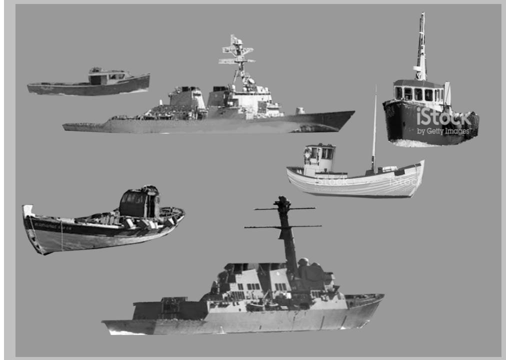
This briefing describes a practical way to
add full color to night vision goggles

- The color goggle design is applicable to both 2nd generation and 3rd generation night vision devices providing they use white phosphors.
- The design is “practical” because:
  - All of the needed technologies (the parts) can be bought or fabricated on the commercial market.
    - Some parts are not “off-the-shelf.”
  - The size and weight of the necessary parts are suitable for mounting on a helmet.
  - Both image intensifier technology and color camera technology have been around for decades.
    - When built to design, these imagers perform as expected.

Benefits of color vision.

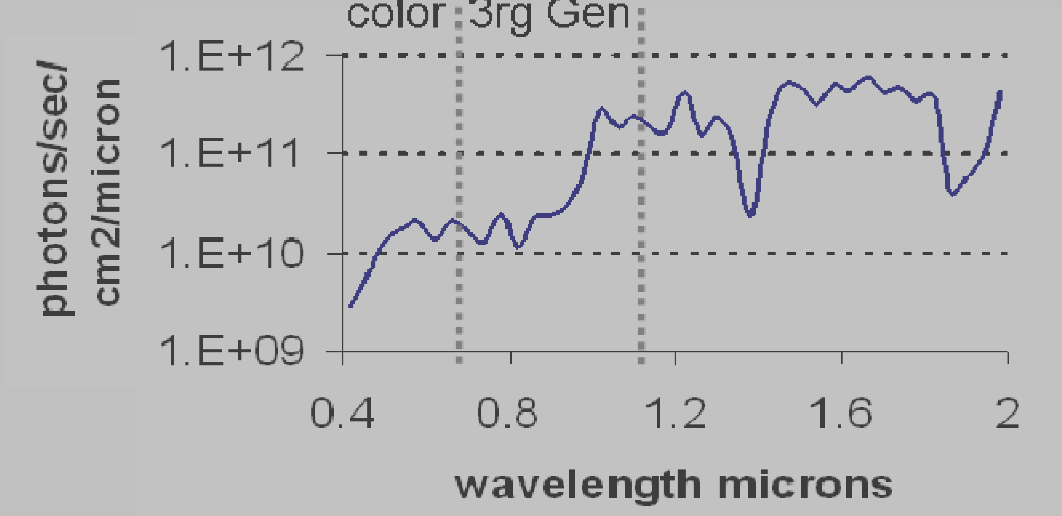
- Color adds a dimension beyond gray scale that aids scene comprehension.
- Adding color is simplified by the fact that scene color and scene resolution need not be supplied by the same imager.




- Edwin H. Land demonstrated that color sensations in real, complex images depend on scene content.
  - Film and focal plane arrays respond to the light falling on each tiny local region of the imager’s detector focal plane.
  - On the other hand, when humans view real scenes, the content of the entire image controls point-to-point color appearance.
  - The arrangement of color cones in the eye does not support sensing color at each point in the visible scene.
  - Our vision adds color to the high resolution scene by interpolating from a low resolution color map.

Why is adding color to night vision a problem?

