SAND2008-5958P

Camera Lenses, Mounts, and Towers

September 24, 2008

Dave Furgal

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Disclaimer

- All material in this module is unclassified
- In this module, photos of equipment are included as examples only
- Sandia National Laboratories does not endorse or recommend any specific equipment

Sandia National Laboratories

Module Objectives

Learn how to choose the appropriate camera equipment to meet minimum performance criteria for an effective assessment system

- **Understand the parts and functions of lenses**
- **Match a lens to a camera to properly view a designated target area of coverage**
- **Understand resolution and minimum resolution criteria**
- **Understand the roles of the different camera mounts and camera towers**

Module Outline

- Introduction
- Lens characteristics and performance
- The assessment zone and resolution
- Camera mounts
- Camera towers
- Summary

Sandia National Laboratories

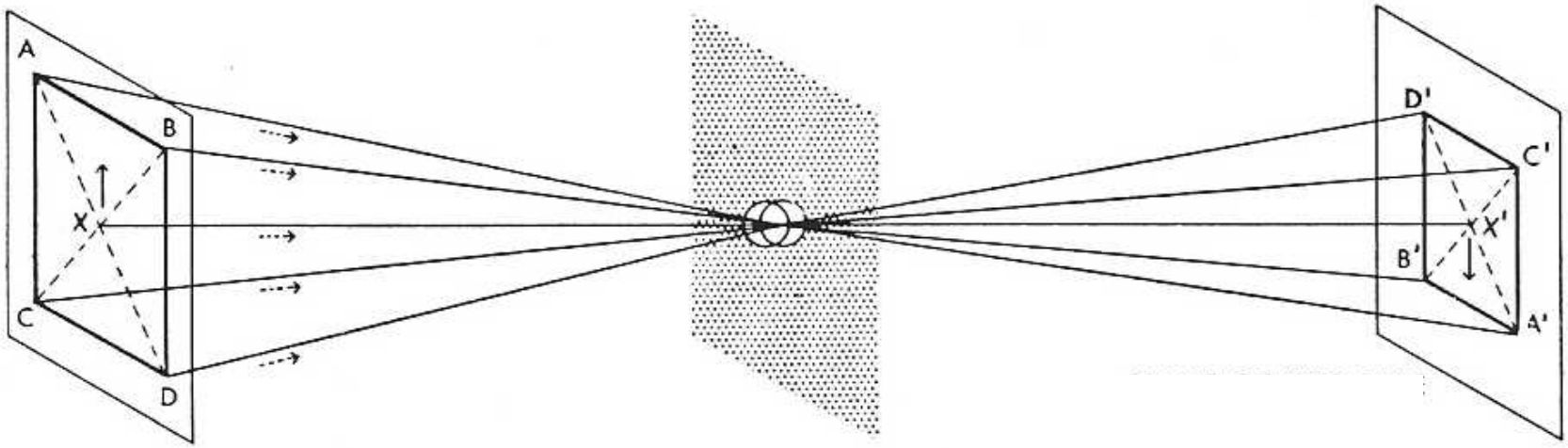
Examples of Camera Lenses

Sandia National Laboratories

Primary Camera Lens Functions

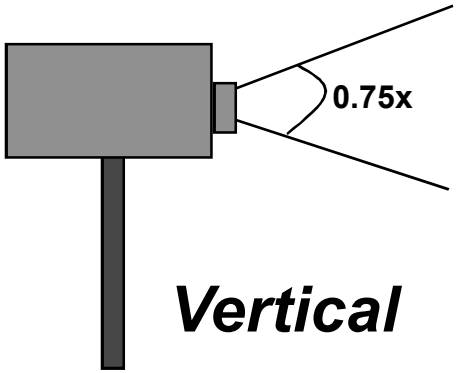
- Collects the reflected light from the scene and focus the light on the photo sensor array
- Magnifies objects within the viewing angle
- Creates a viewing angle that is adjusted by changing the focal length of the lens

Lens Basic Function

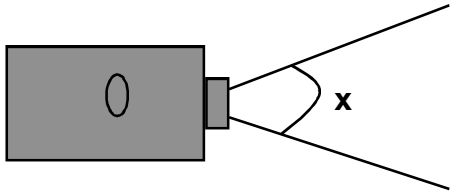


Camera and Lens

- **Field-of-View**
  - **For a standard camera and monitor, the vertical field-of-view = .75 (3/4) times the horizontal field-of-view dimension**
  - **For a wide screen camera and monitor, the vertical field-of-view = .5625 (9/16) times the horizontal field-of-view dimension**



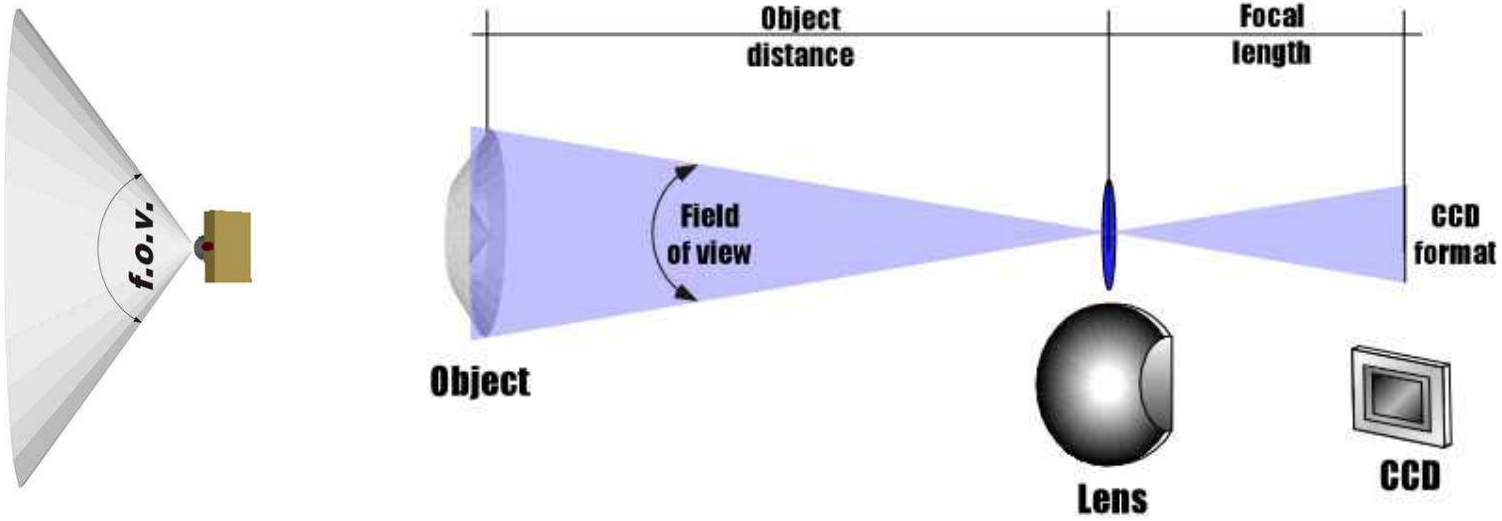
Vertical



Horizontal

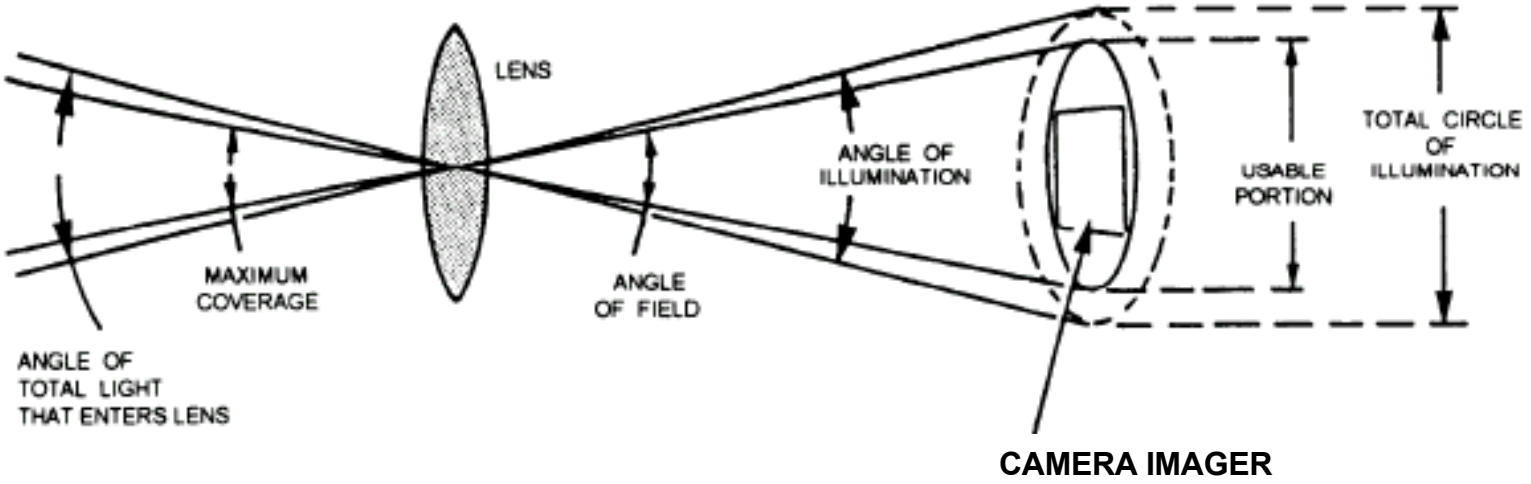
Lens Format

- **Size of scene image projected onto the plane of the camera imager at specified distance behind the lens**



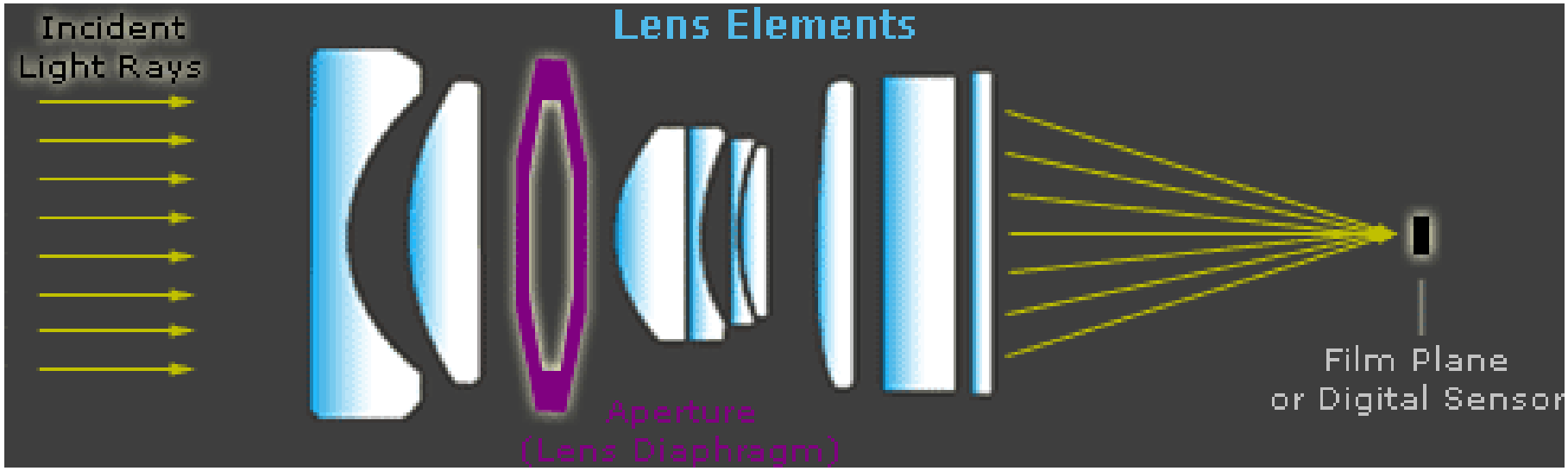
Sandia National Laboratories

Lens-to-Camera Imager Format Relationship



CREDIT SOURCE

Example of Composite Lens Elements

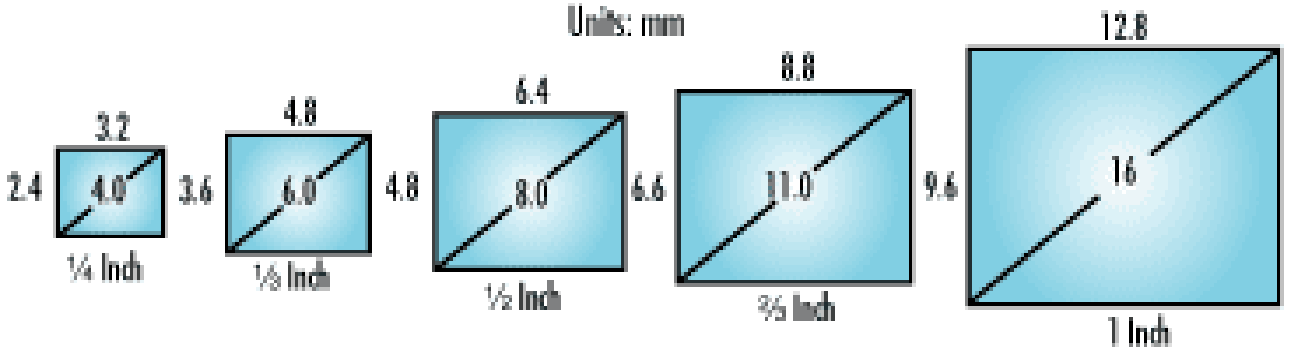


Sandia National Laboratories

Lens Format

- **The format of the lens must match the camera's sensor format to optimize viewing the video image**
- **Standard sizes are**

