EEAP 431

Chapter 1.

1.2 elements of digital image processing

picture elements – pixels.
typically in a rectangular sampling grid

use this rectangular grid to represent an image

image must be converted to digital form.

location is quantized

brightness is sampled and quantized – called a gray level.

1.2.1. Terminology of digital image processing

image contains descriptive information about object it represents.

visible images – our typical interest

optical images – formed with lenses, gratings & holograms

physical images – actual distributions of matter or energy

non visible physical images – temperature, pressure, elevation, etc. maps.

multi-spectral images – trispectral (R, G, B), etc.

picture – distribution of matter that is visible when properly illuminated

digital image processing – subjecting a numerical representation of an object to a series of operations in order to obtain a desired result.

digital image – a sampled, quantized functions of two dimensions that has been generated by optical means, sampled in an equally spaced rectangular grid pattern and quantized in equal intervals of amplitude

some common exceptions

1. non-optical digital images
2. higher dimensional images; multi-spectral, color
3. non-standard sampling
4. non-standard quantization

digital image processing - starts with one image and produces a modified version of the image.
image → image transform

computer graphics - processing & display of images that exist conceptually, or as mathematical descriptions
emphasis on generation of an image given
1. model that describes object
2. illumination
3 geometry of an imaging camera

computer vision - development of systems that can interpret the content of natural scenes

digitizing - process of converting image from its original form into digital form. (reverse operation is display).

scanning - selective addressing of specific locations within the domain of an image.
in digitizing photographs this is the process of sequentially addressing small spots on the film.
rectangular grid scanning pattern is called a raster

operations on digital images
1. global - applied equally throughout entire digital image
2. point - value of output pixel depends only on value of the corresponding input pixel (usually contrast manipulation or contrast stretching)
3. local - gray level of output pixel is computed from gray levels of several pixels in a neighborhood of the corresponding input pixel.

sampling - measuring the gray level of an image at each pixel location
quantization - representation of the measured value by an integer
contrast - amplitude of gray-level differences within an image
gray scale resolution - # of bits/pixel gives number of levels in gray scale.
sampling density - # of sample points/unit length
pixel spacing = 1/sampling density
magnification - size relationship between objects in image and objects in scene it represents.

Chapter 2 – Digitizing Images

2.2 Characteristics

pixel size

image size

local property measured – i.e. for film scanners optical density or transmittance

linearity – of the digitization, how accurate are the gray levels, i.e. proportional to actual brightness, etc.

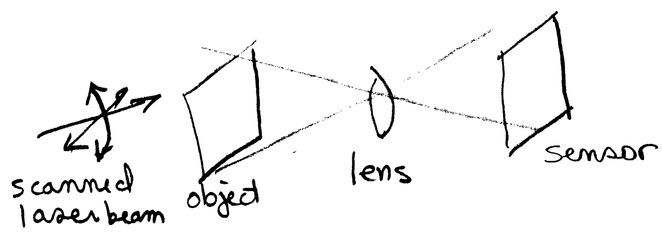
noise

2.3. Types of Image Digitizers

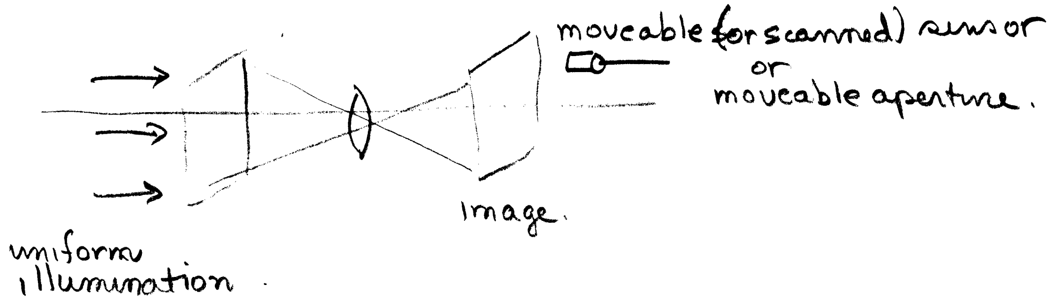
most common is digitizing camera, i.e. a television camera interfaced to a computer

film scanners have historically played a predominant role in image processing.

scan-in digitizing – illuminate small spot of object and collect **all** transmitted light.



scan out digitizer



scan-in/scan-out digitizer – very complex.

