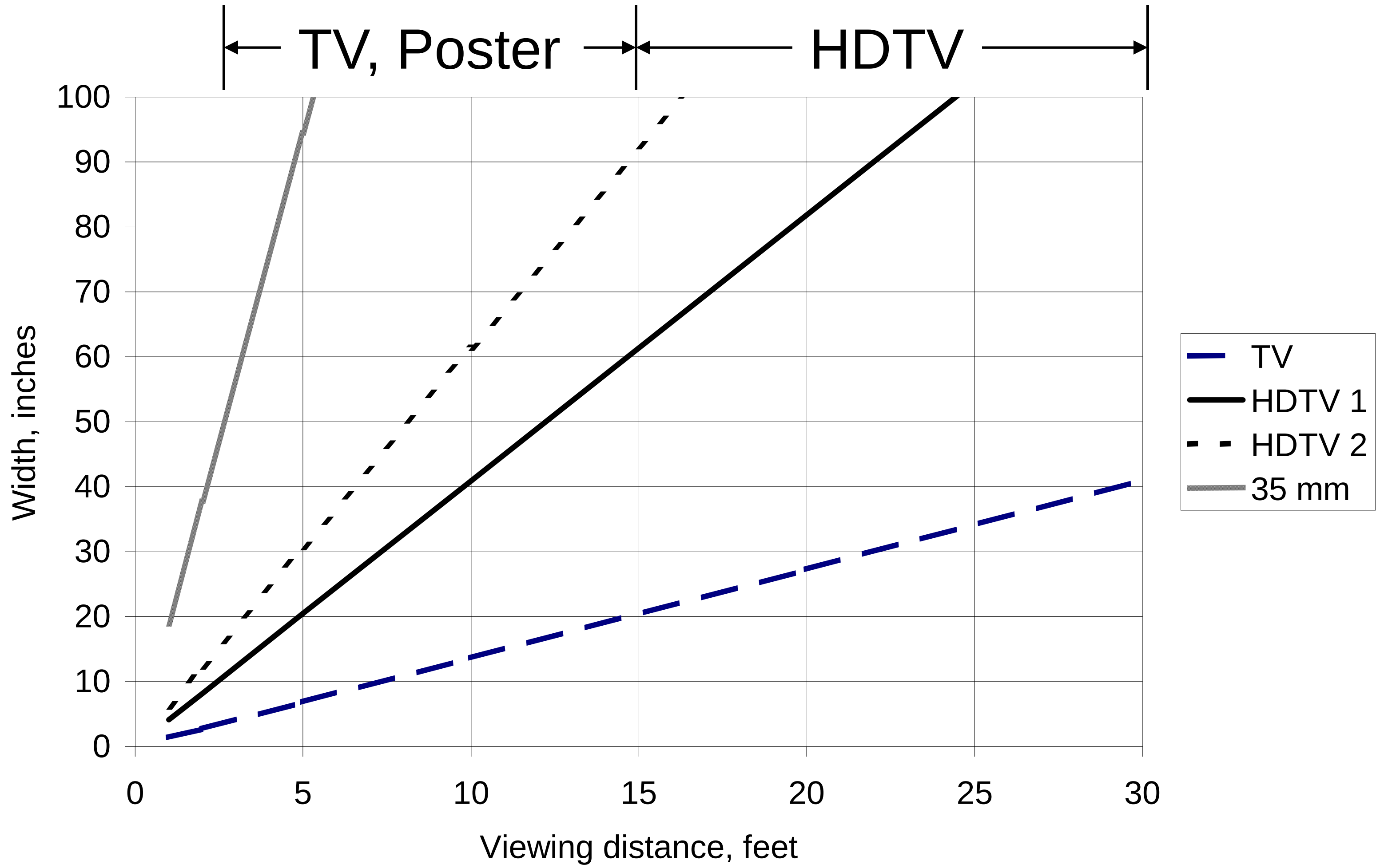
Viewing Image Size vs. Distance



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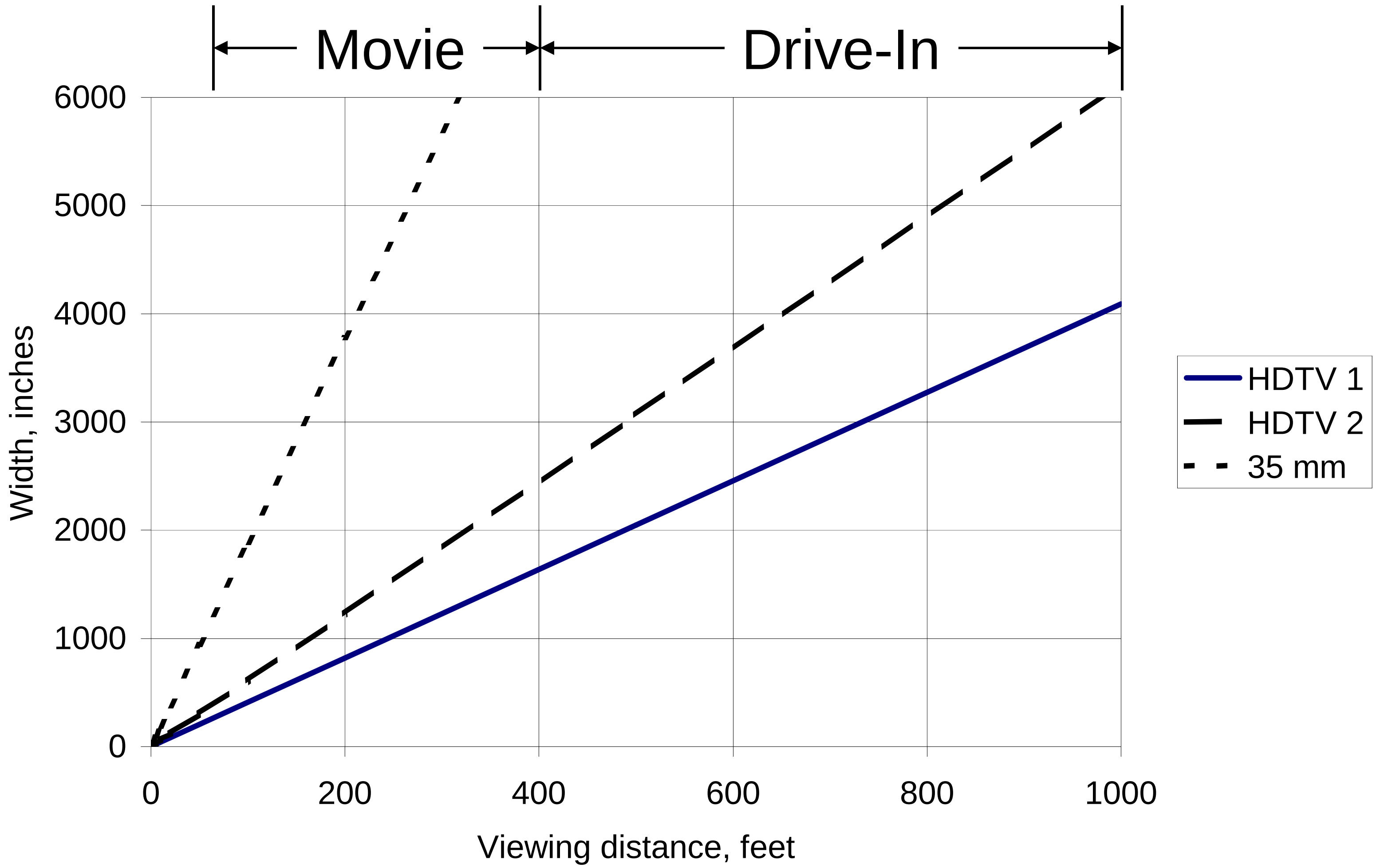
Viewing Image Size vs. Distance