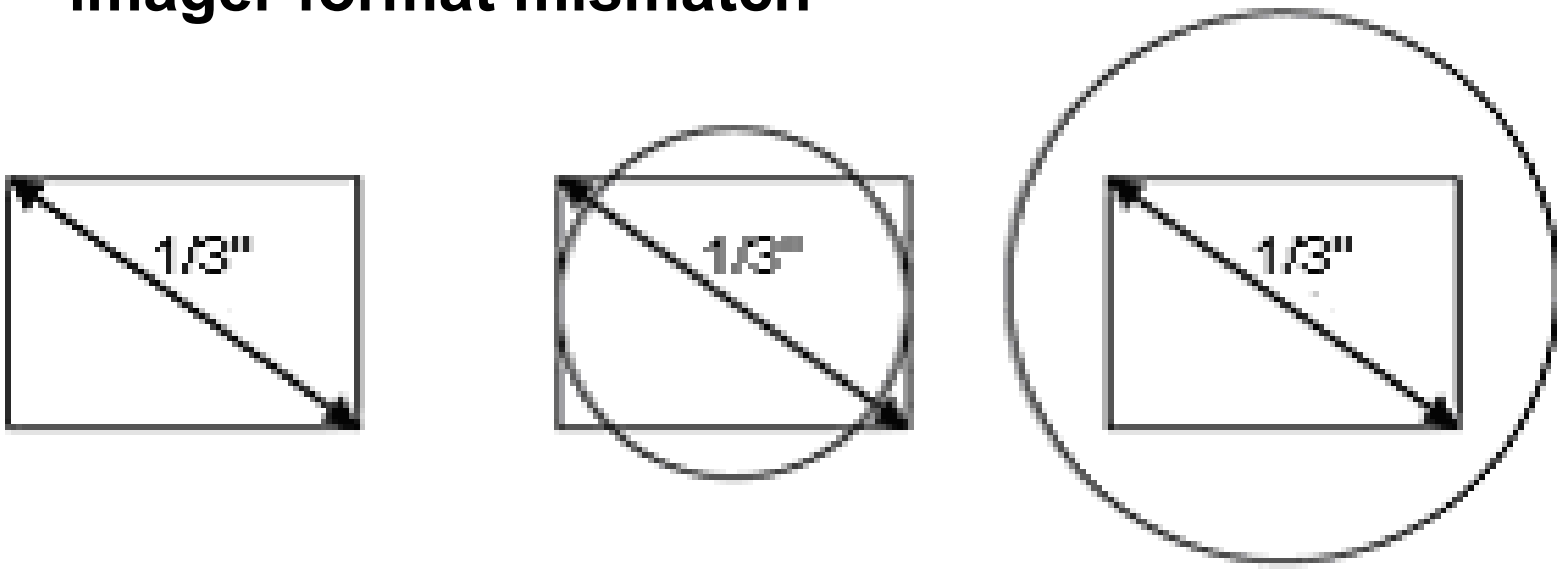
Lens Format	1/8"	1/6"	1/4"	1/3"	1/2"	2/3"	1"
Imager Width *(Wi)*	1.6 mm	2.4 mm	3.2 mm	4.8 mm	6.4 mm	8.8 mm	12.8 mm



Sandia National Laboratories

Lens/Imager Format Mismatch Example

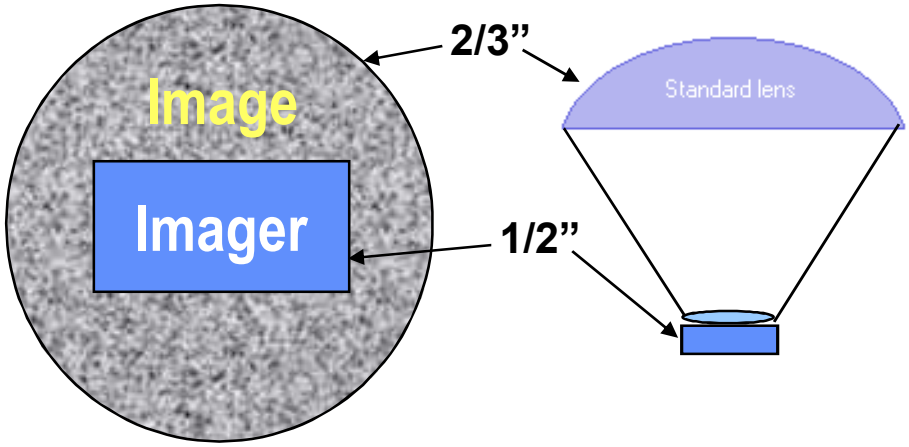
- **Figures below show examples of lens/camera imager format mismatch**



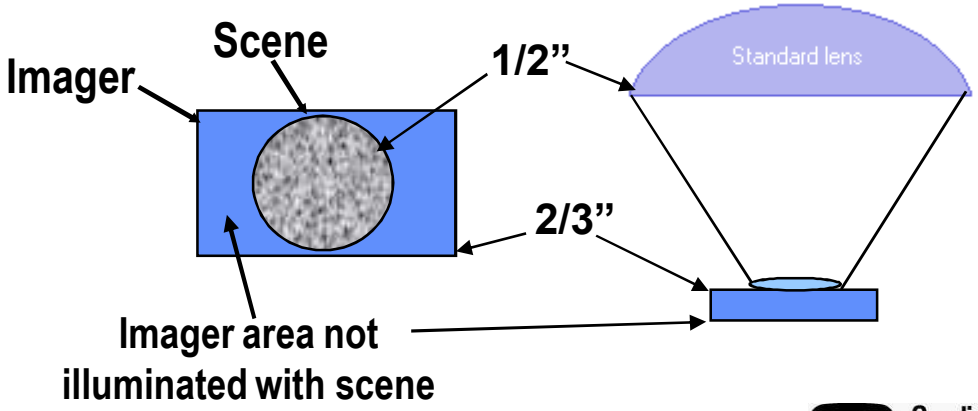
Sandia National Laboratories

Lens-Imager Format Mismatch

- **Lens format larger than camera format**
  - Area larger than 100% of imager exposed
  - Imager not exposed to part of scene



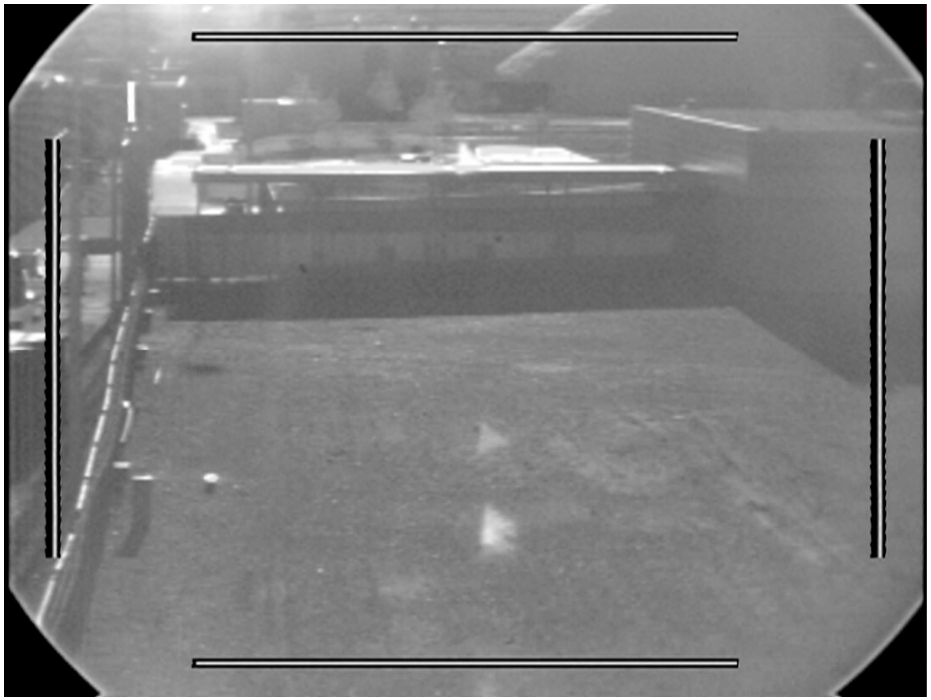
- **Lens format smaller than camera format**
  - Imager not fully illuminated with scene
  - Circular “keyhole” effect



Sandia National Laboratories

Lens-Imager Format Mismatch Examples

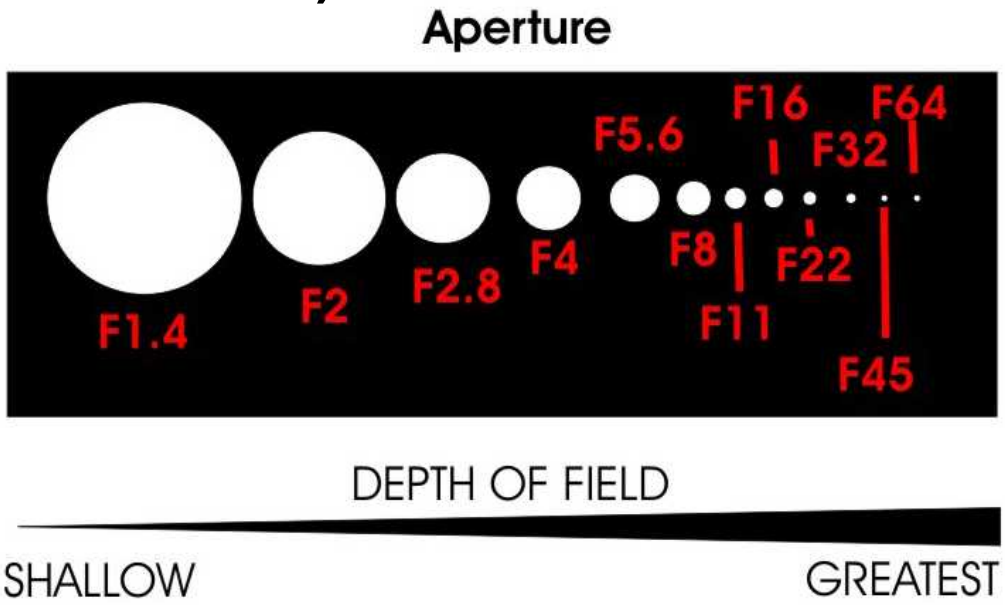
Lens format is smaller than imager format



Sandia National Laboratories

Influence of Lens Aperture or f-number

- The aperture range of a lens refers to the amount that the lens can open up or close down to let in more or less light
- Apertures are listed in terms of f-numbers, which describe relative light-gathering area (depicted below)



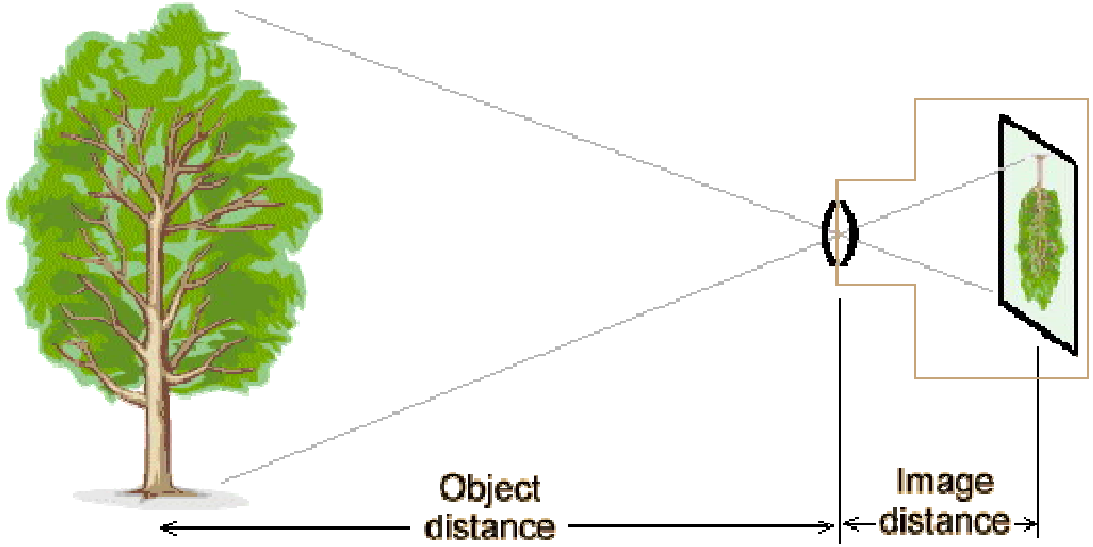
Relationship f-stop & Lens Properties

Impact on Lens Properties			
f-stop	Light Gathering Area (Aperture)	Required Shutter Speed	Depth of Field
Larger	Smaller	Slower	Wider
Smaller	Larger	Faster	Narrower

Focal Length Definition

- Distance from the center of lens to imager, when focused on an object at infinity
- To focus on something closer than infinity, the lens is moved farther away from the imager
- The distances follow the formula:

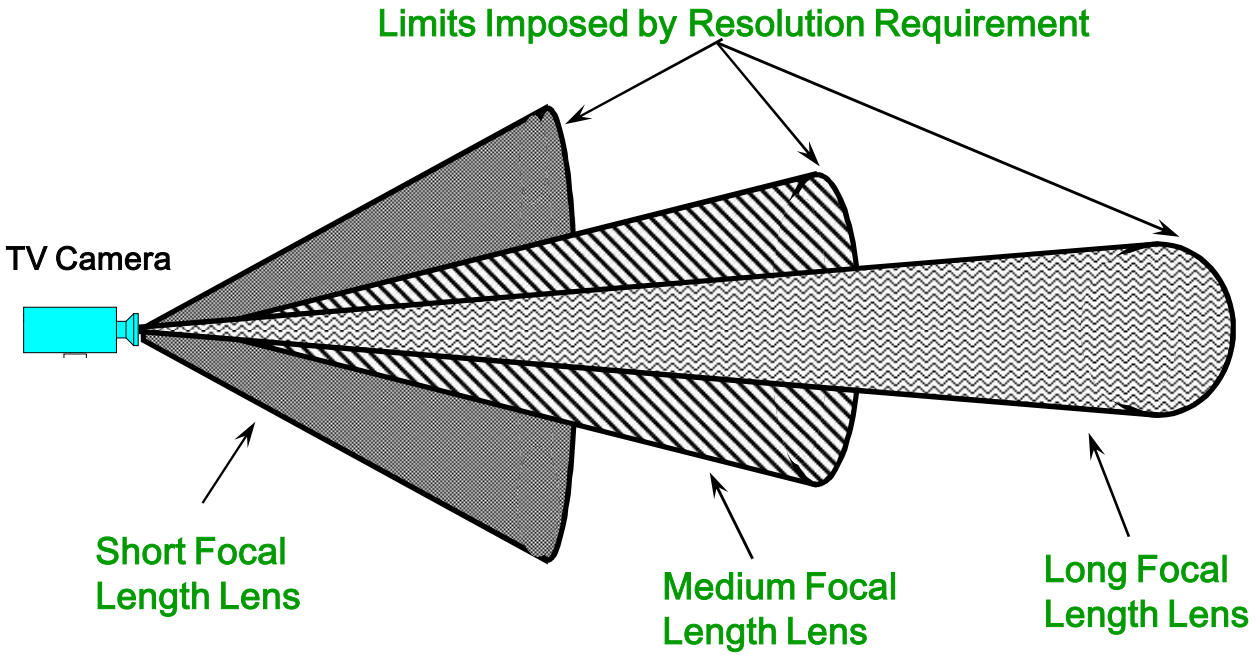
$$\frac{1}{\text{Image}} + \frac{1}{\text{Obj}} = \frac{1}{\text{focal length}}$$