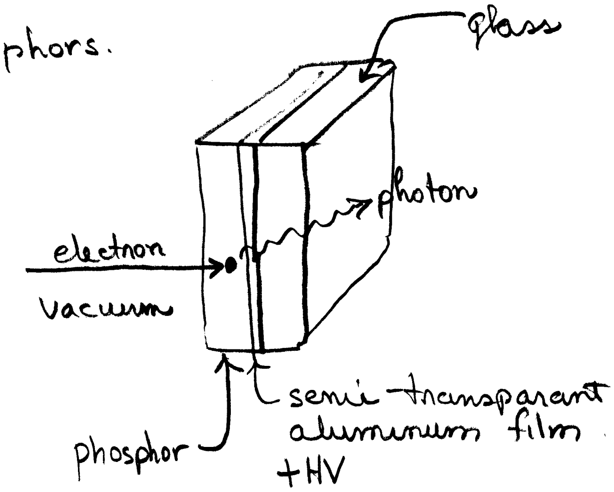
2.4 Image-digitizing components.

Light sources

(1) — incandescent bulbs { good for large area illumination

(2) Lasers
— excellent for scan-in digitizers

(3) Phosphors.

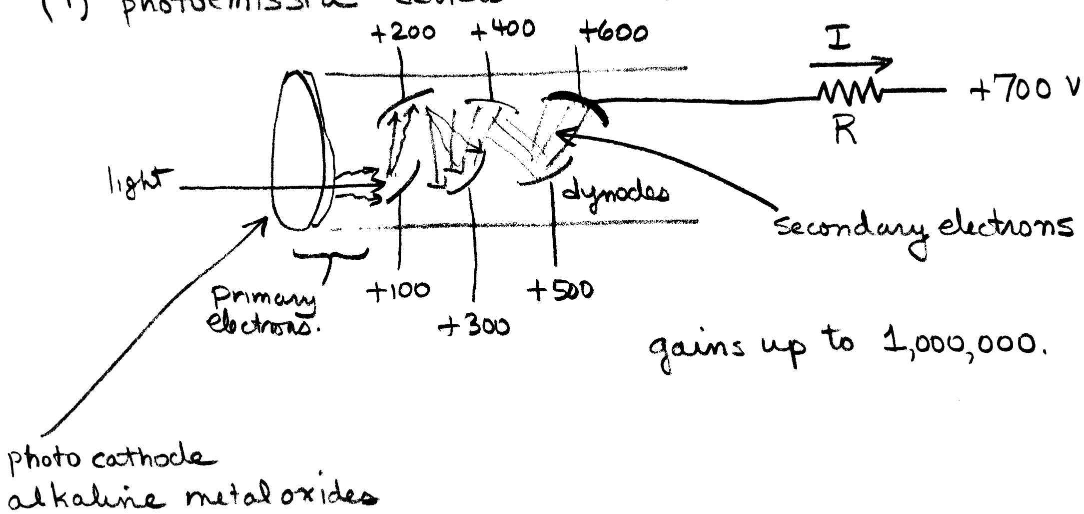


granularity of phosphor limits resolution to about 30-70 lp/mm.

spectrum (color)
persistence (decay rate)
of light generated can be controlled by manufacture of the phosphor

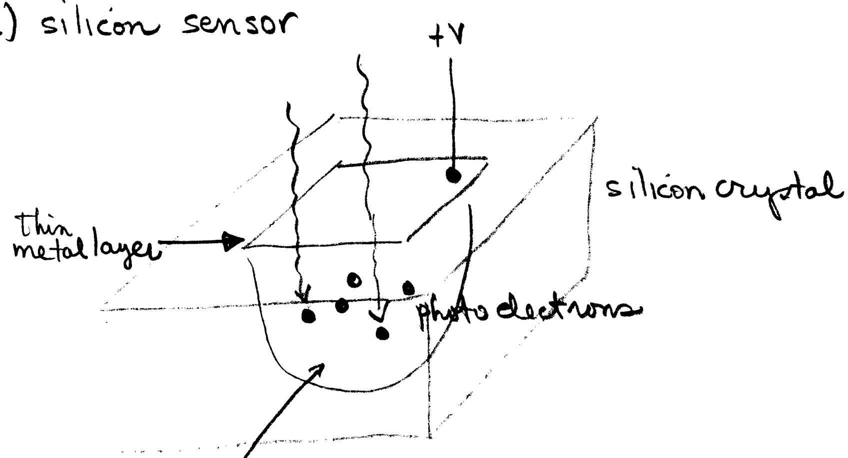
Sensors

(1) photoemissive devices such as PMT's.



gains up to 1,000,000.

