



# Optimising EMCCDs

*How to extract the ultimate performance*

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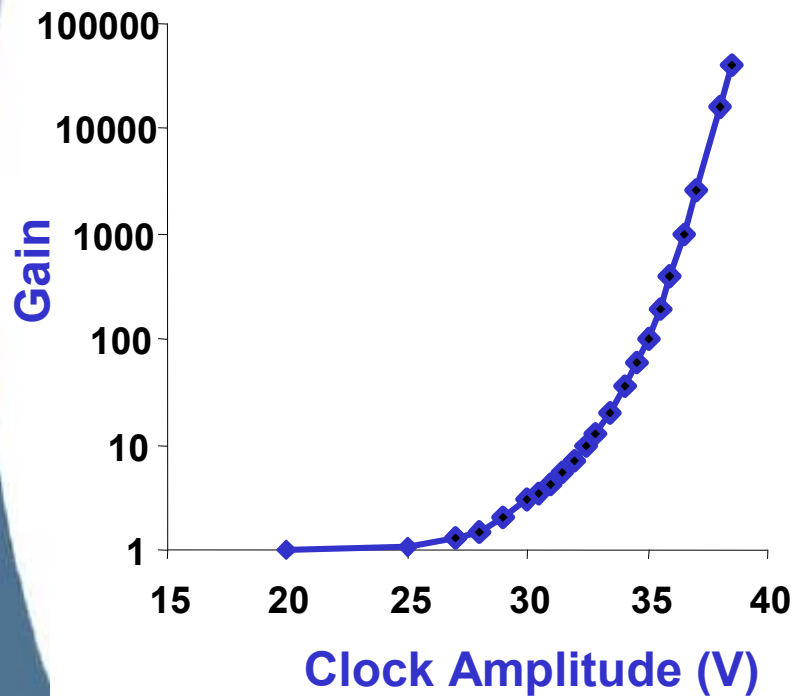


# Agenda

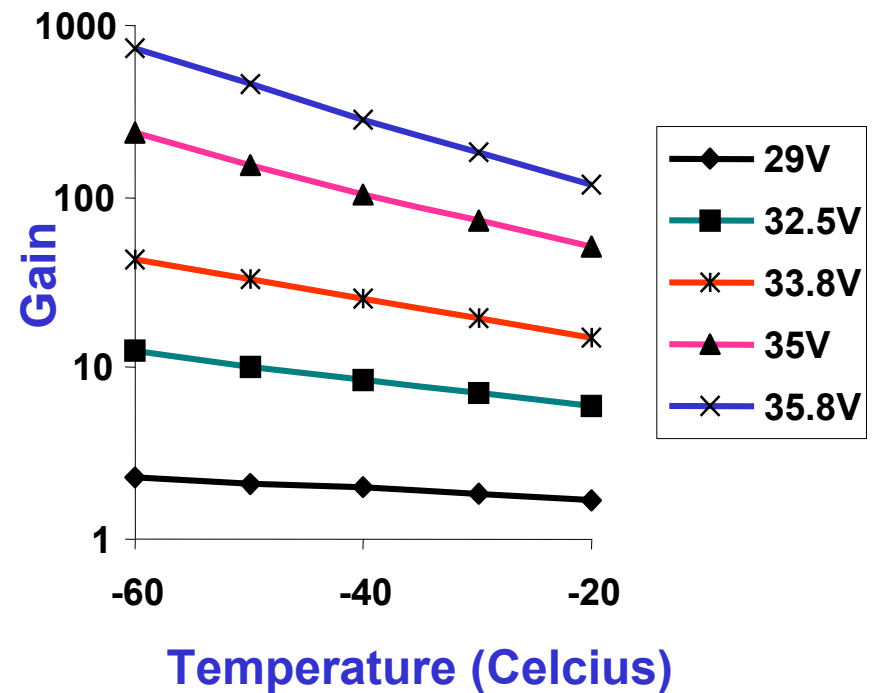
- ✓ **Spurious Charge – Clock Induced Charge**
- ✓ **Darksignal and Cooling**
- ✓ **Vacuum technology**
- ✓ **Baseline Shift**
- ✓ **Horizontal Smearing**
- ✓ **Ageing Effects**
- ✓ **Dynamic Range**