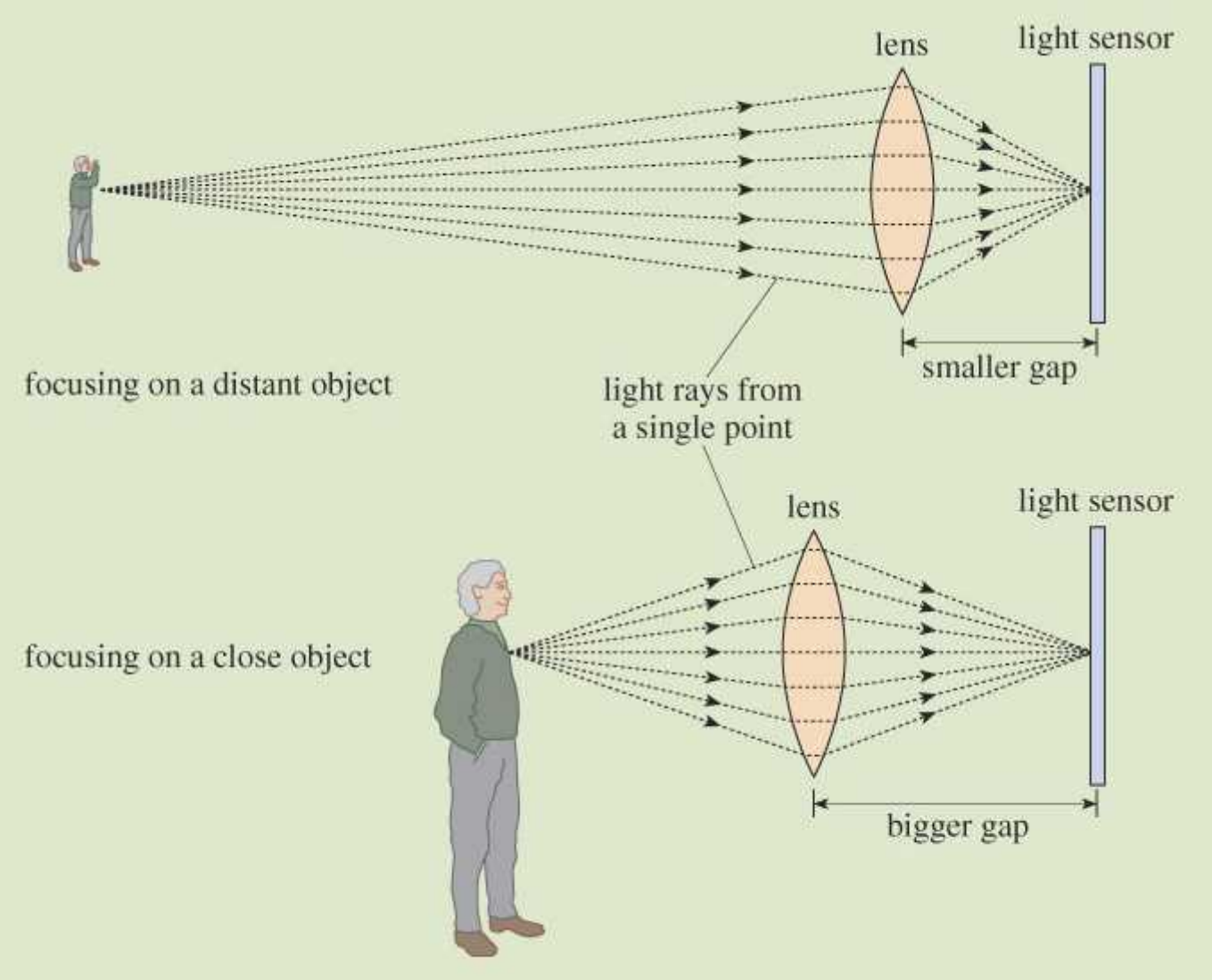
Sandia National Laboratories

Lens Focal Length

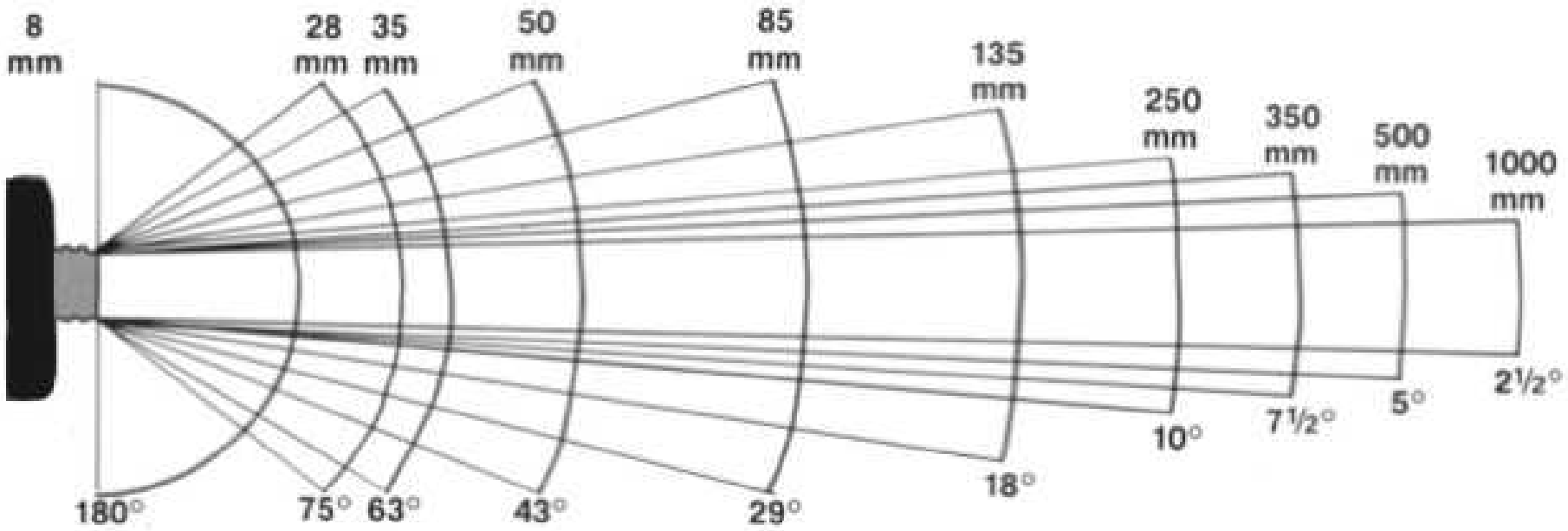
- Relative magnification of an object and size of field-of-view
- Smaller numbers indicate a wider field-of-view
  - e.g., 4mm, 6mm
- Larger number indicate a more narrow field-of-view
  - e.g., 50mm, 75mm



Lens Focal Length Principal



Examples of Lens Focal Length Relationships



Sandia National Laboratories

CREDIT SOURCE

Examples of an Image at Six Different Focal Lengths

24mm

35mm

50mm

100mm

200mm

400mm

Sandia National Laboratories

Long vs. Short Focal Lengths

- Short focal lengths provide close-in views or short sector lengths due to low number of pixels on a target at the far field of view
  - Density of pixels on target
- Longer focal lengths provide for longer sector lengths but narrower fields of view
  - Environmental effects on long distance views can distort the image
    - examples: fog, thermal waves

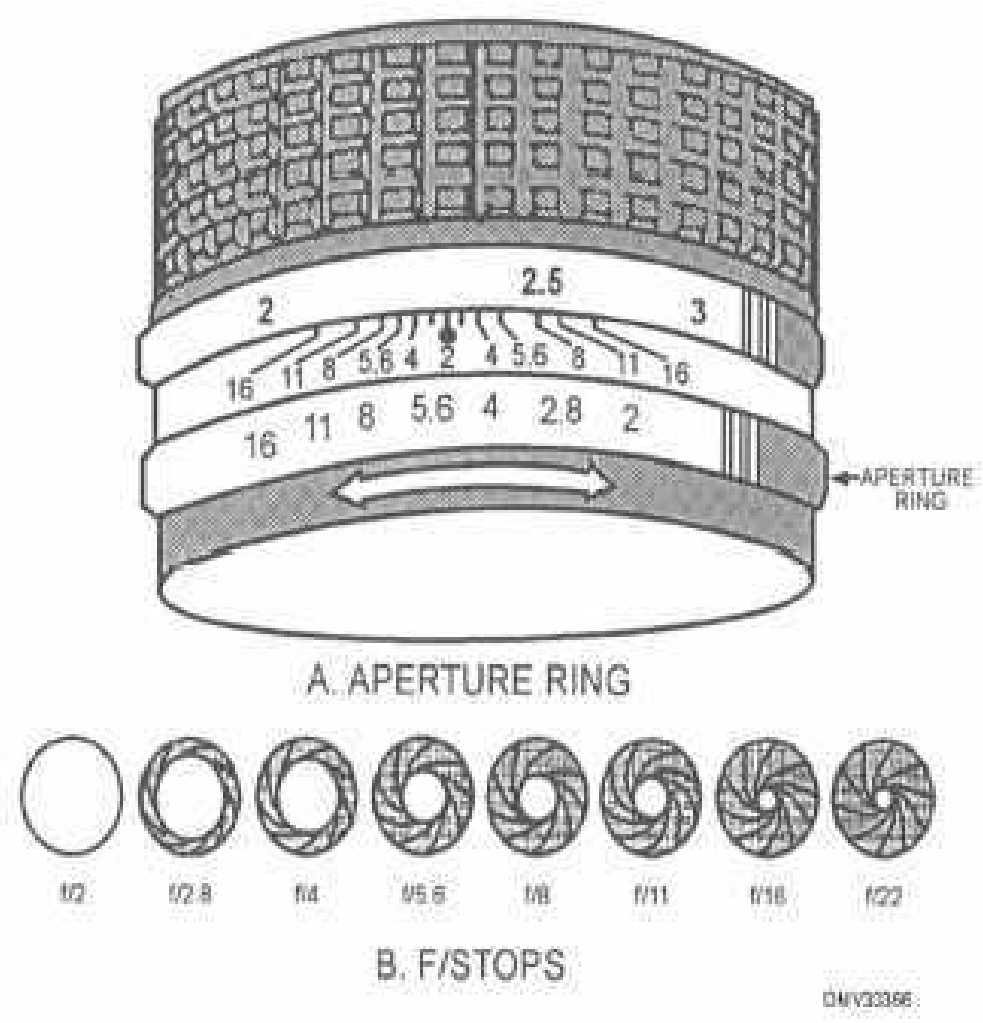
Aperture

- **Adjustable opening that controls the amount of light entering through the lens**

- **Iris**
  - **Manual**
    - **For use in environments where the amount of light is constant**
  - **Auto**
    - **For use in environments where the amount of light is not constant**
      - **Controlled by signal from camera (DC or Video)**

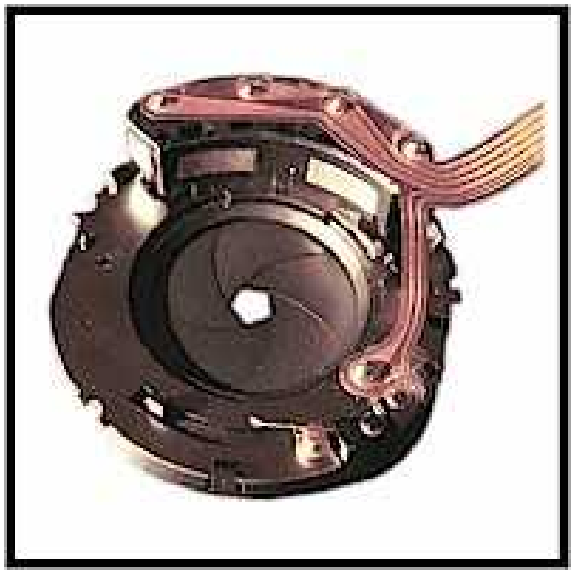
Sandia National Laboratories

Manual Aperture Ring Relationship to Iris Opening



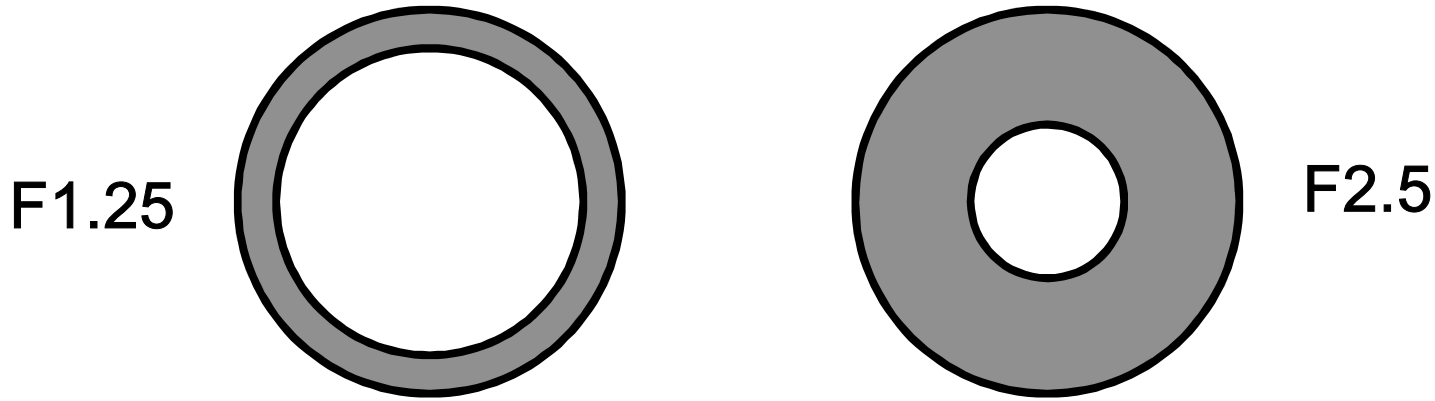
Sandia National Laboratories

Examples of Lens Auto-Iris Mechanisms



Iris Setting (f-stop)

- Ratio of the focal length divided by the aperture opening
- A smaller f-stop number corresponds to a larger opening that passes more light
  - 25mm lens / 20mm opening = F1.25
  - 25mm lens / 10mm opening = F2.5 (1/2 light)



Sandia National Laboratories

f-stop Definition

- F-stop is the focal length divided by the diameter of the lens
- 200mm, f/4 lens is 50mm wide 200mm/50mm = f/4
- f-stop is typically written as f/4, or focal-length divided by four
- Lenses are marked with a series of f-stops, each f-stop increment lets in half as much light as the previous one
- Progression of f-stops, 1 - 1.4 - 2 - 2.8 - 4 - 5.6 - 8 - 11 - 16 - 22 - 32, are powers of the square root of 2

Sandia National Laboratories

dcr1

Depth-of-Field Example

- The depth-of-field does not abruptly change from sharp to unsharp, but occurs as a gradual transition
- Everything immediately in front of or in back of the focusing distance begins to lose sharpness