- There's very little visible light in starlight illumination.
- The plot shows photon flux in visible and 3rd generation image intensifiers spectrums
- There are few photons in the visible spectrum, particularly in the blue spectral region



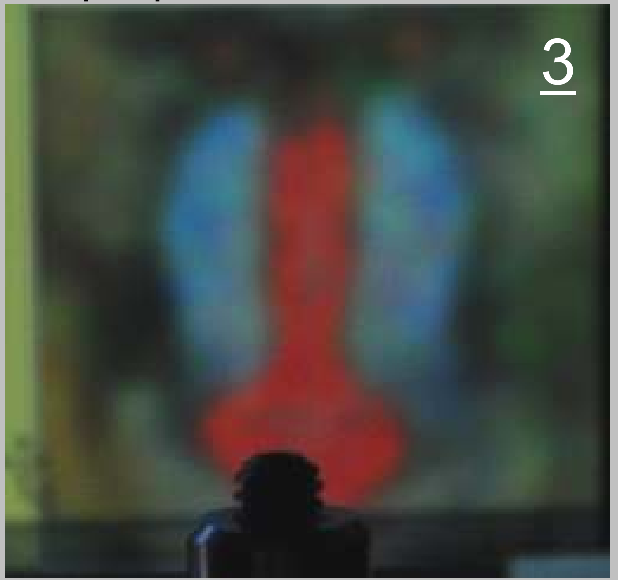
- Color night vision is possible because the color camera can be low resolution. That is, the color camera can have a few, very large pixels that each gather a lot of light.
- Scene color resolution is restored by the visual mechanisms in the eye.

Illustrate Color Sharpening Technique

- Item 1 is a transmissive LCD displaying a low resolution color picture of a Mandrill.
- Item 2 is a high resolution achromatic picture of the Mandrill situated behind the low resolution color picture item 1. The picture is displayed on the lap top.

Two pictures are taken with a digital color camera.

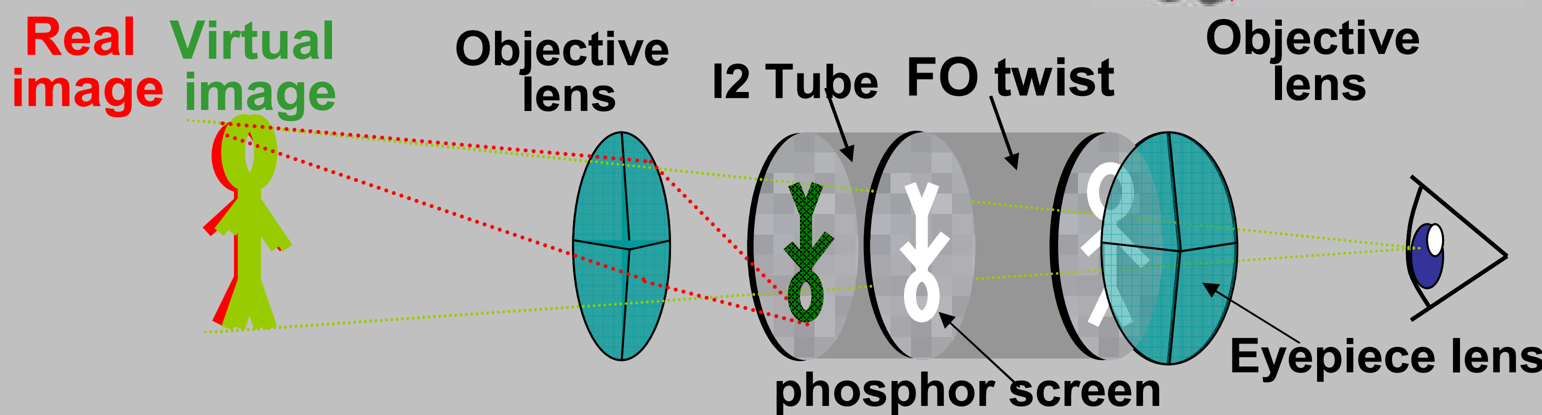
- Item 3 is taken with white background behind the low resolution color picture item 1.
- Item 4 is taken with the high resolution monochrome picture item 2 registered behind the low resolution color picture item 1.