(2) silicon sensor



potential well
collects photoelectrons
approximately 800 electrons / μ^2

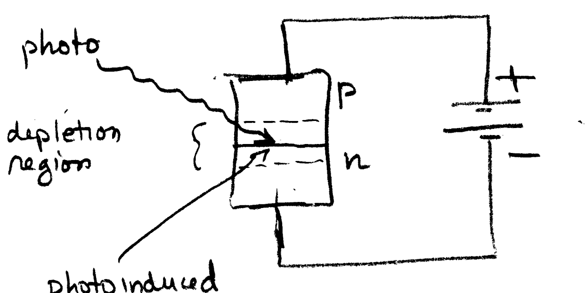
dynamic range — capacity in electrons / readout noise level in electrons
(can be as low 5-10 electrons)

<u>overexposure</u> causes excess electrons that spread to other wells causing <u>blooming</u>

dark current is produced by Thermal electrons (random bond breakage)
can be reduced by cooling

(3) photodiodes — solid-state PN junction

(a) depletion (reverse bias) mode

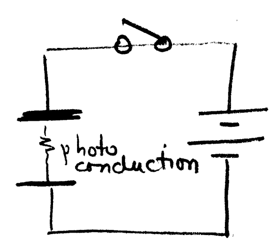


hole-electron pairs cause signal current

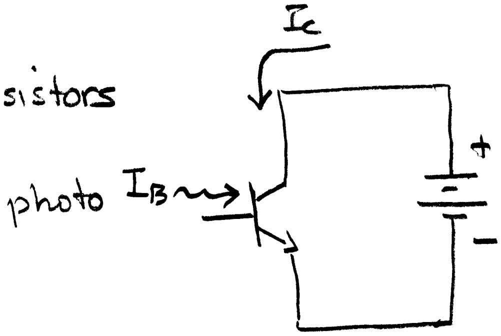
avalanche photodiode — very high reverse polarity gives electron multiplication similar to PMT
gain up to 1000.

(b) integrating mode

p-n depletion region is a capacitor
charge it up and remove potential
photo conduction bleeds off charge.
limits: small capacitance & dark current
signal is required recharge.



(4.) photo transistors

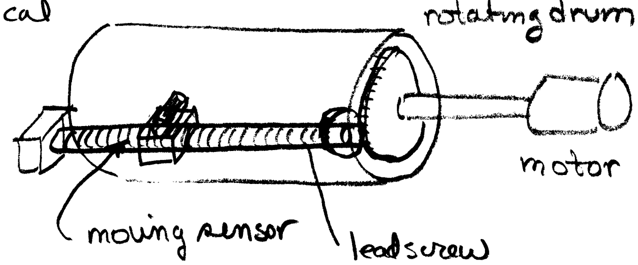


$$I_c = \beta L I_B$$

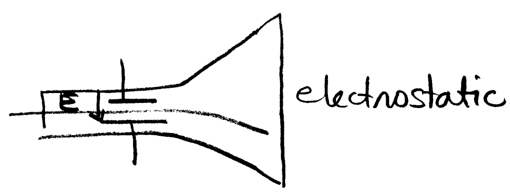
↖ light level.