Sandia National Laboratories

Slide 29

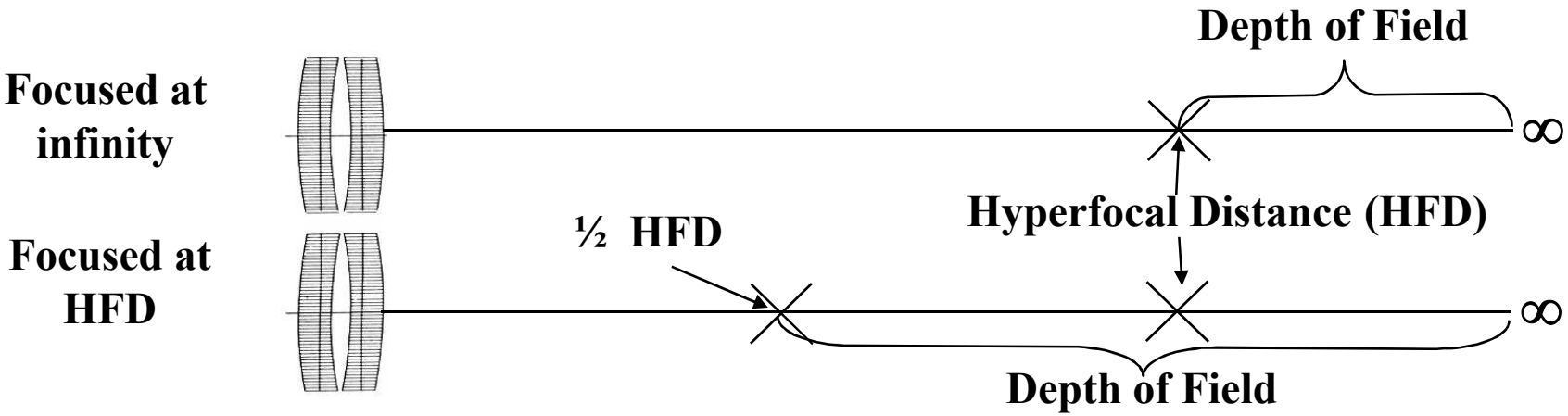
dcr1 is picture taken without attribution
dcross, 9/12/2008

Depth-of-Field

- Amount of scene in focus, greatest at ½ hyperfocal distance
- Greater
  - When higher F-stops used
  - When smaller focal lengths used
  - When subject distance from camera is larger
  - Behind (2/3) the focused subject than in front (1/3)

Hyperfocal Distance (HFD)

- Nearest point at which you can focus and have objects at infinity in focus
- Setting focus of lens to hyperfocal distance allows objects half that distance to infinity to be in focus
  - Largest depth-of-field



Sandia National Laboratories

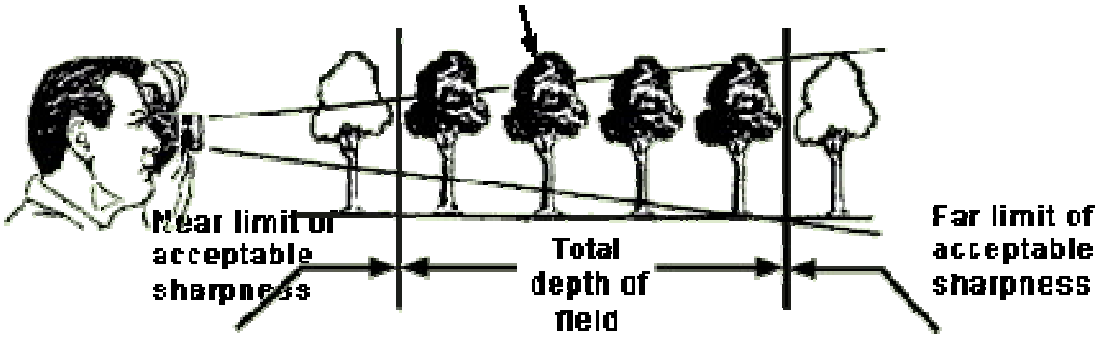
Hyperfocal Distance Charts

- **Applies to 35-mm cameras**
- **Hyperfocal Distance = focal length2 / (aperture x diameter or circle of least confusion)**
- **“Circle of Confusion” (CoC)**
- **Hyperfocal point in feet from shooter**

	15 mm	17 mm	20 mm	24 mm	28 mm	35 mm	50 mm	100 mm	150 mm	200 mm
f 2.8	8.79	11.29	15.62	22.50	30.62	47.85	97.64	390.58	878.80	1562.30
f 5.6	4.39	5.64	7.81	11.25	15.31	23.92	48.82	195.29	439.40	781.15
f 8	3.08	3.95	5.47	7.87	10.72	16.75	34.18	136.70	307.58	546.81
f 11	2.24	2.87	3.98	5.73	7.79	12.18	24.85	99.42	223.69	397.68
f 16	1.54	1.98	2.73	3.94	5.36	8.37	17.09	68.35	153.79	273.40
f 22	1.12	1.44	1.99	2.86	3.90	6.09	12.43	49.71	111.85	198.84
f 36	0.68	0.88	1.22	1.75	2.38	3.72	7.59	30.38	68.35	121.51

Focus Point & Depth-of-Field Examples

Focus at 10 ft distance

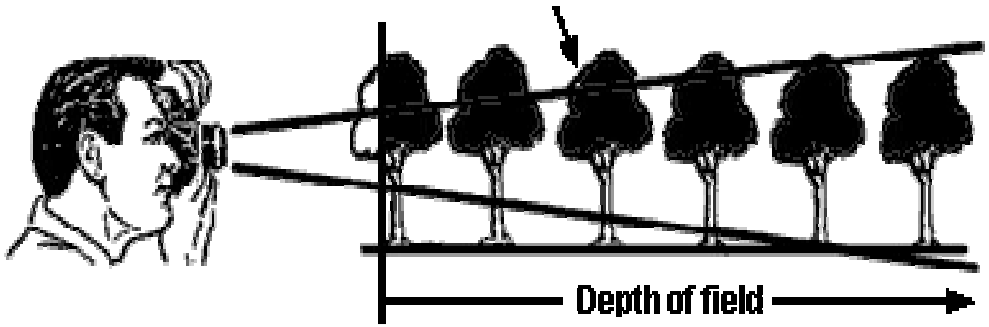


7.69 ft

6.61 ft

14.3 ft

Focus at the hyperfocal distance 32.8 ft



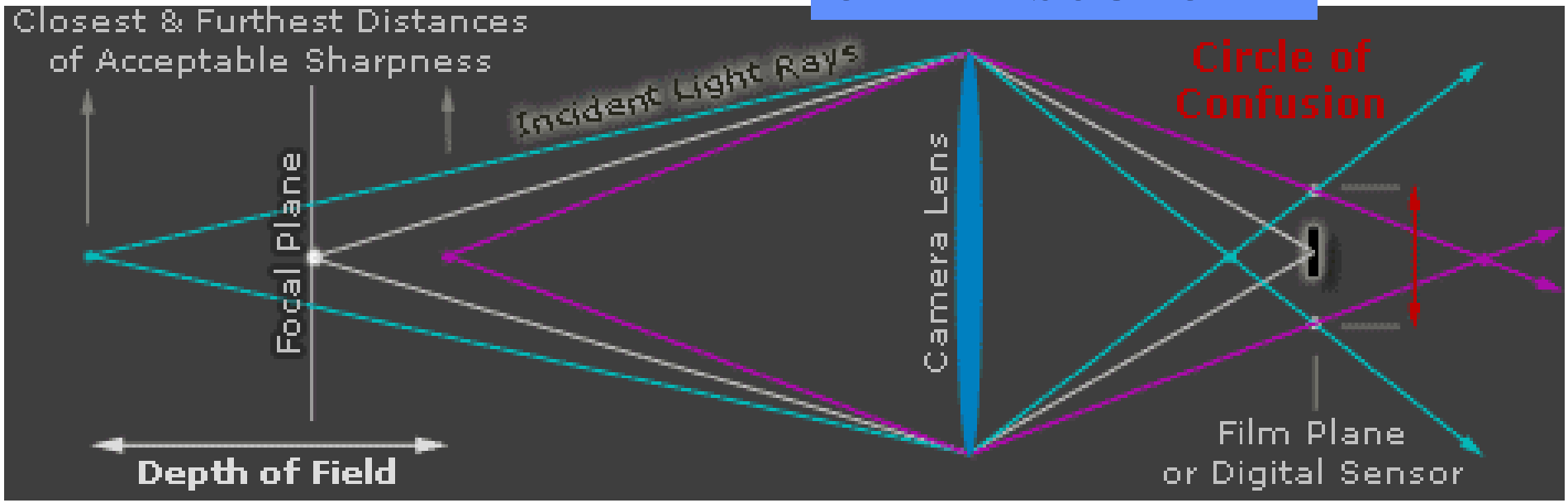
Depth of field extends from 16.4 ft to infinity

Sandia National Laboratories

Measure of Image Sharpness

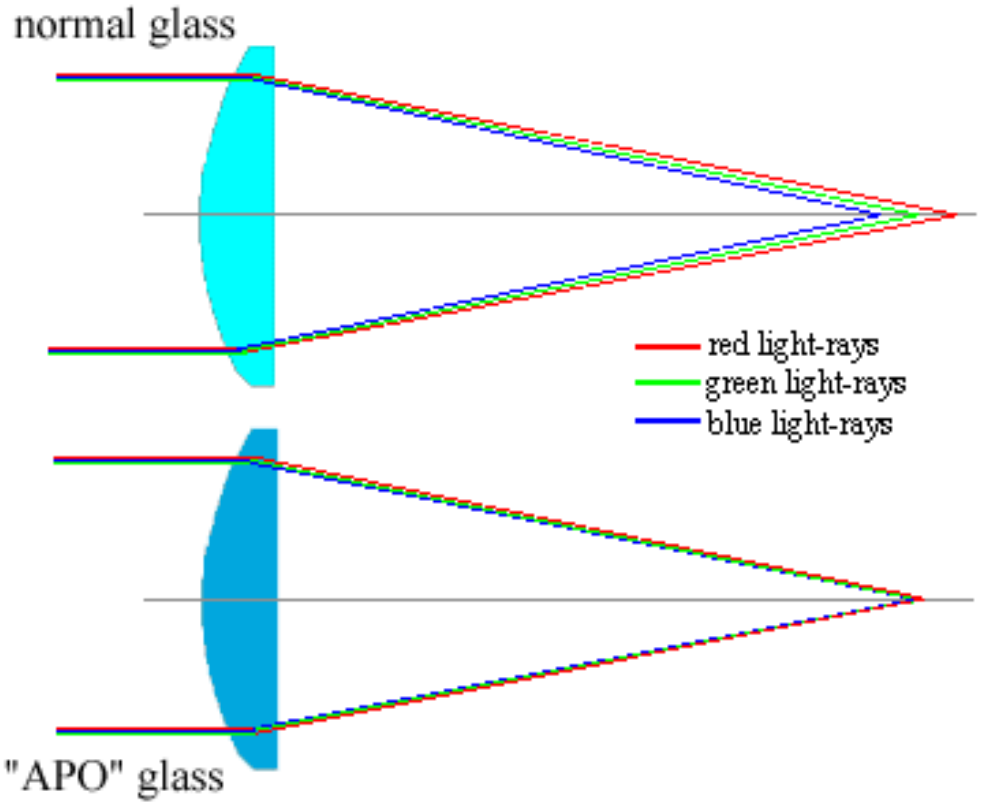
Since focus transition is not abrupt, a term called the "circle of confusion" is used to define how much a point needs to be blurred in order to be perceived as unsharp

CREDIT SOURCE



Sandia National Laboratories

Specialized Glass / Coatings



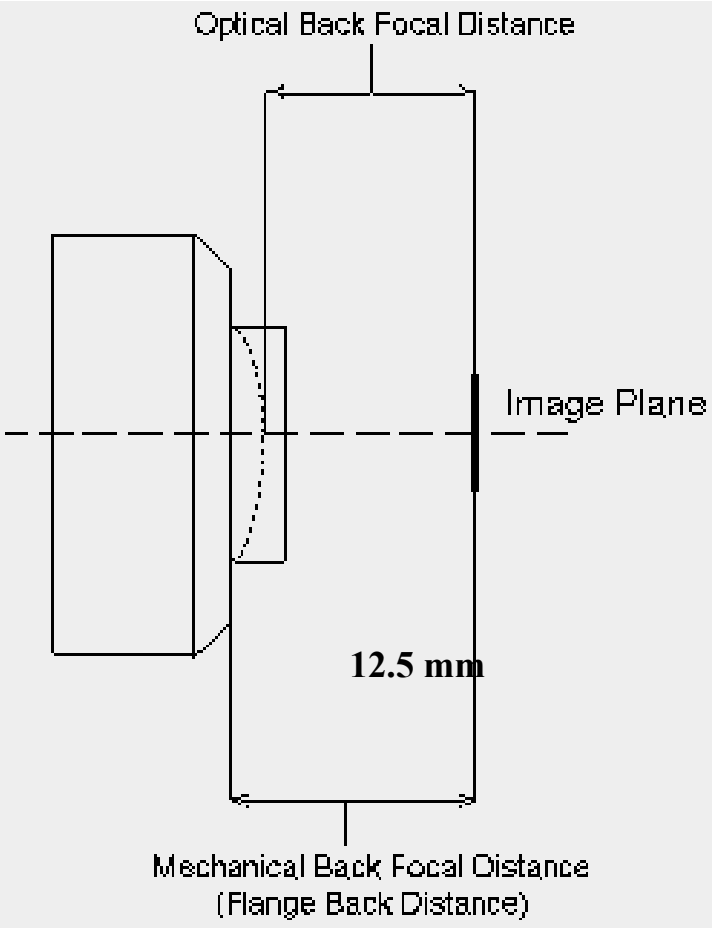
Apochromatic Elements – to accurately focus different wavelengths

Sandia National Laboratories

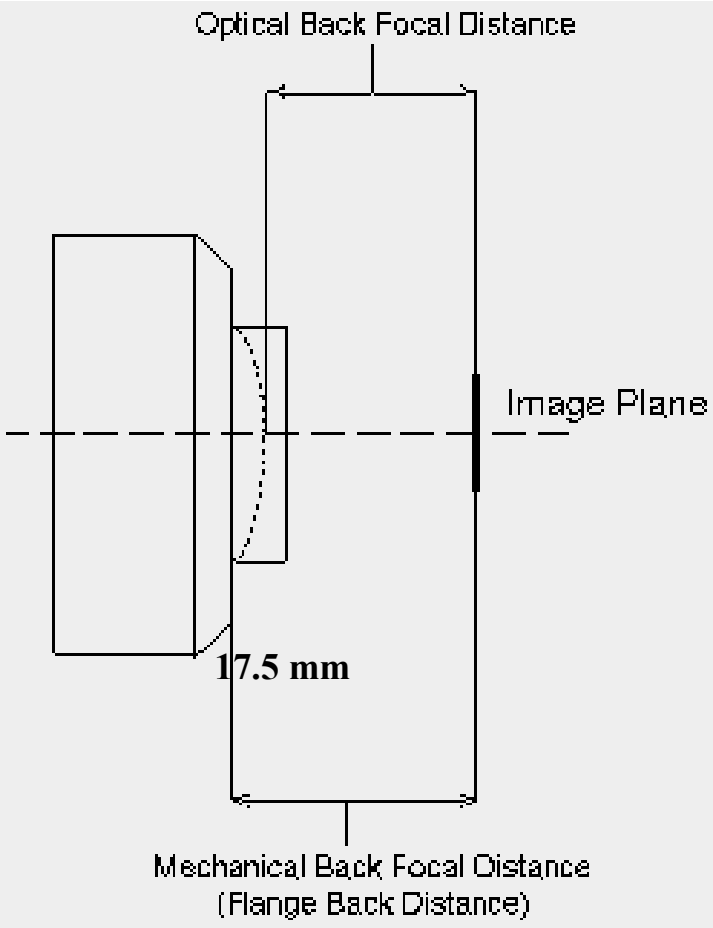
Lens Mounts

- "Flange back distance" is between the flange of the lens and the focal plane of the lens
- C – flange back distance is 17.5mm
- CS – flange back distance is 12.5mm
- CS camera to C mount adapter (5mm spacer)
- C mount camera to CS lens not possible
- Others – normally still image photography