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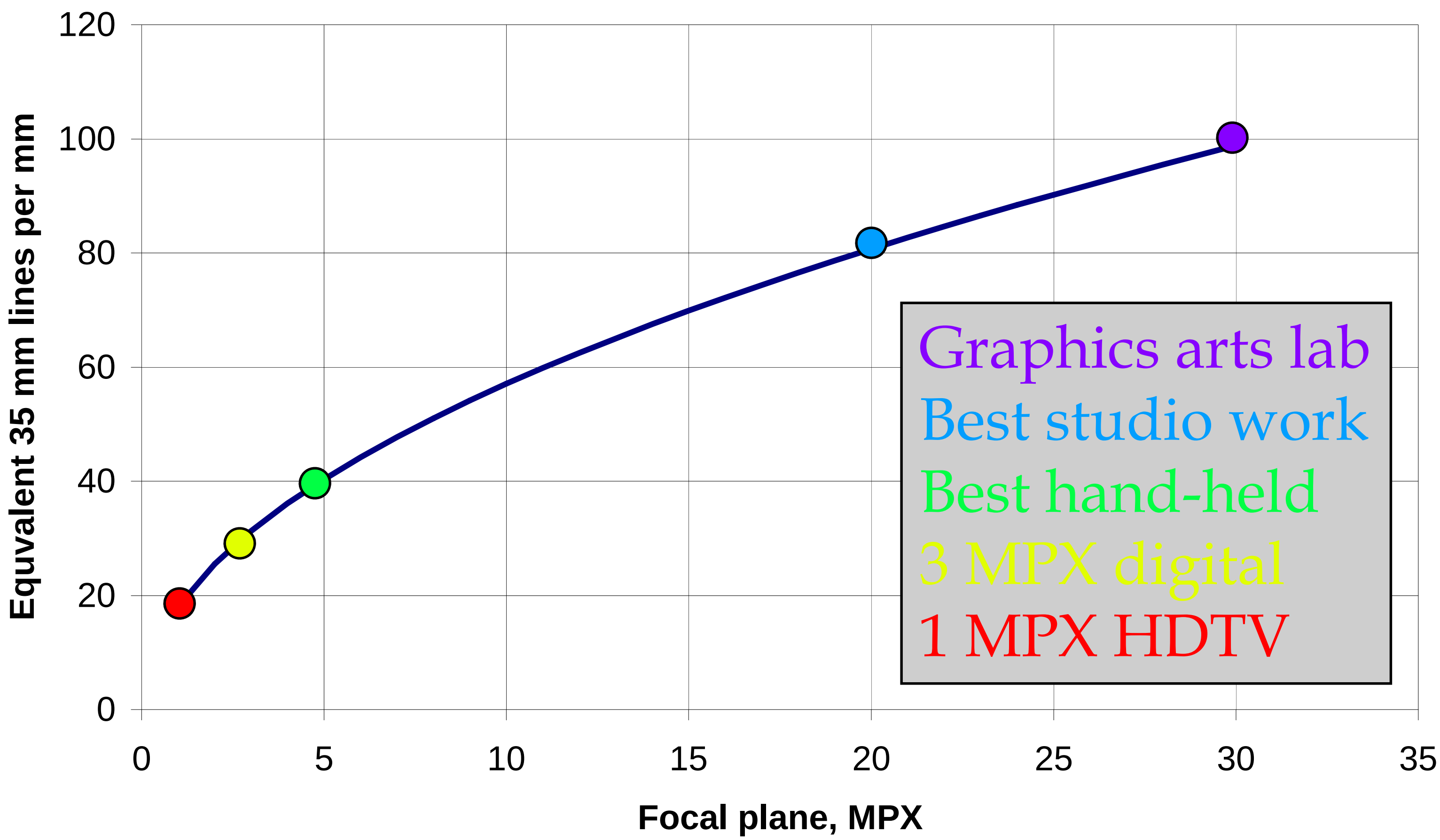
Comparing Digital and 35 mm Focal Plane Resolution



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- Foveon digital photography focal planes
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  - http://www.sigma-photo.com/
- Popular Photography Magazine
  - http://www.popphoto.com/

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