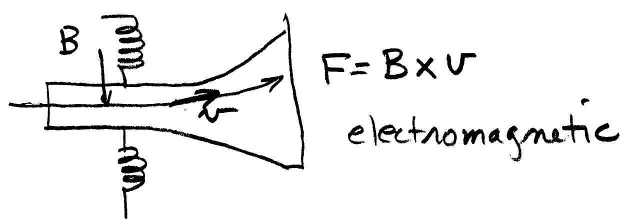
2.4.3 Scanning mechanisms

mechanical



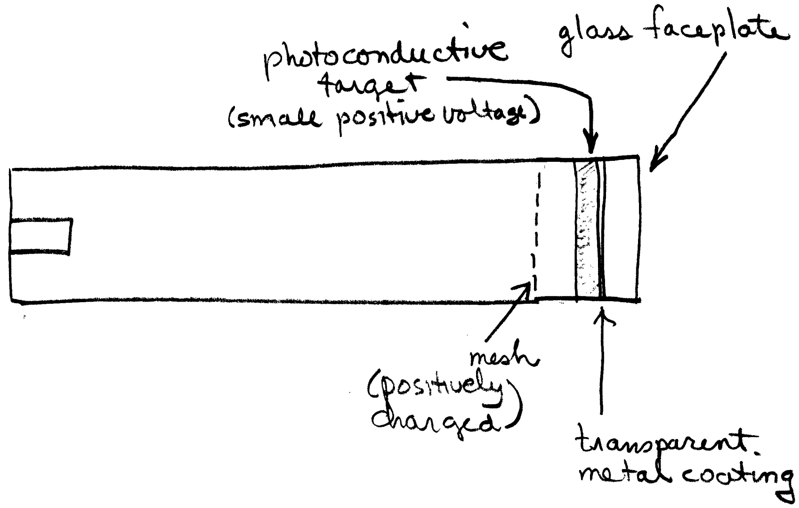
electron beam





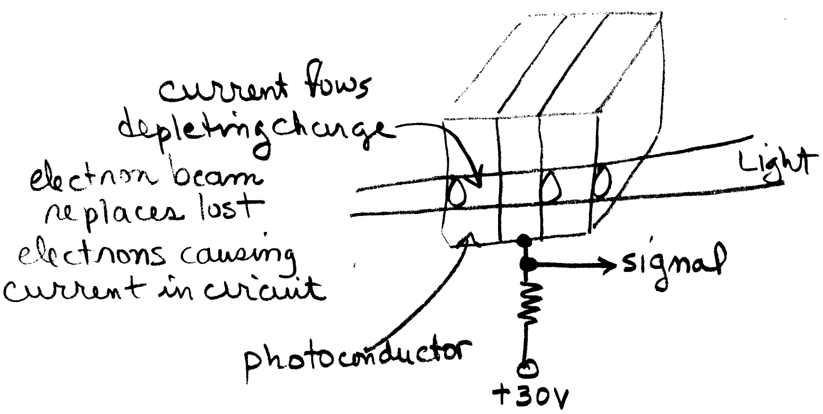
2.5 Electron Image Tube Cameras

Vidicon

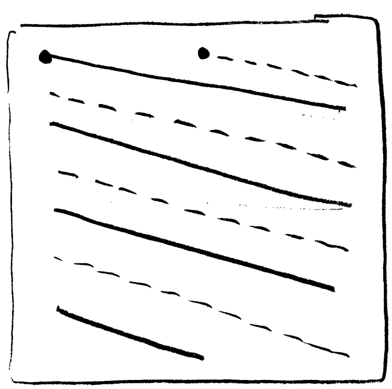


mesh decelerates incoming electrons

photoconductor is an insulator with no incident light
electron beam negatively charges inside of photo conductor to balance + charge on metal coating



Scanning convention RS-170.



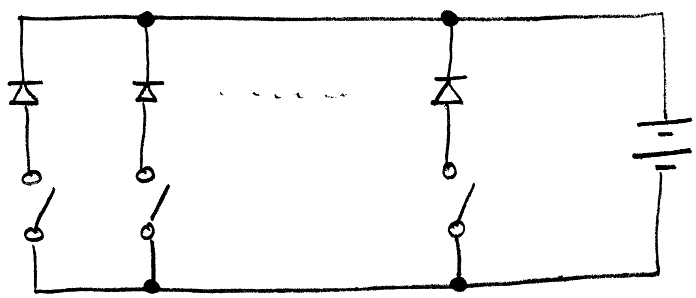
30 frames/sec.
525 lines/frame
15750 lines/sec.
63.5 μsec/line
2 fields/frame.
262.5 lines/field
60 fields/sec.