C and CS Mount



CS - Mount

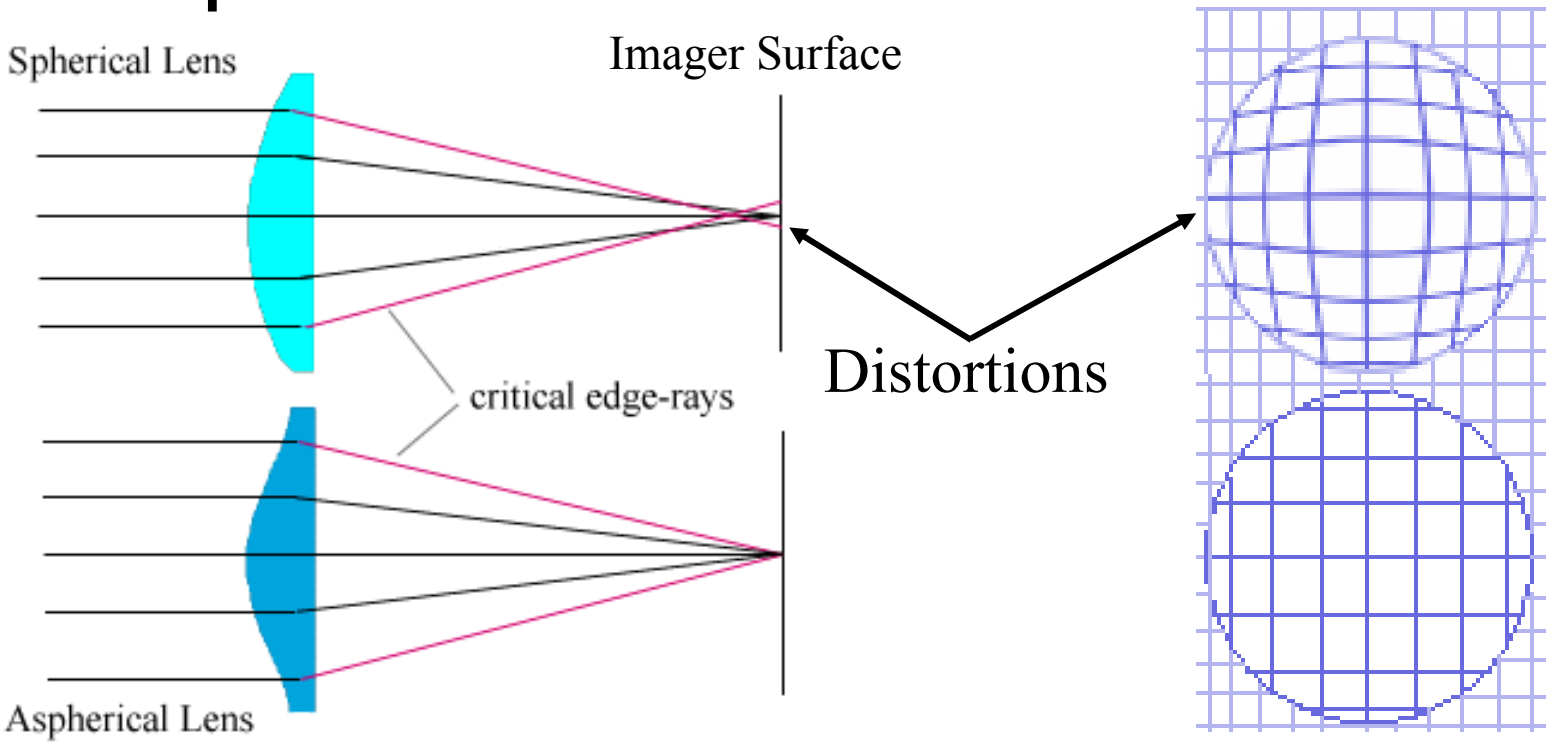


C - Mount

Sandia National Laboratories

Lens Types

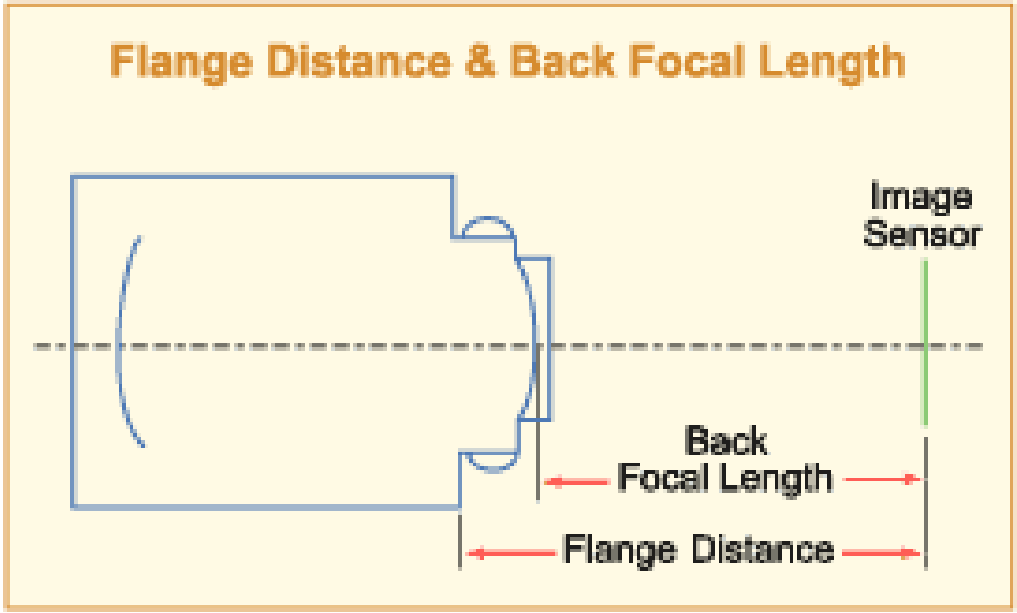
- **Spherical**
- **Aspherical**



Sandia National Laboratories

Focus

- **Mechanical (Back Focus)**
  - **Adjustment of lens flange to camera housing distance**
- **Optical (Front Focus)**
  - **Using lens focus to move lens assembly closer or farther away from target**



Back Focus (Mechanical)

- Sometimes a camera cannot be focused by the optical focusing ring on the lens or on a zoom lens at either end of the zoom range
- May indicate a back focus problem
- It means that the flange back is not at the proper distance from the imager
- Cameras have either a lens mount adjustment ring or imager plane adjusting screw
  - Some are now electronically adjustable focus

Back Focus Fixed Focal Length

- Focus target is positioned to fill most of image area
- Set iris wide open in low light environment
- Set focus ring on lens to minimum (nearest) setting
- Move camera imager plane adjustment screw or mechanical adjustment ring so focus goes from blurred through clear to slightly blurred again
- Check that focus ring adjustment on lens can now go from blurred to focus to blurred again
- Lock pickup devices or mechanical ring set screw

Matching Lens and Camera

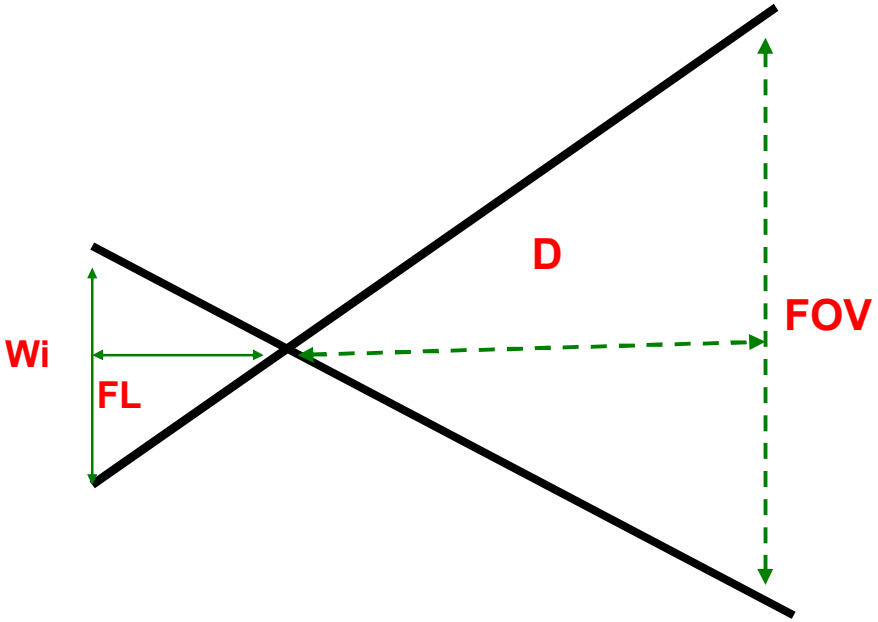
- Format compatibility
- C or CS mount, use of adapter ring
- Light controls
  - Auto-iris controls matched (DC, Video)
  - Electronic shutter, manual / fixed iris
- Mechanical focus
- Filters, coatings, lens type match application

Selection Factors

- Distance of camera tower to the zone
- View entire sensor coverage area
  - Sector or zone – full width and length
  - Sensors in view
  - No blind spots
- Sufficient resolution at the most distant point in the zone to be able to make an assessment

Lens

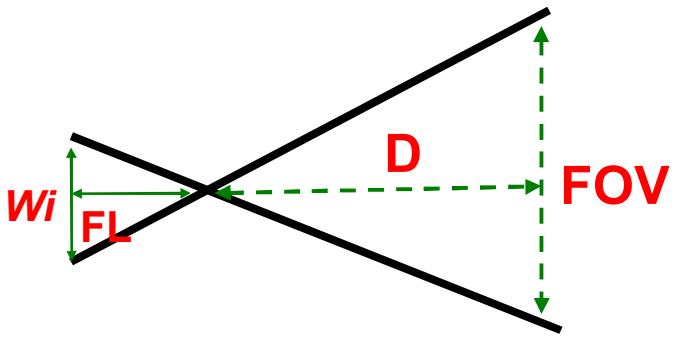
- Lens format must match camera format
  - Equal or larger format on lens than camera
- Focal length (8mm, 25mm, 75mm)
  - Relative magnification of an object and width of field of view



Field-of-View (FOV) Formula

To calculate Horizontal FOV and distance to camera

D = FOV (FL / *Wi*)



Where

- D is distance from camera (m)
- W is width of field-of-view (m) at distance D
- f is focal length of lens (mm)
- *w* is width of imagers sensitive area (mm)

w = 6.4 for 1/2”

w = 4.8 for 1/3”

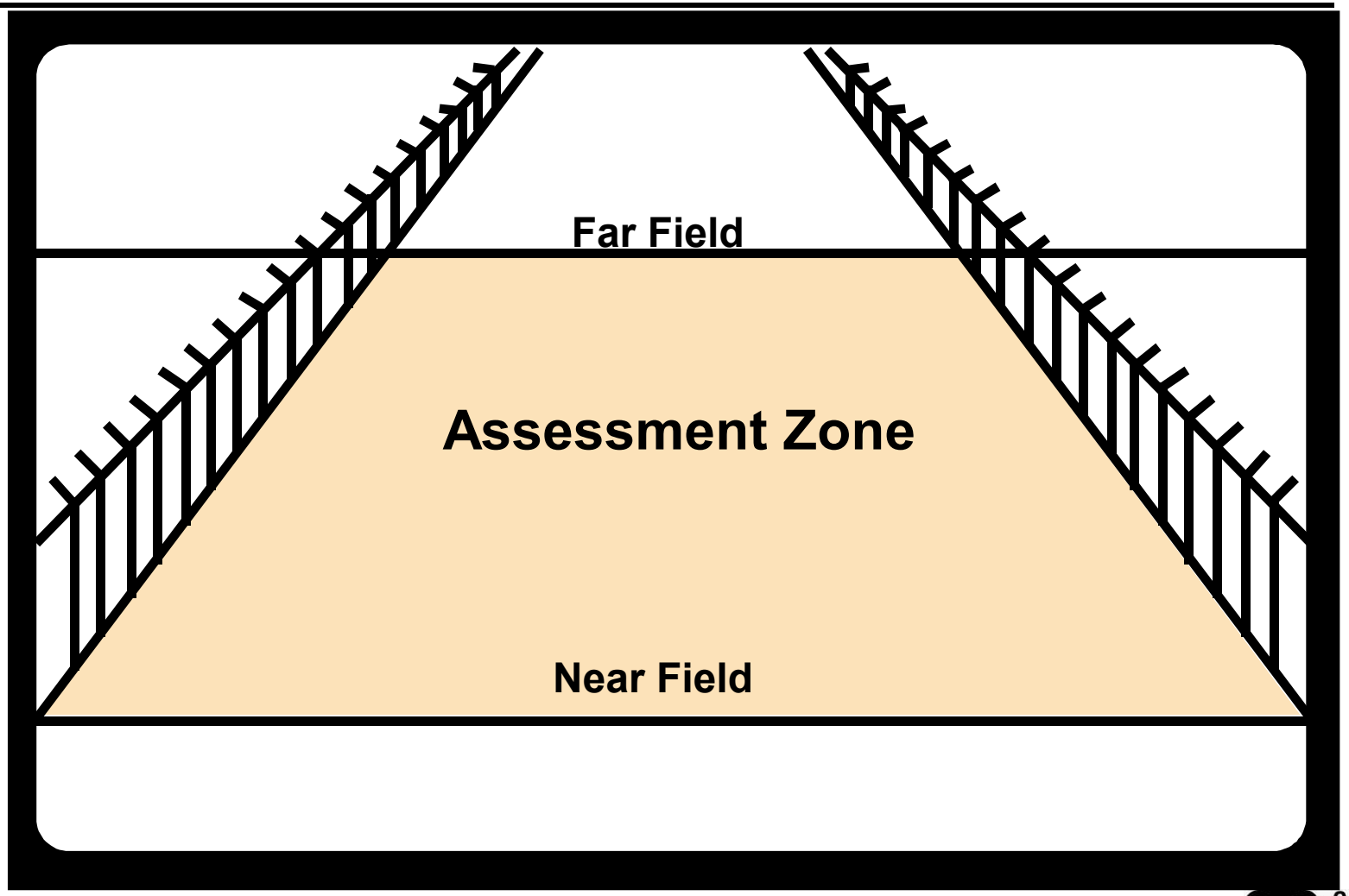
w = 3.2 for 1/4”

w = 1.6 for 1/8”