Although the registration between pictures 1 and 2 is imperfect, the very much improved color resolution of picture 4 compared to picture 3 illustrates the sharpening concept.

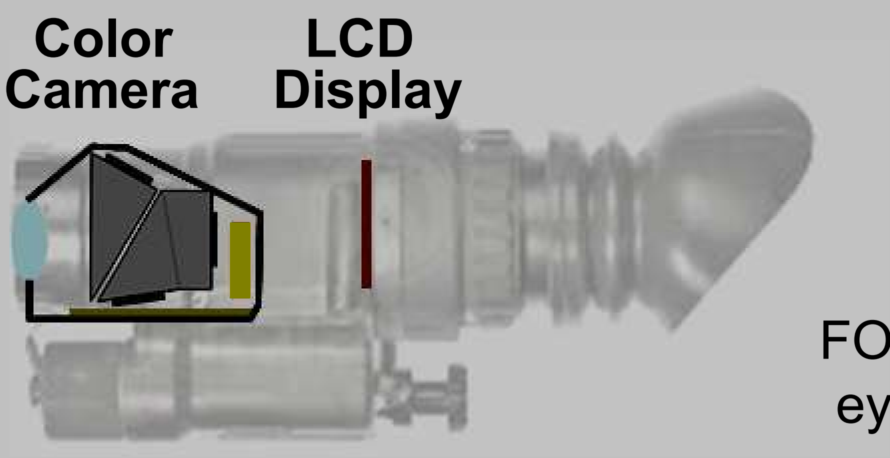
Image Intensifier (I2) Operation

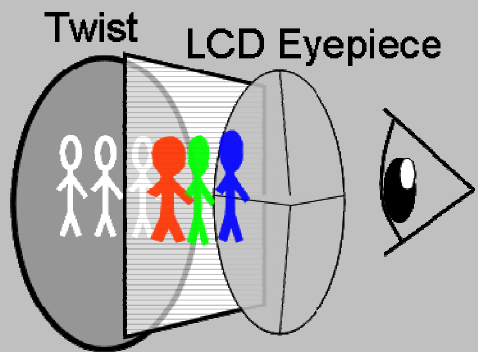
The I2 tube is used in an optical system to form a brighter, virtual image of the scene.



- A lens images the scene on the image intensifier (I2) cathode.
- The cathode emits electrons that are amplified (multiplied) by the I2 tube, and that creates a bright image on the I2 tube phosphor screen.
- The image on the screen is upside-down, and a fiber optic twist is used to erect the image.
- The small image at the user end of the fiber optic is viewed using a magnifying eyepiece.