——— odd line.
- - - - - even line

60 Hz field rate minimizes perceived flicker
30 Hz frame rate reduces transmission bandwidth.

2.6 Solid State Cameras.

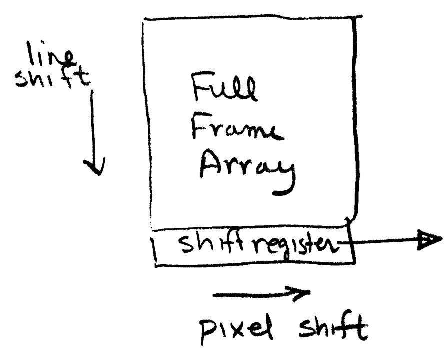
(1) Photodiode arrays



operates diodes in light integrating mode
diodes are charged up one at a time, charge current is signal
usually 1-D arrays   FAX scanners, spectroscopy

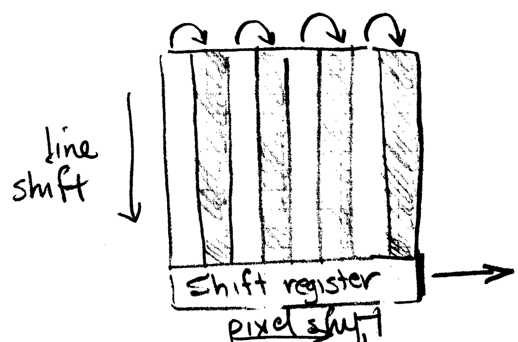
(2) CCD's — 2-D arrays of potential wells (photodetector wells) in silicon

Full Frame

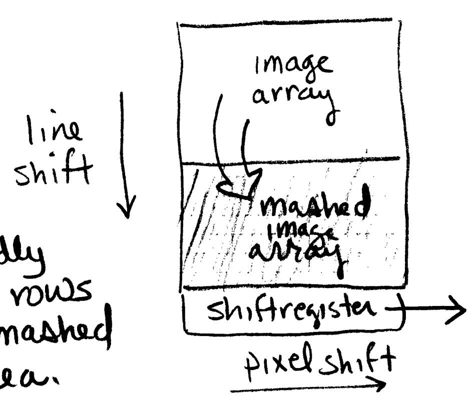


keep CCD shuttered during readout
shifts out one row at a time

Inter Line Transfer



shift charge packets to mashed wells after exposure
All shifted at once.
Read out while accumulating next image.
50% of chip mashed



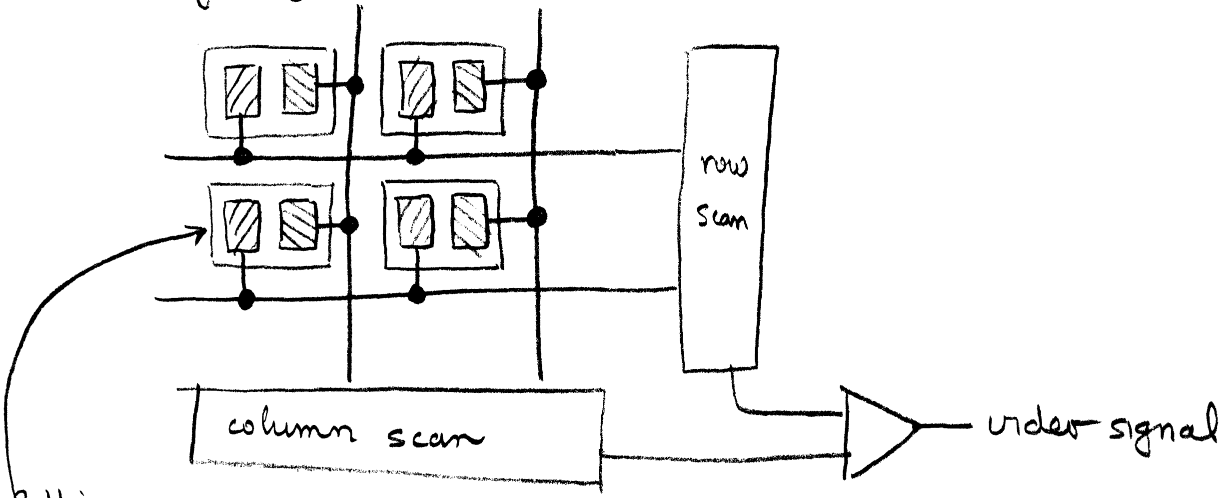
rapidly shift rows into mashed area.