- **Vertical FOV = HFOV * .75**

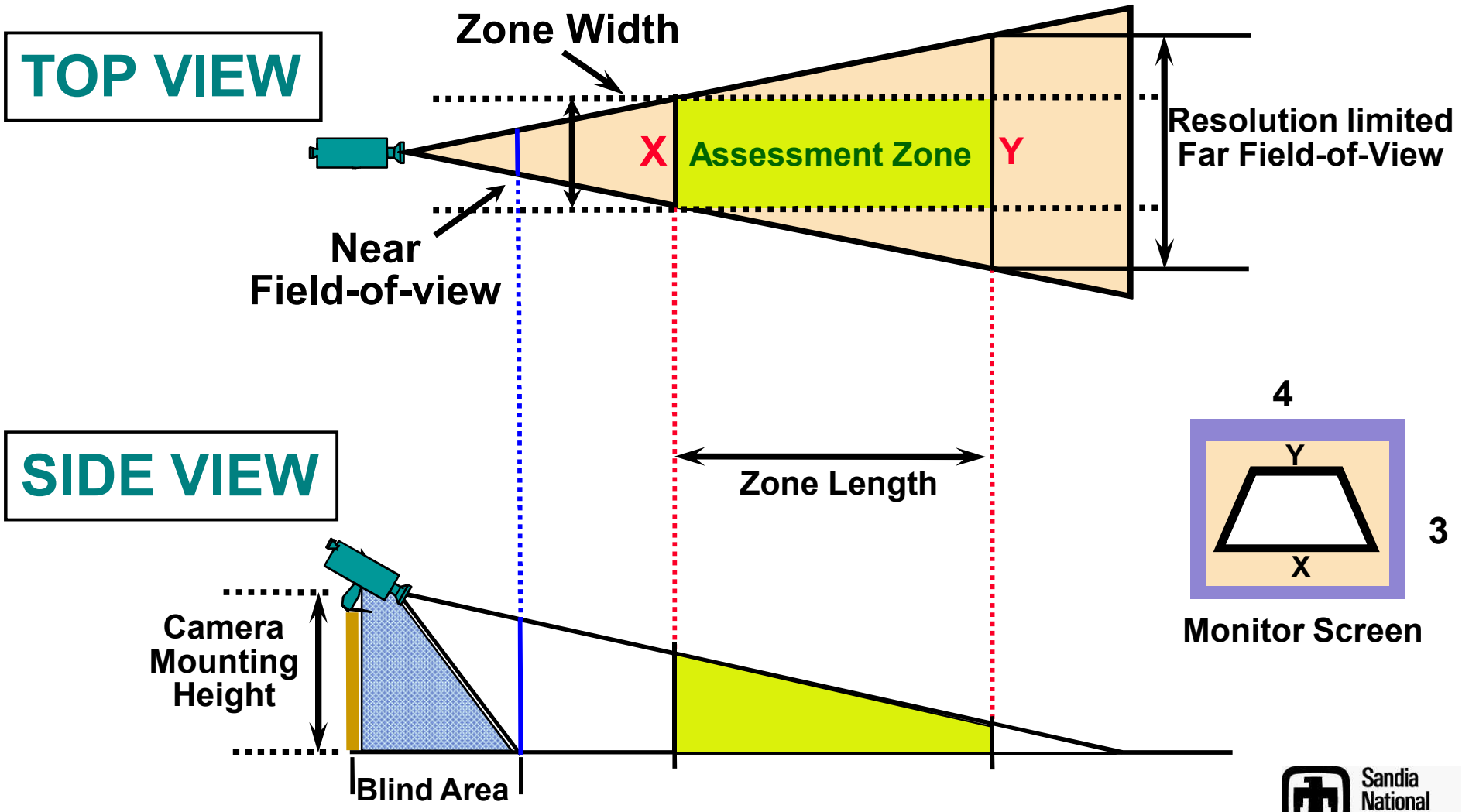
Sandia National Laboratories

The Monitor Picture of Camera's Field-of-View



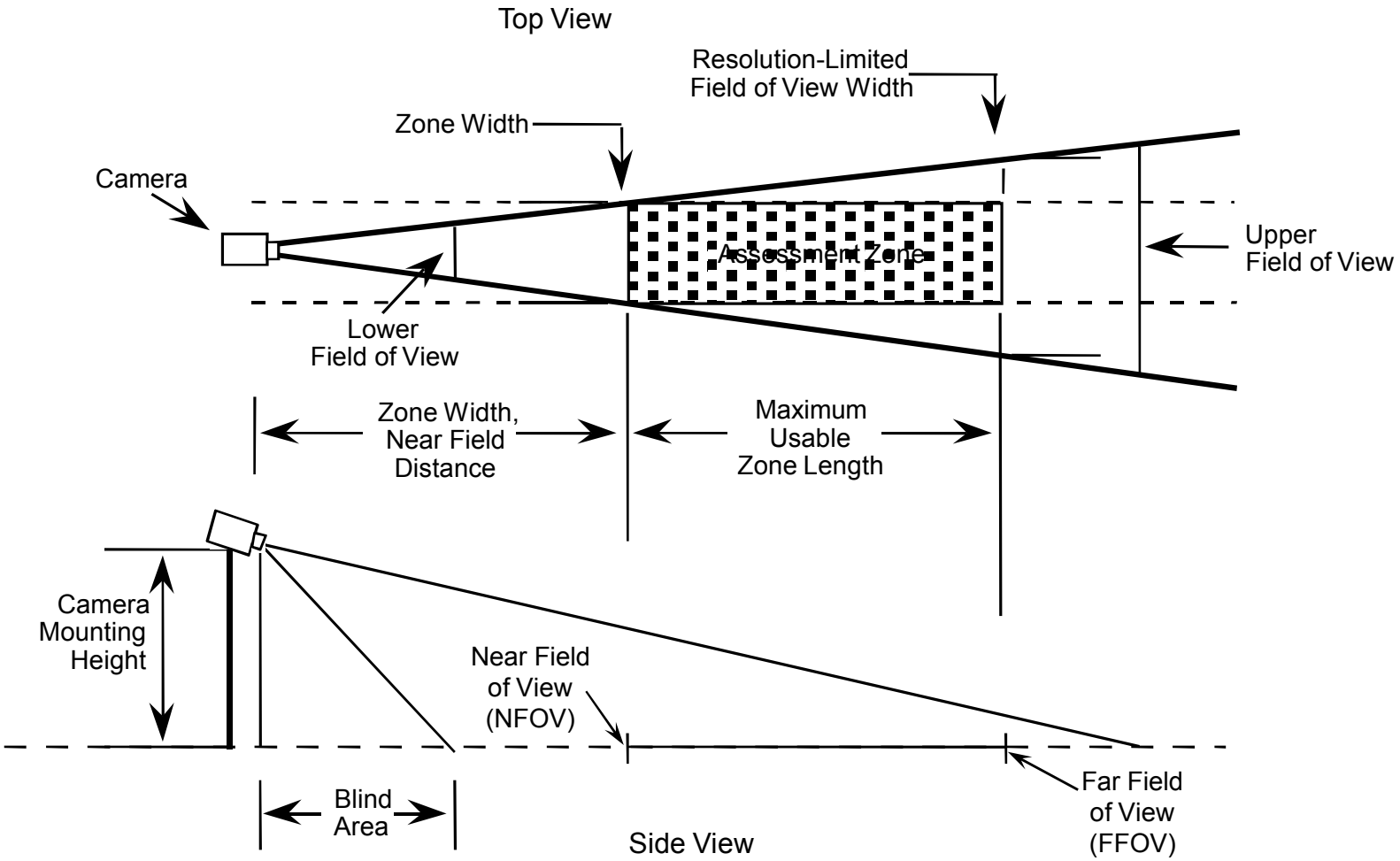
Sandia National Laboratories

Geometry of Assessment Zone



Sandia National Laboratories

Geometry of Assessment Zone



Sandia National Laboratories

Exterior Monitor View

Day

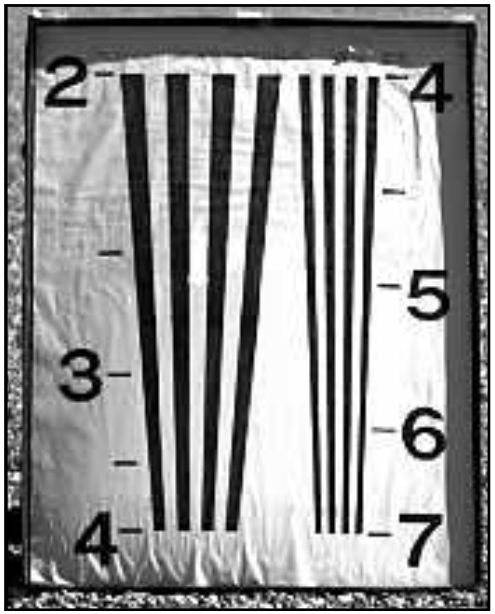
Night

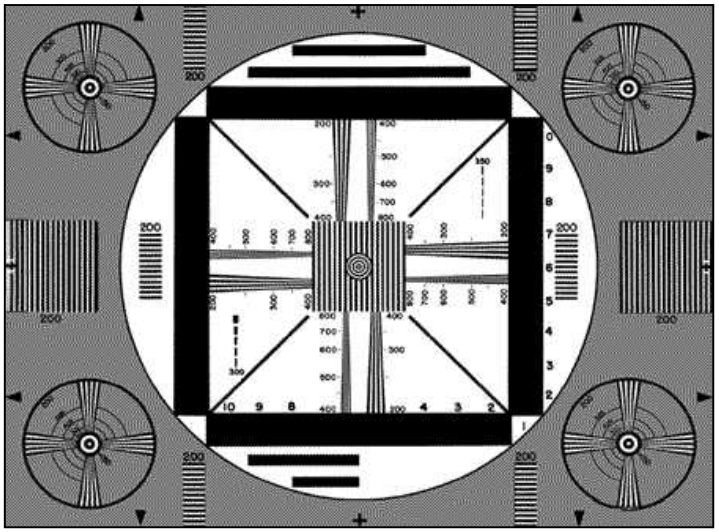
Sandia National Laboratories

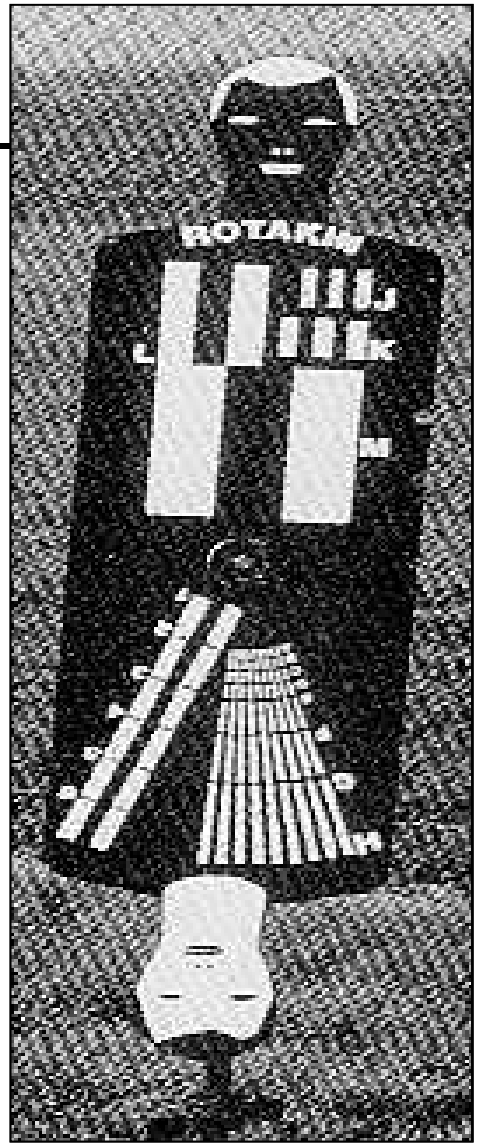
Resolution

- Degree to which you can see fine details in viewed image
- Measured using resolution chart -200-1600 lines
- Units of measure stated as:

  “Horizontal or Vertical TV Lines”

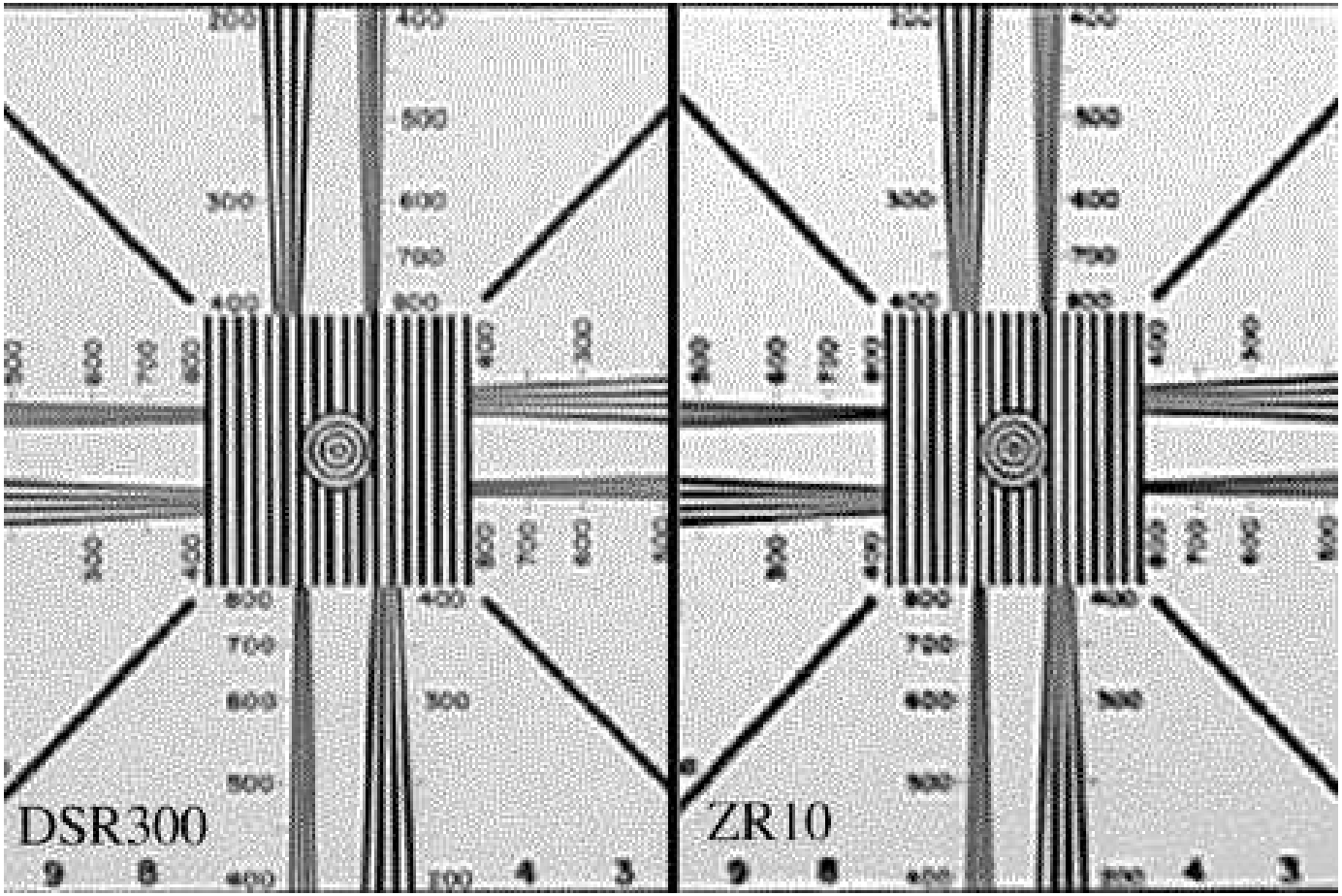






Sandia National Laboratories

Examples of Resolution Chart Images



Sandia National Laboratories

Resolution (cont.)