Color Goggle Implementation

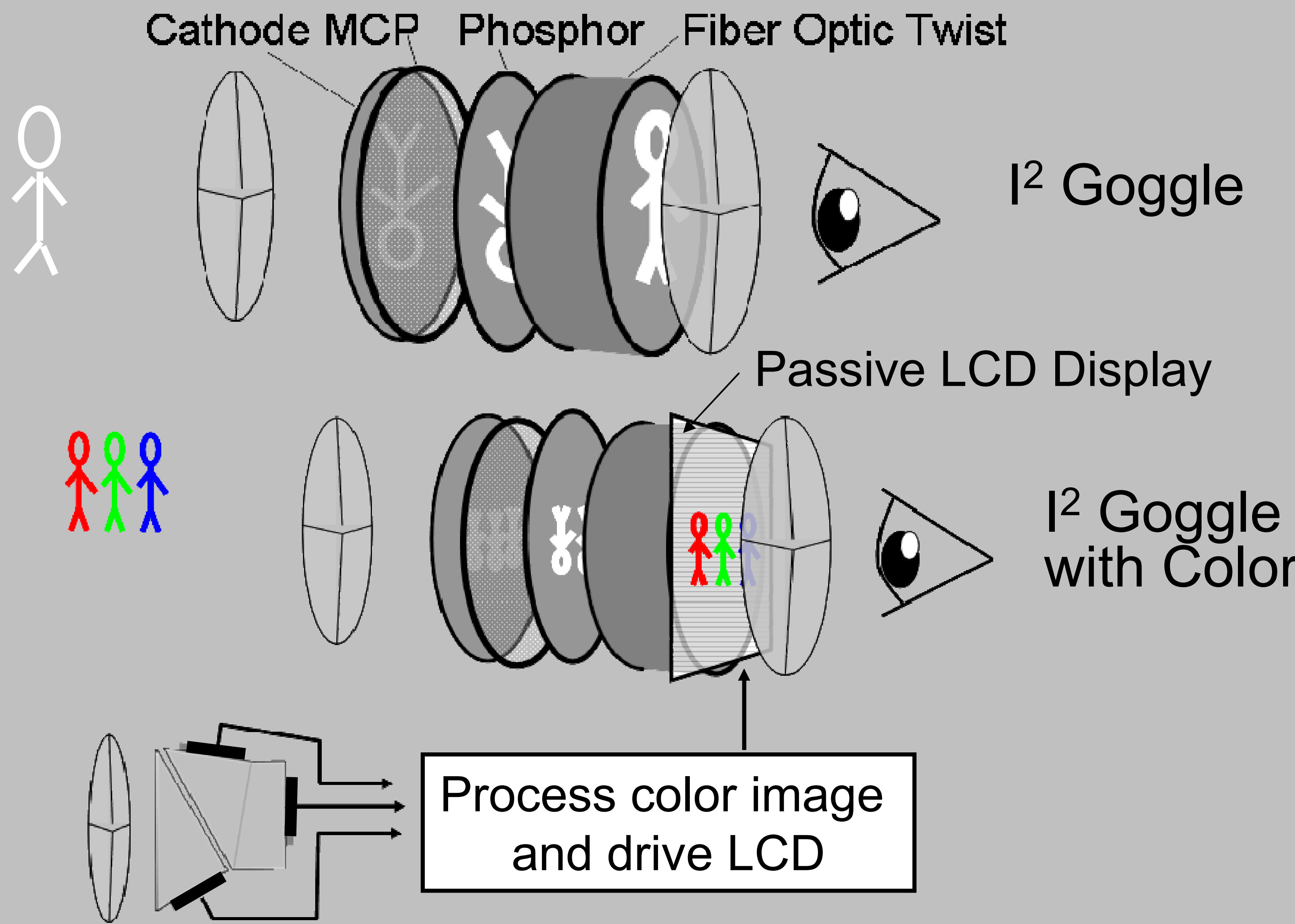




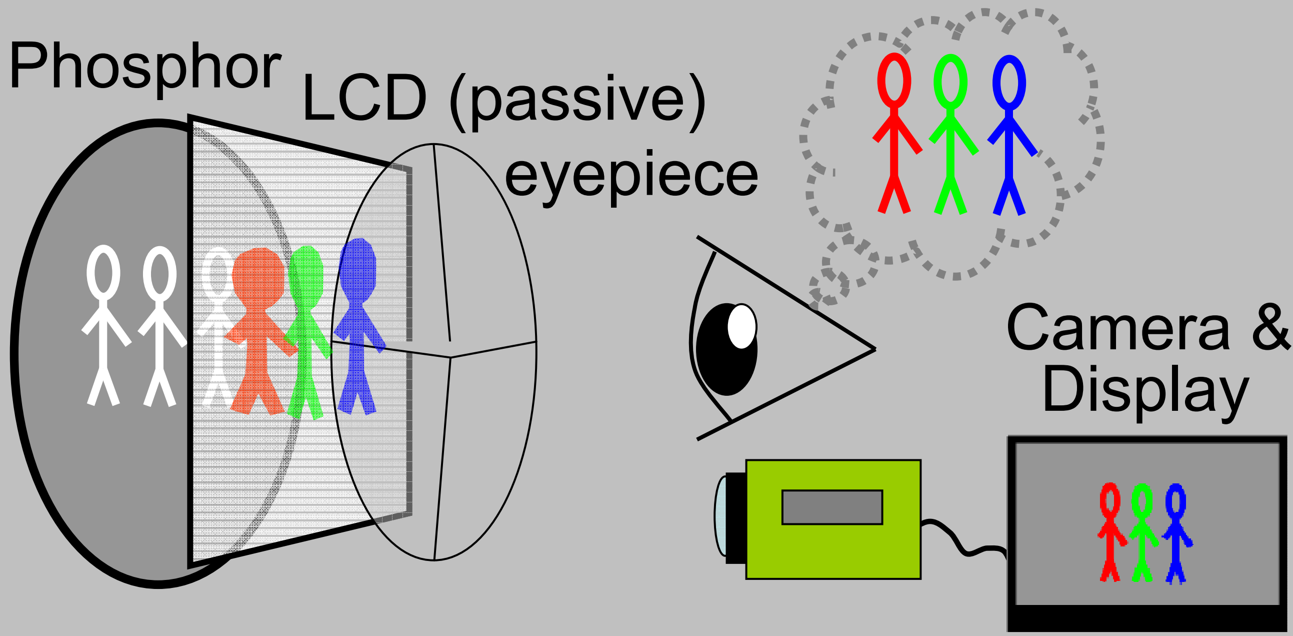
FO twist is in the image plane of the eyepiece and the color LCD is not.

- Build a low resolution color camera with large pixels and low noise
- Mount the camera so that it is boresighted with image intensifier image
- Put a low resolution passive color LCD between the twist and eyepiece
  - The fiber optic twist (FO twist) is in the image plane of the eyepiece. That is, the goggle image is in focus.
  - The LCD with the color image is forward of the image plane, and the low resolution color image is not in focus.
- Intensities multiply when the white, high resolution image is viewed through the low resolution color LCD, and that multiplication adds color to the goggle image.