readout noise – random noise generated by electronics

photon noise – quantum nature of light $= \sqrt{\#\text{ of electrons in well}}$

charge transfer efficiency

2.6.3. Charge Injection Devices



2 thin metal electrodes on each well

① when row & column electrode +, photoelectrons will accumulate (integration mode). All rows & columns + to acquire an image.

② when one electrode driven to 0 or −, photoelectrons shift to under other electrode creating a signal current pulse. Can shift back & forth as needed. (non-destructive readout mode)

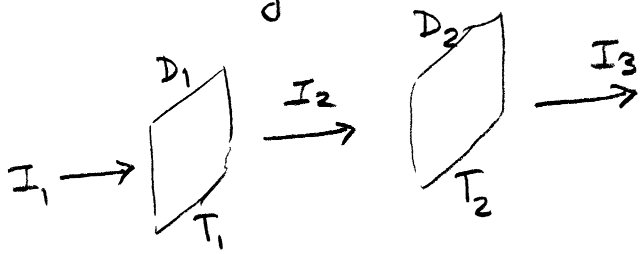
③ if both electrodes $\leq 0^V$ then charge flushed into substrate. This gives substrate current but empties well. (destructive readout mode)

Advantages of CID

- good in severe environmental & lighting conditions
  - very little blooming since no pathway connecting cells.
  - no worry about charge transfer efficiency

Considerably less sensitive than CCD's.

2.7 Film Scanning



$$T_1 = \frac{I_2}{I_1} \quad \frac{\text{transmitted flux density}}{\text{incident flux density}}$$

optical density $D_1 = \log \frac{I_1}{I_2} = \log \frac{1}{T_1} = -\log T_1$ $\quad 0 \le D_1 \le \infty$ since $T_1 < 1$

$$D_2 = \log \frac{I_2}{I_3} = \log \frac{1}{T_2} = -\log T_2$$

$$T_2 = \frac{I_3}{I_2}$$

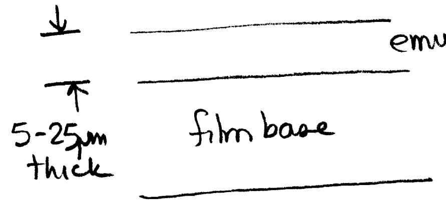
For two filters in series,

$$T_3 = \frac{I_3}{I_1} = \frac{I_3}{I_2}\frac{I_2}{I_1} = T_2 T_1$$

but $D_3 = \log \frac{I_1}{I_3} = \log\left(\frac{I_1}{I_2}\right)\left(\frac{I_2}{I_3}\right) = \log\left(\frac{1}{T_1}\right)\left(\frac{1}{T_2}\right) = D_1 + D_2$.

transmittances multiply
densities add: $T = 10^{-D(x,y)}$

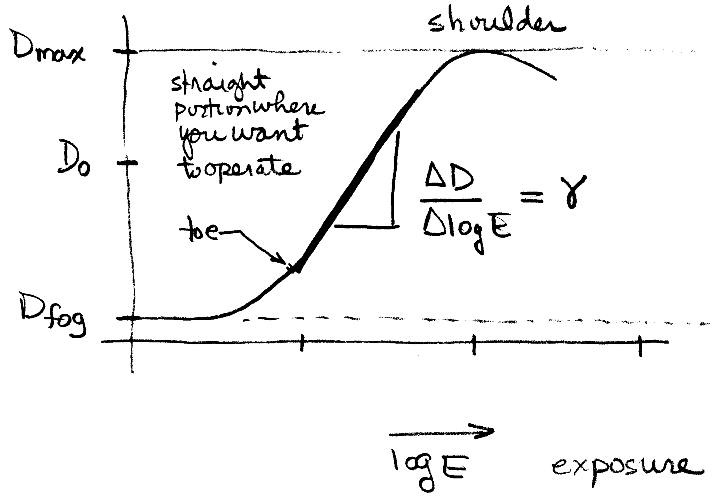
Photographic film



emulsion of silver salt grains in gelatin
typically AgCl, AgBr, AgI

exposing emulsion to light, molecules are reduced to silver and grain becomes exposed