- The higher the resolution, the more details can be resolved in an image
- The far field-of-view is limited by design criteria of requiring a certain amount of horizontal TV lines-of-resolution to fall on a target
- Design criteria change for the resolution function required
  - *Detection, Classification, or Identification*

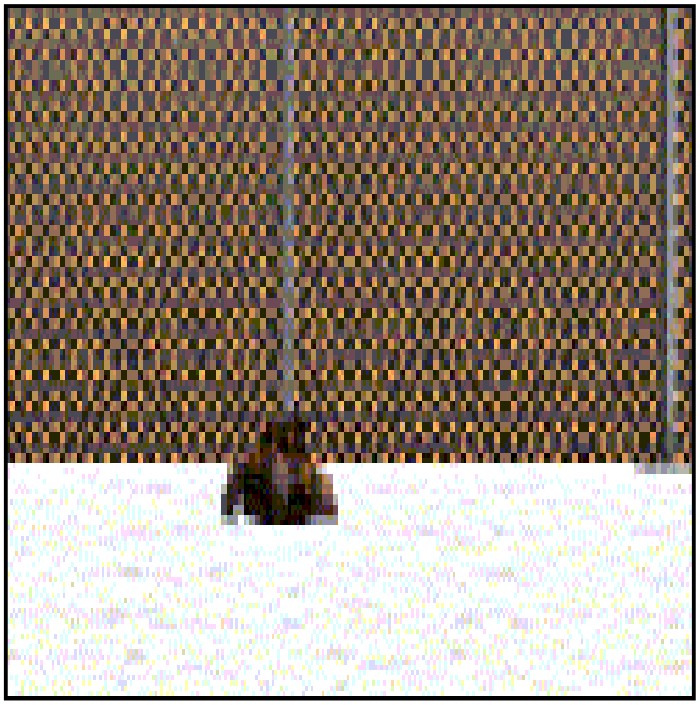
Resolution at Far Field-of-View to Classify Targets

The picture quality allows the operator to recognize and discriminate between human and animal in the camera field-of-view.

Sandia National Laboratories

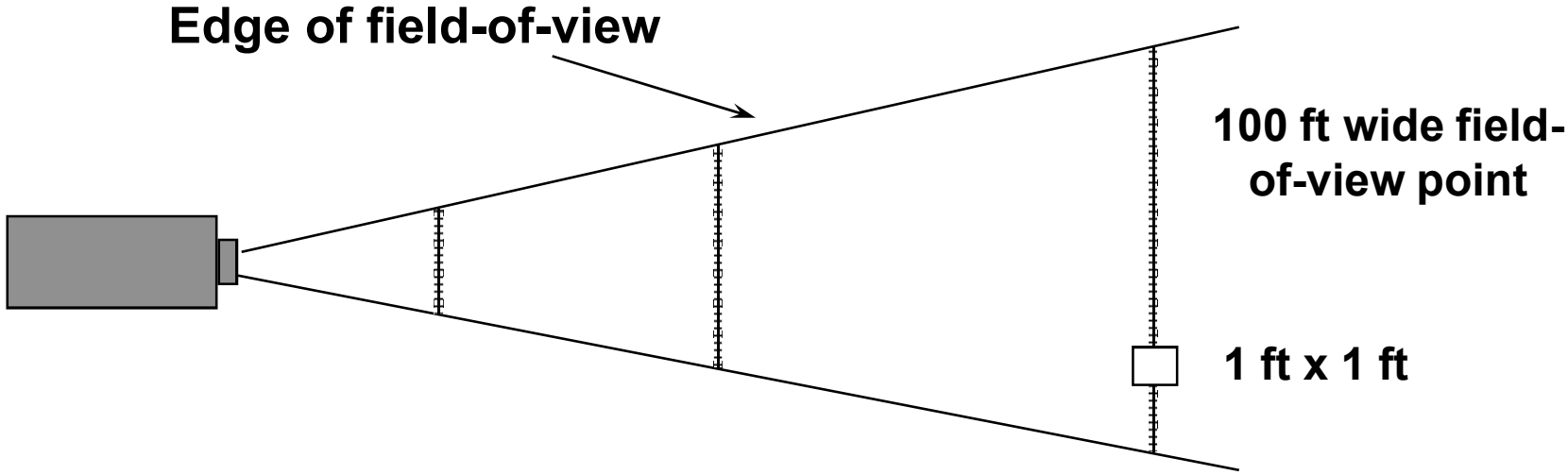
Assessment Resolution

- Classifying an object depends on camera resolution, lens focal length, size of object, object contrast to background, and motion
- Alarm assessment distinguishes between nuisance and real
  - Small animal and smallest human profile to camera
- Testing has indicated for human classification:
  - 6 HTVL or 8 pixels on a 1-ft target at the far field of view is required



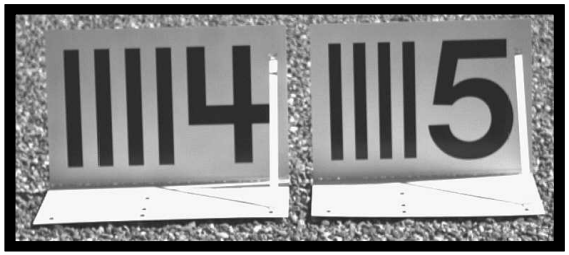
Sandia National Laboratories

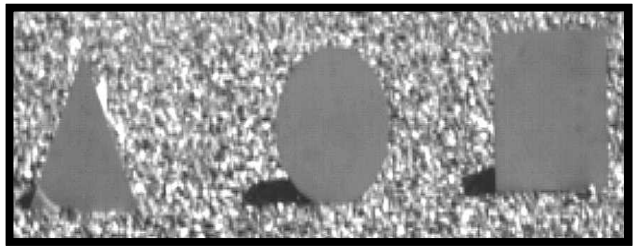
Lens Selection and Resolution



Horizontal view

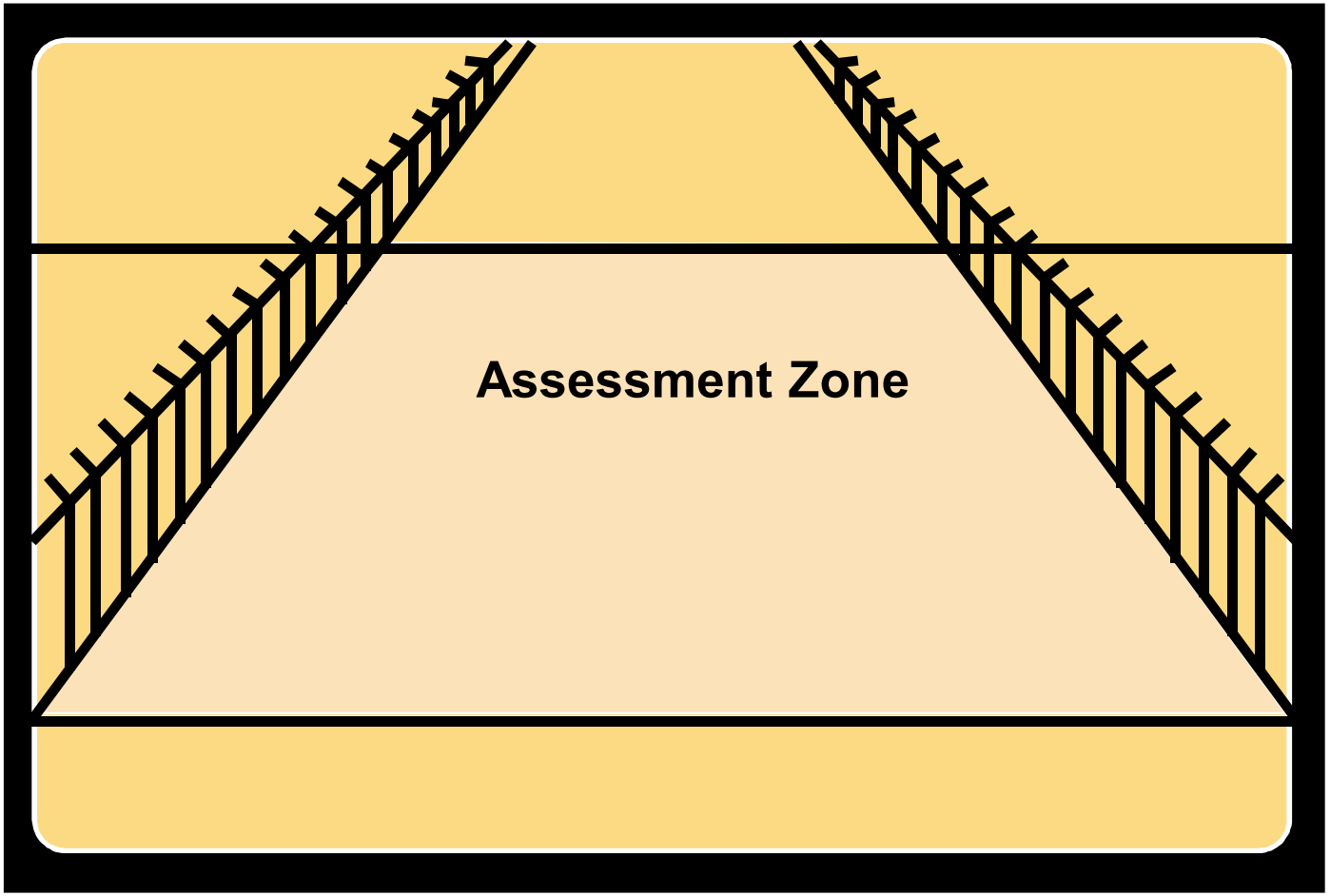
- Camera specification 600 horizontal TV lines of resolution
- Minimum target size for classification is 6 HTVL (8 pixels) of resolution for a 1 square-foot target





Sandia National Laboratories

Resolution



Sandia National Laboratories

Classification Examples


Video Clip

Bird


Video Clip

Shadows


Video Clip

Airplane


Video Clip

Coyote


Video Clip

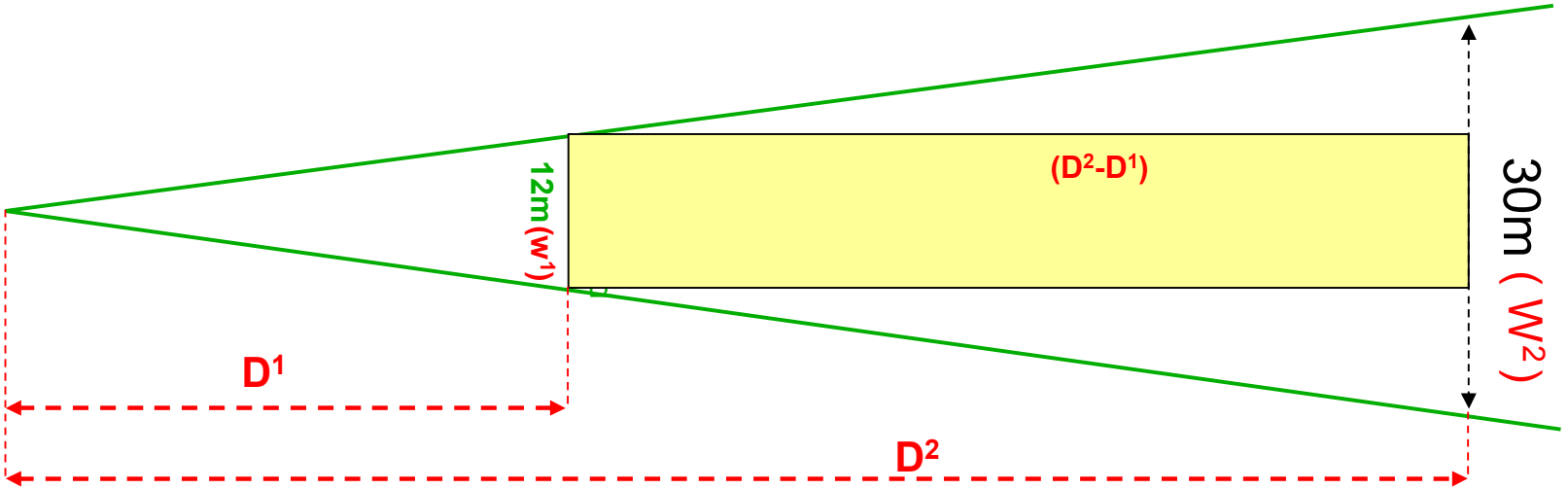
Walker Dark


Video Clip

Fog

Sandia National Laboratories

Calculation for Zone Length



Focal Length of lens

w is width of imager format

Width of FOV at a distance (D)

Distance

$$D = \frac{W F}{w}$$

w= 6.4 for 8mm format

w= 4.8 for 6mm format

w= 3.2 for 4mm format

w= 1.6 for 2mm format

$$D^1 = \frac{W^1 F}{w} \qquad D^2 = \frac{W^2 F}{w}$$

$D^2 - D^1$ = zone length

Sandia National Laboratories

Resolution at Far-Field

12 in. at 8 pixels = no more than **1.5 in. per pixel (line pairs).**
If a camera/monitor provides **800** pixels of horizontal resolution (*600 HTVL), then the maximum field of view width is :

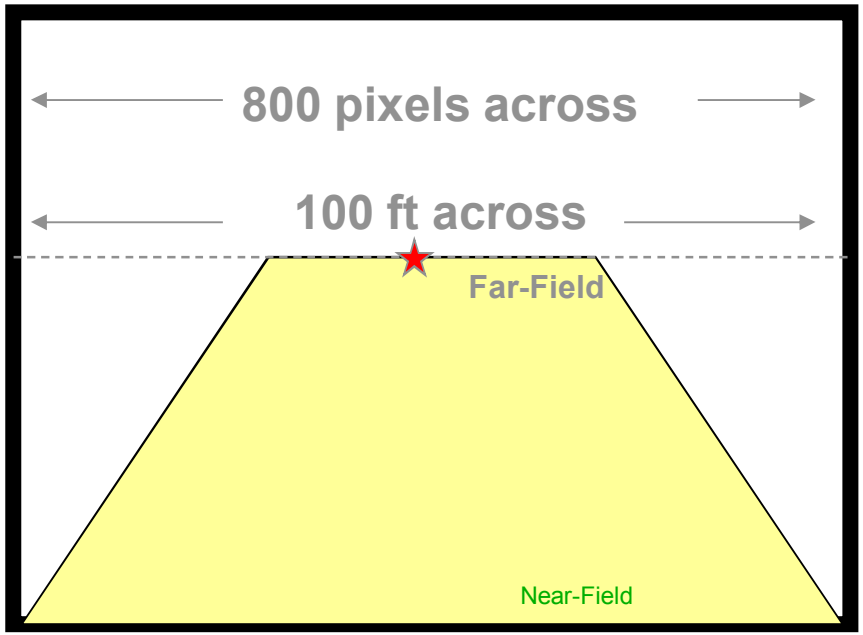
1.5 in. * 800 **pixels** = 1200 in. = 100ft

Another way to reach this is using ratios:
8 pixels to 12 in. = 800 pixels to X.

$$\frac{8}{12 \text{ in.}} = \frac{800 \text{ pixels}}{X}$$

Solve for X = 1200 in. or 100 ft.