Placement of the Color Display Within the Goggle



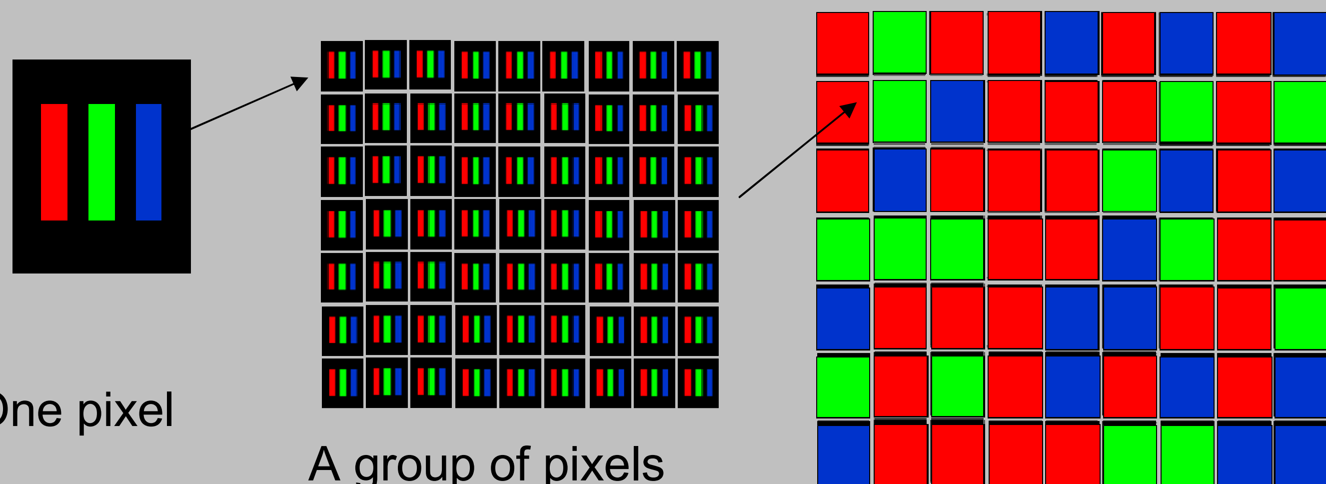
Color Goggle Implementation



- Color LCD is not in the image plane of the eyepiece.
- I^2 Phosphor is in the image plane of eyepiece
- Intensities multiply when the white high resolution image is viewed through the low resolution color LCD
- Probably want a passive color LCD without a pixel mask
  - We want visible structure to be in goggle image

Desired LCD Characteristics

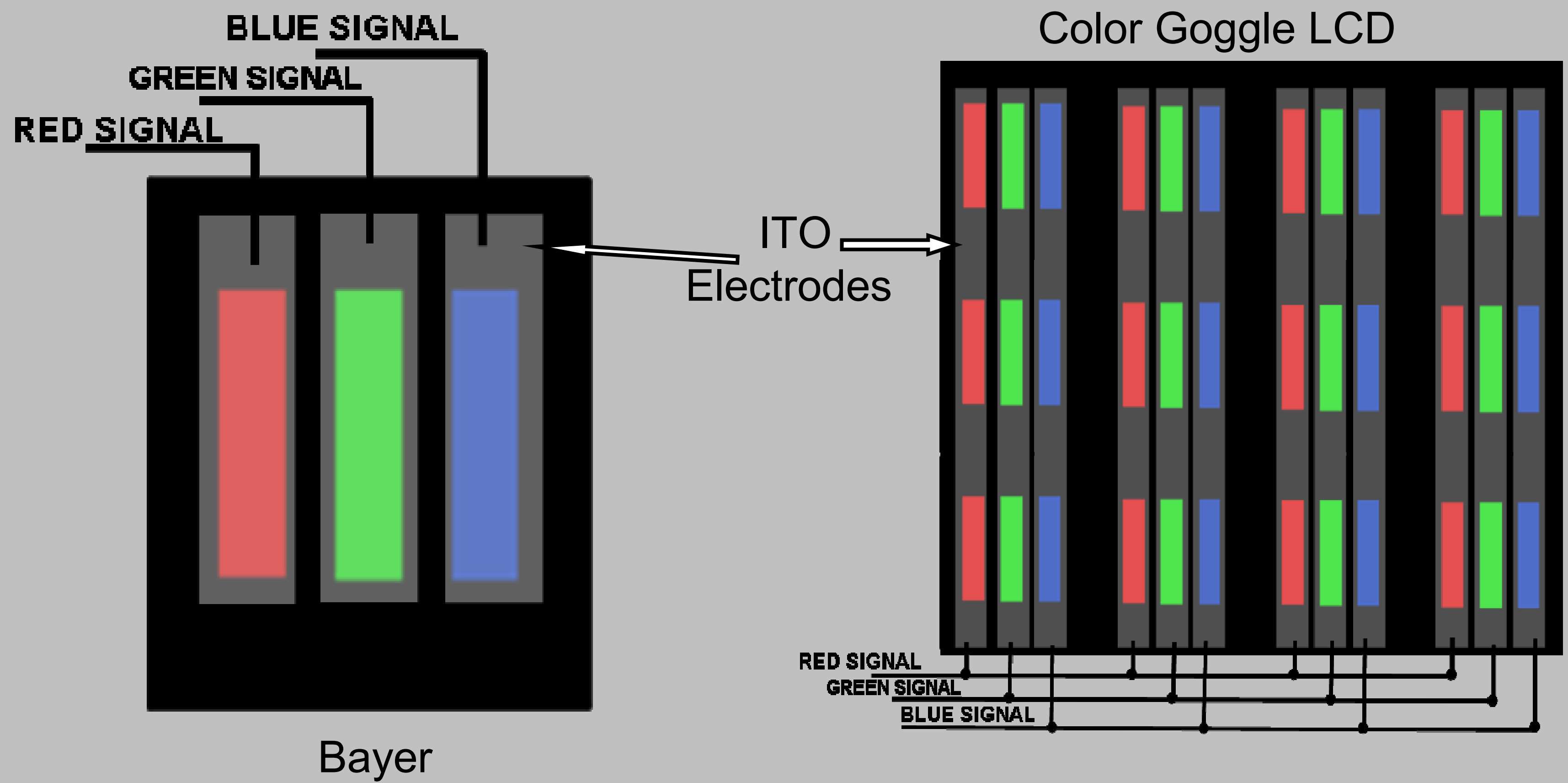
- The low resolution color pictures of the Mandrill on Slide 4 were produced using a high definition active matrix LCD.
  - That is what I could buy off the shelf.
  - As illustrated below, the high resolution pixels were combined to create a low resolution color display by simply blurring a high resolution picture.
- That method would be difficult to implement in a goggle-size display.
- Also, a low resolution, “Bayer-like” display would likely have a problem with the user seeing the color sub-pixels.