# EMCCD Gain

## Voltage dependence



## Temperature dependence

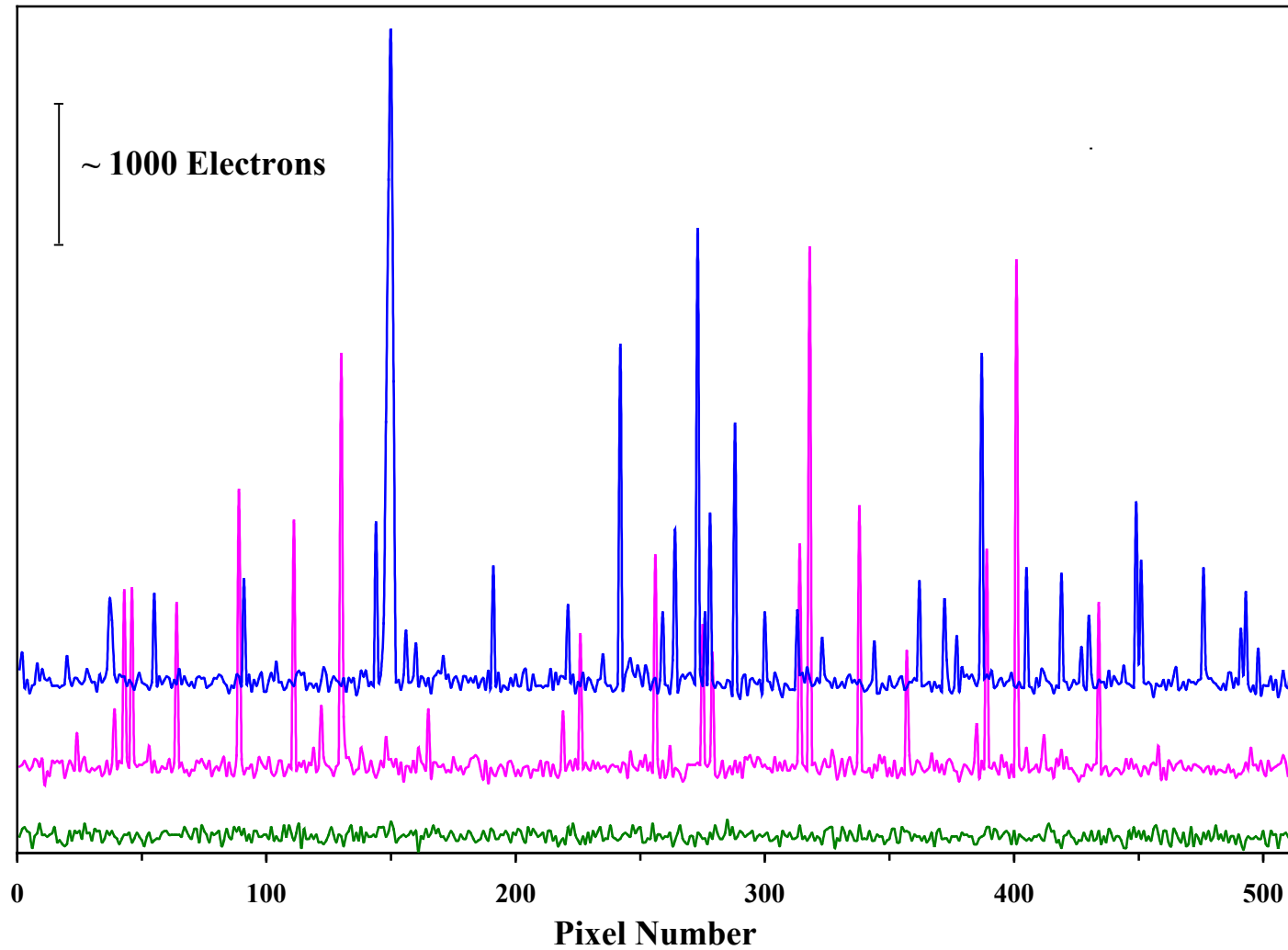




# Spurious Charge Clock Induced Charge (CIC) 1

- **CIC occurs as a result of impact ionization (possibly of holes) during charge transfers, either in sensor pixel or shift/gain registers**
- **All CCDs have CIC – it is only with EMCCD technology that we are seeing them**
- **Random single pixel, single electron spikes**

# Spurious Charge Clock Induced Charge (CIC) 2



# Spurious Charge Clock Induced Charge (CIC) 3

- **CIC sets the ultimate limit on sensitivity**
- **Minimization – Careful control over clocking parameters**