What if camera was **400** pixels?



Sandia National Laboratories

6mm Format Camera Example

A 6mm (1/3”) format 800 pixel camera has a width *w* of 4.8mm.
For a 100m zone length at 12 m width:

What focal length lens do we need?

How far away from the near field should the camera be placed?

$$\frac{(30)\,F}{4.8} - \frac{(12)\,F}{4.8} \geq 100$$

$$(6.25)\,F - (2.5)\,F \geq 100$$

$$(3.75)\,F \geq 100$$

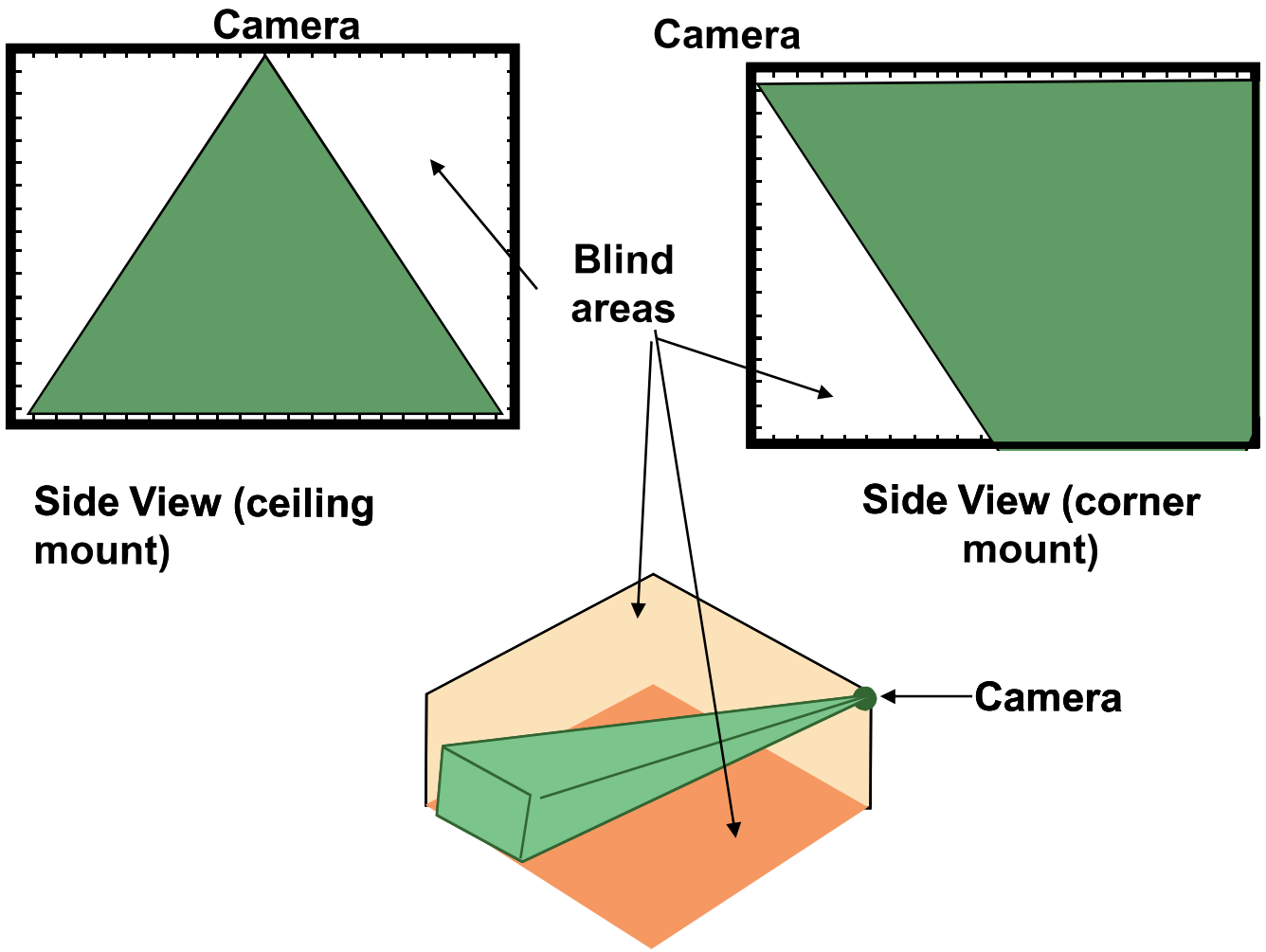
$$F \geq 26.7\text{mm lens}$$

What lenses are available?

$$\frac{(12)\,(26.7)}{4.8} = D_{\text{from near field}} = 66.8\text{m}_{\text{ from near field}}$$

Sandia National Laboratories

Geometry for Interior Assessment



Interior Assessment

- **Extreme wide angle can cause fish-eye effect, making identification difficult**

Sandia National Laboratories

Types of Camera Mounts

- Tower – mounts camera to top of platform of tower
- Pole – mounts to cylindrical pole
- Parapet – top of wall at roof line
  - Comes over top of wall
  - Made to swing onto roof for safer servicing
- Pedestal – flat surfaces like roof, overhang

Types of Camera Mounts (cont.)

- Corner – outside corner of intersecting walls
  - Usually wall mount with 90° adaptor plate
- Ceiling – horizontal overhang surface
  - Can use pedestal mount or wall mount
- Wall – vertical surface, wall, or column
  - Many “J” shaped or “L” shaped

Mount Criteria

- Must be sturdy enough for all environmental effects
- Ice, wind, and snow must be factored into load rating
- Rated by amount of load safely supported
- Attach with proper hardware & anchors to support weight
- Break-away features
  - Special mounting brackets
- Minimize vibrations to camera to lessen camera movement
- Many mounts are weak at single contact points

Camera Mount Examples

Sandia National Laboratories

Mount Vibration

Sandia National Laboratories

Camera Tower Requirements

- Stable in wind
- Tower does not interfere with sensors
- Minimum obscuration
- Minimum exploitability by an adversary
- Not on wooden pole
- Lower than lighting poles
- High enough to avoid pointing at camera above horizon

Sandia National Laboratories

Camera Tower Examples

Sandia National Laboratories

Summary

- Camera video signals may be influenced by lens settings
  - Out of focus during day or night reduces assessment
  - Depth of view for full area coverage to be in focus
  - Different wavelengths of light may influence the focus if lens coatings are not used to compensate
  - Poor aperture settings for auto-iris cameras can make the camera electronics work harder or not produce a full video signal

Summary (cont.)

- Evaluation of assessment capabilities includes technical personnel training on camera / lens setup
- Have maintenance personnel indicate how they set-up and service the cameras to determine their performance level
- Determine if camera mount and tower selection are appropriate for application and environment
- Determine if camera movement comes from the tower or the camera mount

Module Objectives

Learn how to choose the appropriate camera equipment to meet minimum performance criteria for an effective assessment system

- **Understand the parts and functions of lenses**
- **Match a lens to a camera to properly view a designated target area of coverage**
- **Understand resolution and minimum resolution criteria**
- **Understand the roles of the different camera mounts and camera towers**

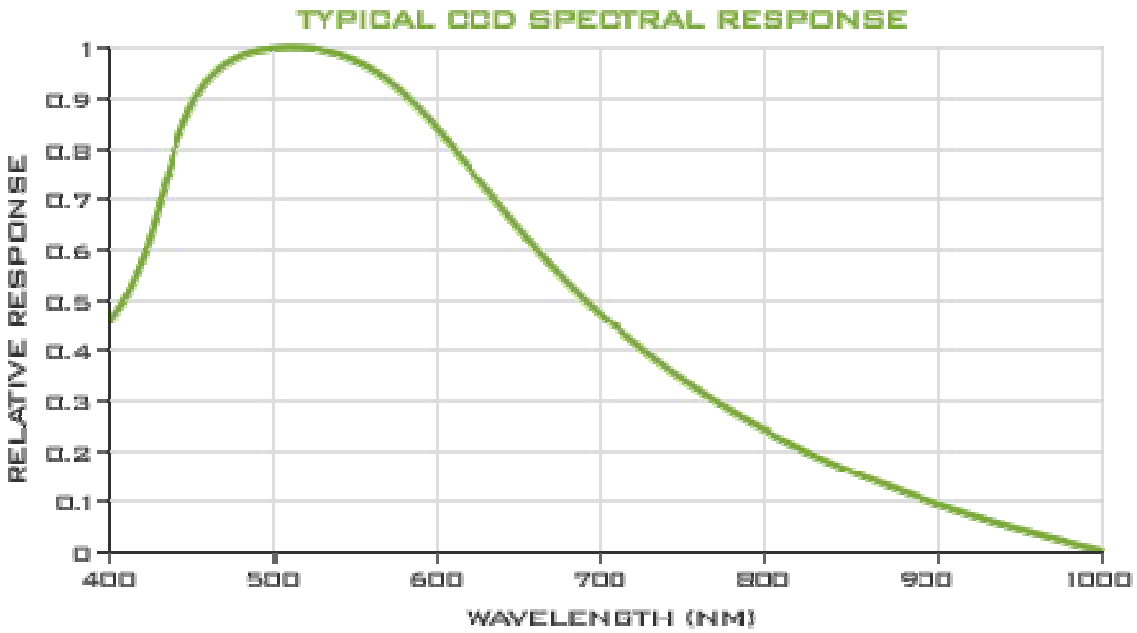
Sandia National Laboratories

CREDIT SOURCE

Sandia National Laboratories

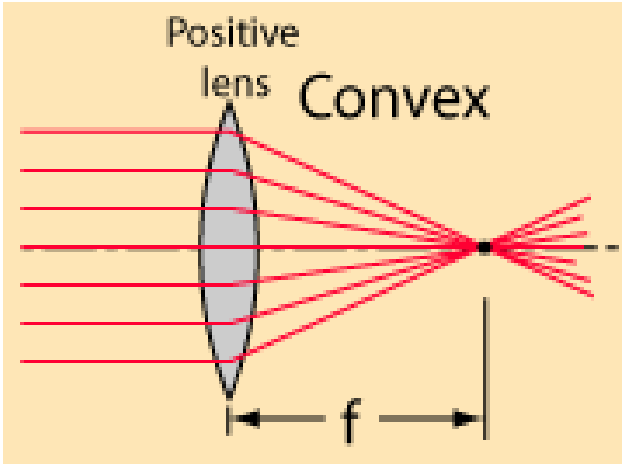

2007-DEC-09 SUN 21:39:54
2007-DEC-09 18:05:36
FRAME
HD
05

Sandia National Laboratories

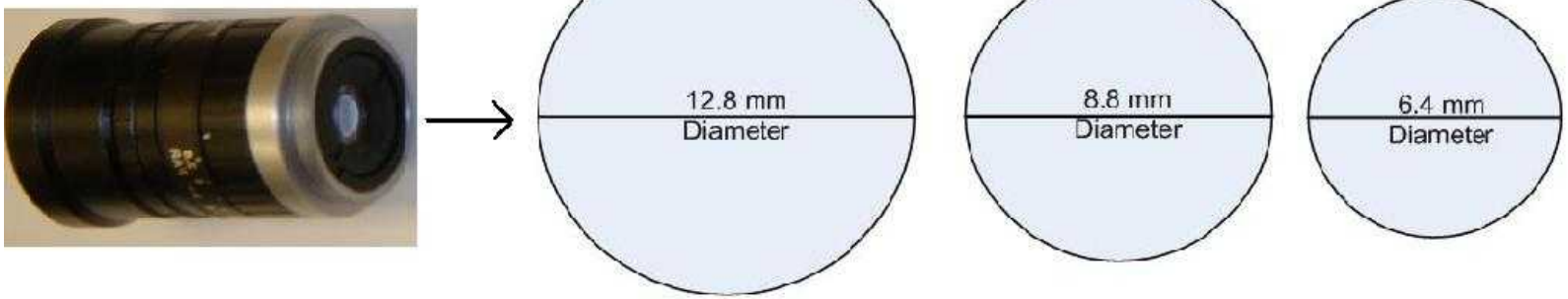


Sandia National Laboratories

Focal Length of Lens



Sandia National Laboratories



Sandia National Laboratories

Commonly Used Equations

CAMERA RESOLUTION

$$\text{Camera Res. (µm)} = \frac{1000}{\text{Camera Res. (lp/mm)}}$$

ANALOG

$$\text{Horiz. Camera Res. (lp/mm)} = \frac{\text{Horiz. TV line} \times 1.333}{2 \times \text{Sensor Size (Horiz.)}}$$

$$\text{Vertical Camera Res. (lp/mm)} = \frac{\text{Vertical TV line}}{2 \times \text{Sensor Size (Vert.)}}$$

DIGITAL

$$\text{Camera Res. (lp/mm)} = \frac{\text{\# Pixels}}{2 \times \text{Sensor Size}}$$

$$\text{Camera Res. (µm)} = 2 \times \text{Pixel Size (µm)}$$

MAGNIFICATION

$$\text{PMAG} = \frac{\text{Sensor Size (Horiz.)}}{\text{Field of View (Horiz.)}}$$

$$\text{System Mag.} = \text{PMAG} \times \frac{\text{Monitor Size (diag.)}}{\text{Sensor Size (diag.)}}$$

SYSTEM RESOLUTION

$$\text{System Res. (µm)} = \frac{\text{Camera Res. (µm)}}{\text{PMAG}}$$

$$\text{System Res. (lp/mm)} = \text{PMAG} \times \text{Camera (lp/mm)}$$

Abbreviations Used:

Res. = Resolution	Vert. = Vertical
Mag. = Magnification	Horiz. = Horizontal
Diag. = Diagonal	FOV = Field of View
PMAG = Primary Magnification	

Sandia National Laboratories

T- Number

- The spectral transmittance of the lens to allow light to pass through the lens material
- The transmittance of a lens is not generally 100%
- Lenses with two different T-numbers would let a different amount of light pass through
- Accounts for transmittance of a lens and the F-stop setting to account for differences in lens qualities

Back Focus Zoom Lens

- Position subject or test pattern 75 feet or more away
- Set iris wide open in low light environment
- Set focus to far distance; lens to wide angle
- Adjust camera ring / imager plane adjustment screw for best focus
- Adjust lens to telephoto, then lens focus ring for best focus

Back Focus Zoom Lens *(cont'd)*

- **Set lens back to extreme wide angle**
- **Use camera pick up device or mechanical adjust for clear picture again**
- **Tighten set screw**
- **Check focus from wide to zoom**
- **Perform adjustments over again until a focused image remains throughout zoom adjustment**