One pixel

A group of pixels each driven by computer to one color

Result is a low resolution color image



- The LCD pixel layout might look like the illustration at right above.
- The red, green, and blue emitting areas are small and spread around the pixel area.

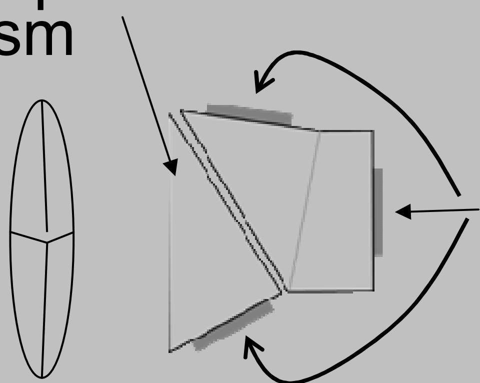
Camera Example: Clear Starlight

- The following assumes a 9 millimeter focal plane
- Need high fill factor and quantum efficiency
- Revert to achromatic image under overcast starlight

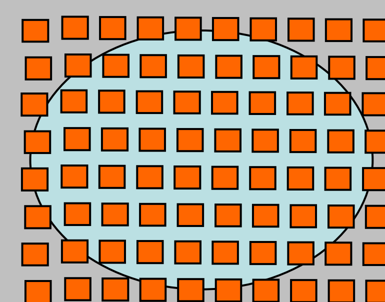
F/1, 128 by 128 pixels, 70 μ pitch,
4 electrons read noise, 60 Hz. frame rate

Band (μ)	Photons / detector	Average Photons	Signal (0.2 contrast)	Pixel signal to noise
0.4 -0.52	240	120	24	2.1
0.5 - 0.62	460	230	46	2.9
0.56- 0.68	520	260	52	3.1

Philips Prism



9 mm by 9 mm focal planes
128 by 128, 70 micron pixels



Square array are silicon pixels and circle is imposed image to match 40 degree goggles

Known Unknowns

- There's a lot of variability of the amount and kind of light at night; specifying camera parameters is hard.
- Note that average electron levels in clear starlight ran between 200 and 500. That is basically a digitizer bit per electron. It's easy for the computer to do in simulation, but perhaps an EMCCD might be considered.
- I believe that motion blur will be based on the goggle achromatic image, such that we can use passive LCD displays with tens of milliseconds rise and fall times
- We do know that visible structure in the color LCD will degrade the color image
  - That is, avoid an active LCD if possible
- In overcast starlight, goggle luminance must be maintained while operating through the LCD display
  - Not talking abut 3 foot Lamberts! However, performance under overcast starlight might require added tube gain.