# Spurious Charge Clock Induced Charge (CIC) 4

## CIC sources

- Image area clocking
- Electron multiplier clocking

## In Practice

- When clocked appropriately the EM CIC will dominate
- CIC should be temperature dependent, but for a fixed gain EM CIC does NOT change with temperature

# Spurious Charge Clock Induced Charge (CIC) 5

## CIC and Vertical Clocking

Faster vertical clocking (for higher frame rates)  
needs higher vertical clock amplitudes

This leads to increased image area CIC  
(can overtake EM CIC)

Use non-MPP or non-IMO devices  
(but need more cooling)

# Darksignal and Cooling 1

*A single thermally generated electron will be amplified  
by the gain register*

**CIC sets the ultimate limit on sensitivity**

**But Only If**

**Darksignal  $\ll$  CIC**

# Darksignal and Cooling 2

**Take Best Case:**  
**Maximum frame rate**  
**30 frames/second**  
**Full resolution**

For Darksignal = CIC  
need 3 ele/pix/sec

For Darksignal  $\ll$  CIC plus safety margin  
need 0.3 ele/pix/sec

This means  
-25°C to -30°C

# Darksignal and Cooling 3

**Back Illuminated 4X darkcurrent of Front Illuminated**

This means at least  
–35°C to –45°C

**Non-MPP or non-IMO for lower CIC**

This means at least  
–60°C to –65°C

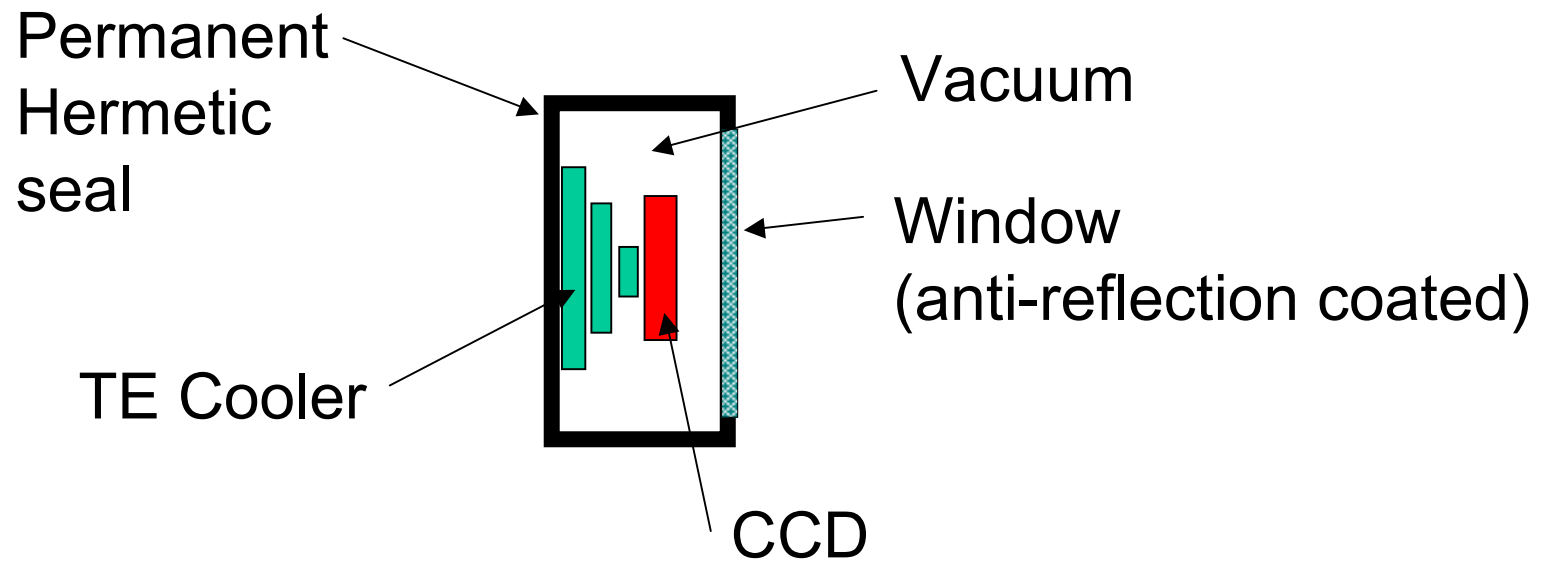
**What about longer exposures?**

**Reduction of hot pixels?**

No temperature is too cold!