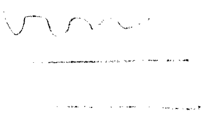
development reduces silver halide grains to silver
exposed grains reduce MUCH more rapidly than unexposed ones
after developing wash unreduced grains away



Film resolution

expose emulsion with sinusoidal pattern of light intensity

$$\log E = \log E_0 + \sin(2\pi f x)$$



where E_0 puts us in the central part of the H-D curve.

just using H-D curve

$$D(x) = D_0 + \gamma \sin(2\pi f x)$$

however, if f is large grain size and light scattering reduce contrast

$$D(x) = D_0 + \gamma\, M(f) \sin(2\pi f x)$$

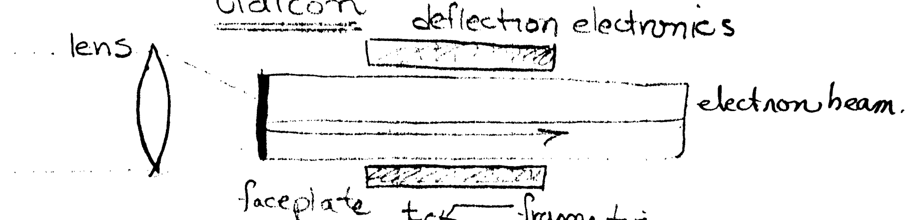
$M(f)$ is called the modulation transfer function (MTF)

f_L frequency at which M drops to 0.1

HW 1, 5, 7, 9, 10, 11

Image sensors

vidicon



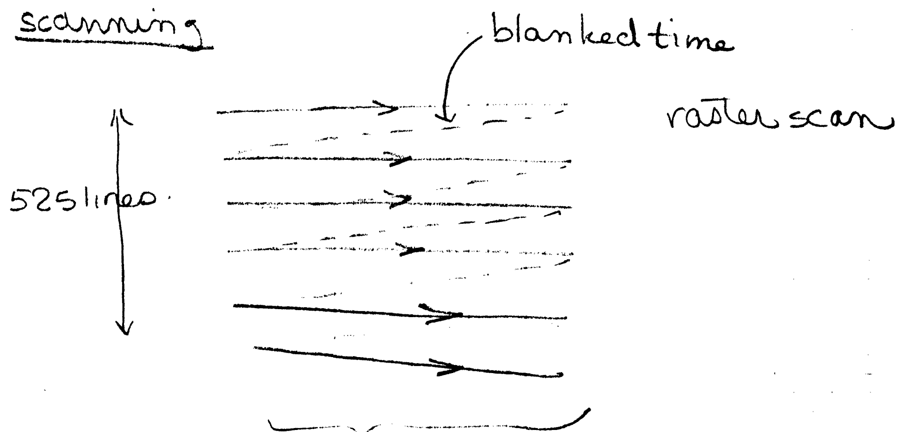
t_f ← frame time.