Color under Clear Starlight

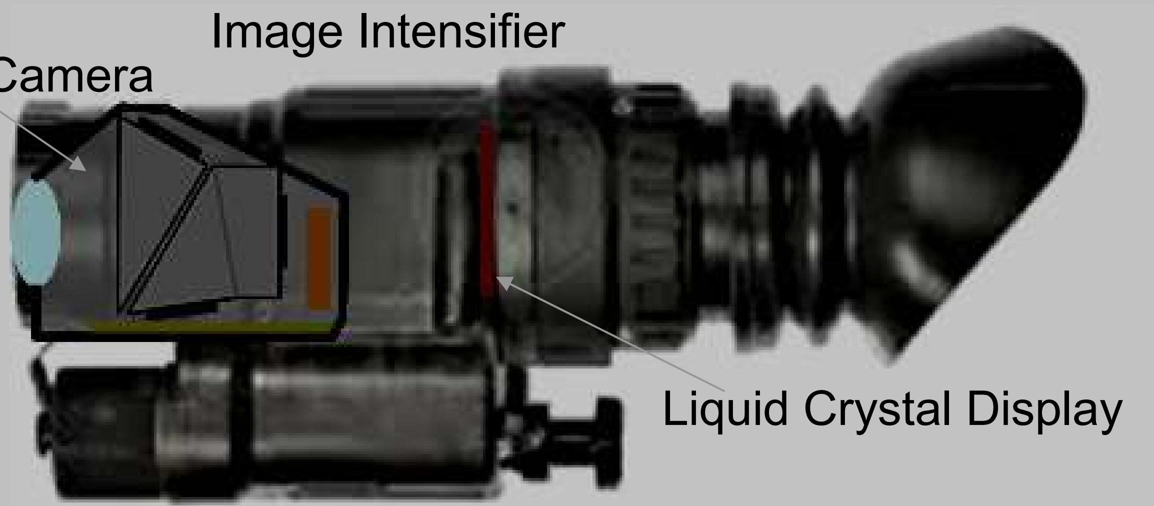
- With F/1 optics and 9 mm silicon focal planes, color is present but degraded under clear starlight
- The starlight illumination used for analysis is pessimistic in the sense that there is generally more light available.
- The conditions modeled should not occur often; normal would be better.

Original

Clear Starlight

Color Goggle Summary

- The proposal adds color while maintaining full performance of current goggle technology
- The large color pixels come close to compensating for the lack of visible illumination
- The required LCD display is commercially available technology but not off-the-shelf in the form required.
- The color camera, like the LCD, uses existing technology but does require chip design and development.



Combining Uncooled Thermal with Color and Image Intensifier

- Adding a low resolution uncooled thermal imager would provide useful thermal cues.
- The thermal imager would have the same resolution as the color camera, making it small and inexpensive.
- The following slides use simulation to:
  - Compare goggle fusion with 1024 by 768 thermal pixels to fusion with 128 by 128 thermal pixels
  - Compare false color display to achromatic presentation
    - The false color restores picture resolution due to color sharpening.

Thermal Fusion

- Below is a 1024 by 768 uncooled thermal image of man walking in front of miniature cows
- Below right the picture is down sampled to 128 by 128
- Image intensified picture at right
- On the next slide, both thermal resolutions are shown fused with the image intensified image

Image Intensified Image

Thermal 1024 by 768 pixels

Thermal 128 by 128 pixels

Fused image intensifier and thermal

- On this slide, the thermal images are used in all three color slices of the LCD.
- The thermal signatures are highlighted in both cases.
- However, the low resolution thermal does seriously degrade the fused imagery.

Fused with 128 by 128 thermal

Fused with 1024 by 768 thermal

Color Thermal Fusion

• False color can bring back image intensified details
• Pictures at right compare false color display of I^2 fused with both high and low resolution thermal.

• Adding a low resolution color LCD display to PVS-14 or other image intensified devices that have white phosphors can provide thermal cues as well as color imagery