# Vacuum Technology 1

## A high-end essential



# Vacuum Technology 2

## Why Hermetic Vacuum Seal?

Vacuum means no convection

Therefore

- Better cooling in all ambients
  - Lower power
  - Smaller size
- No heat flow from window leading to condensation in humid environments

# Vacuum Technology 3

## Hermetic seal using metal glass ceramic, No O-Rings

- Allows permanent vacuum and permanent protection from moisture with only one window
  - Only one window means lower losses, less reflection artifacts
  - No maintenance

# Baseline Shift 1

**Higher than normal amplitude clocks  
combined with speed and  
varying readout patterns**

**Variable amplitudes to change EM gain**

# Baseline Shift 2

- **Active compensation for large changes**
- **Better thermal management**
- **Use dark reference**

# Horizontal Smearing 1

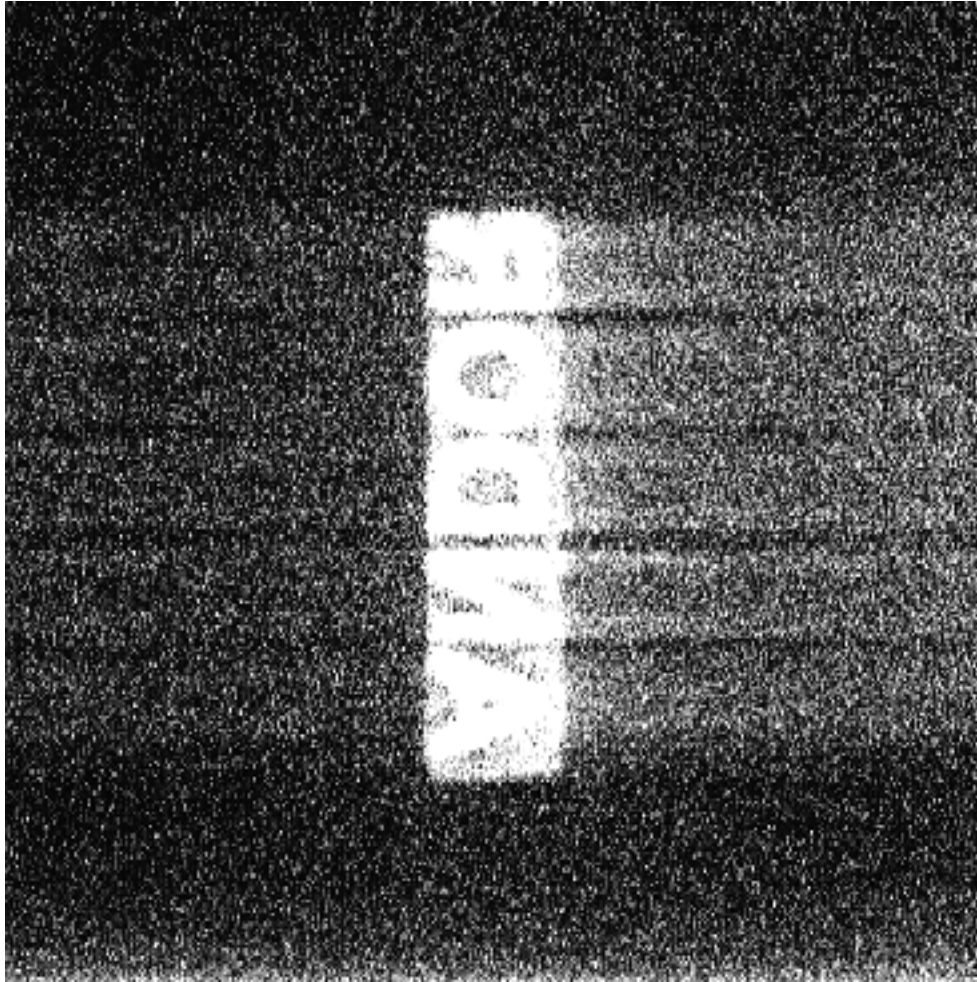
- **A low level horizontal smearing from bright areas of image**
- **Seen at high gain and high signal**
- **Signal charge trapped in long lived surface states?**

## Horizontal Smearing 2



Bright image  
No gain

# Horizontal Smearing 3



Saturated image  
at X2000 gain  
(Total smeared  
charge is about 50%  
of total image charge)