charge $q = \int_0^{t_f} i \, dt$

↑ light intensity

to make this process correspond to reading intensity is to keep t_f a constant

scanning

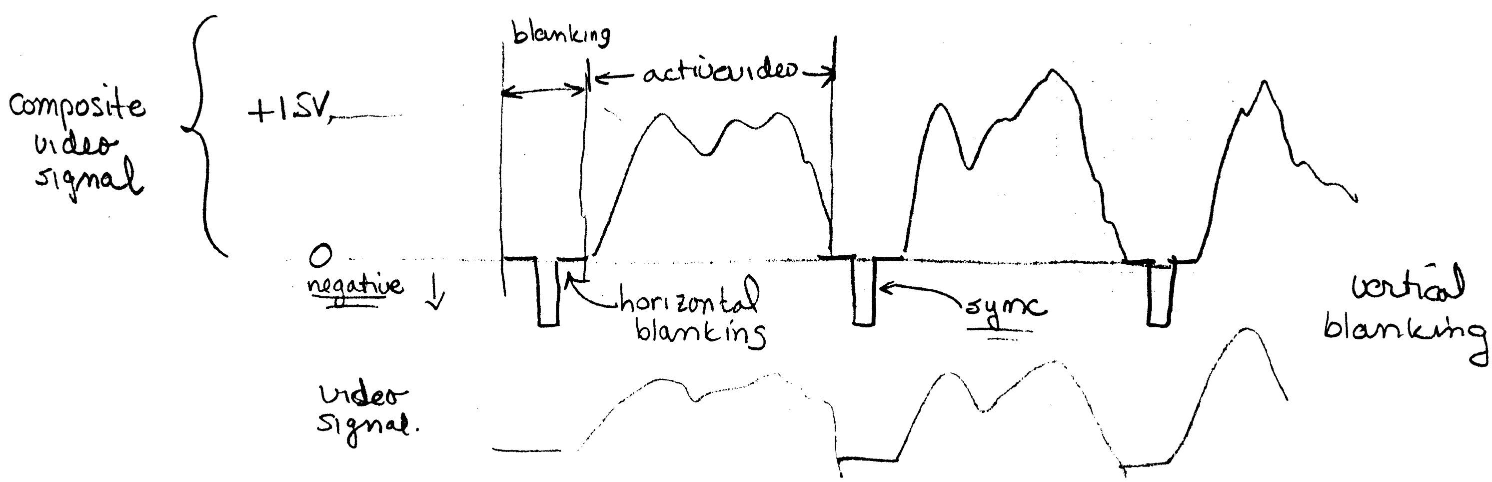


non-interlaced frame   30 frames/second

$$\text{scan velocity} = \frac{1 \text{ sec}}{30 \text{ frames}} \cdot \frac{1 \text{ frame}}{525 \text{ lines}} = \frac{63.5 \mu\text{sec}}{\text{line}}$$

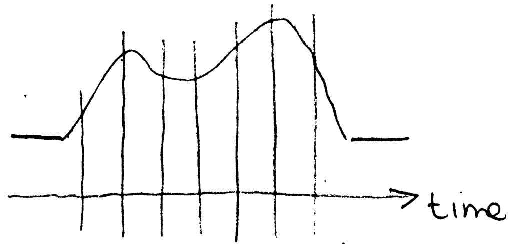
U.S. standard.

52 μsec active + 18 μsec blanking

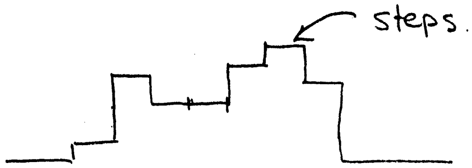


Sampling process

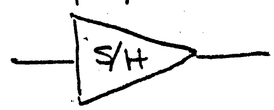
video signal



Sample at regular intervals



sample/hold

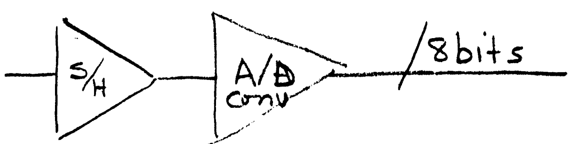


\# of samples/line = horizontal resolution

\# of lines = vertical resolution

often 10 nsec/pixel giving ≈ 512 pixels/line good!

Dynamic Range

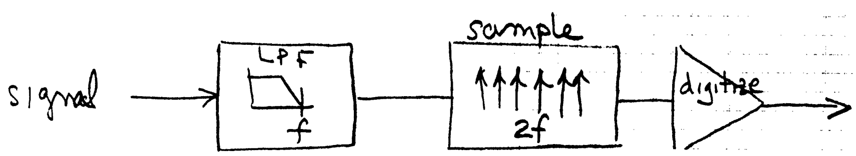


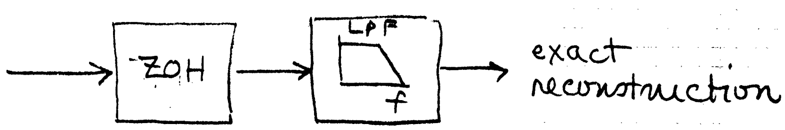
\# of bits/sample = dynamic range.

mention iris on camera.

Sampling Theorem

1948





mention effects of spatial resolution