# Ageing Effects 1

- **Fall-off in EM gain with amount of high gain charge through the gain register**
- **Can be compensated with higher clock amplitudes**
- **Possibly due to charge buildup in oxide layer**
- **Gain fall-off slows with age**

# Ageing Effects 2

## Treat EMCCDs as you would a Photocathode

- Avoid saturation
- Minimize/switch off gain when not needed

## Unlike a Photocathode

- No burn spots  
(cumulative effect in gain register)
- No problem when powered off

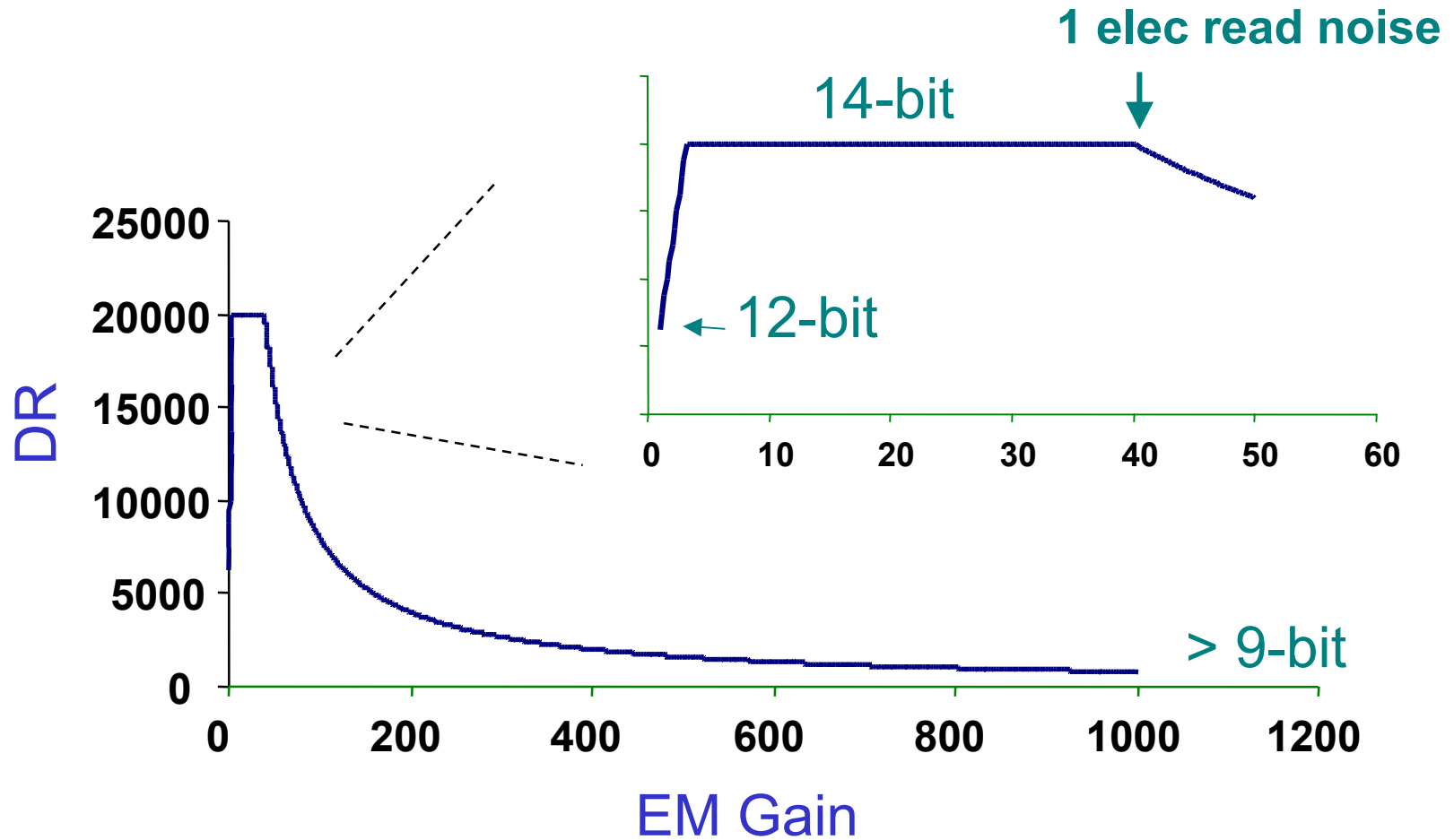
# Dynamic Range

$$DR = \frac{\text{Well capacity}}{\text{Detection Limit}}$$

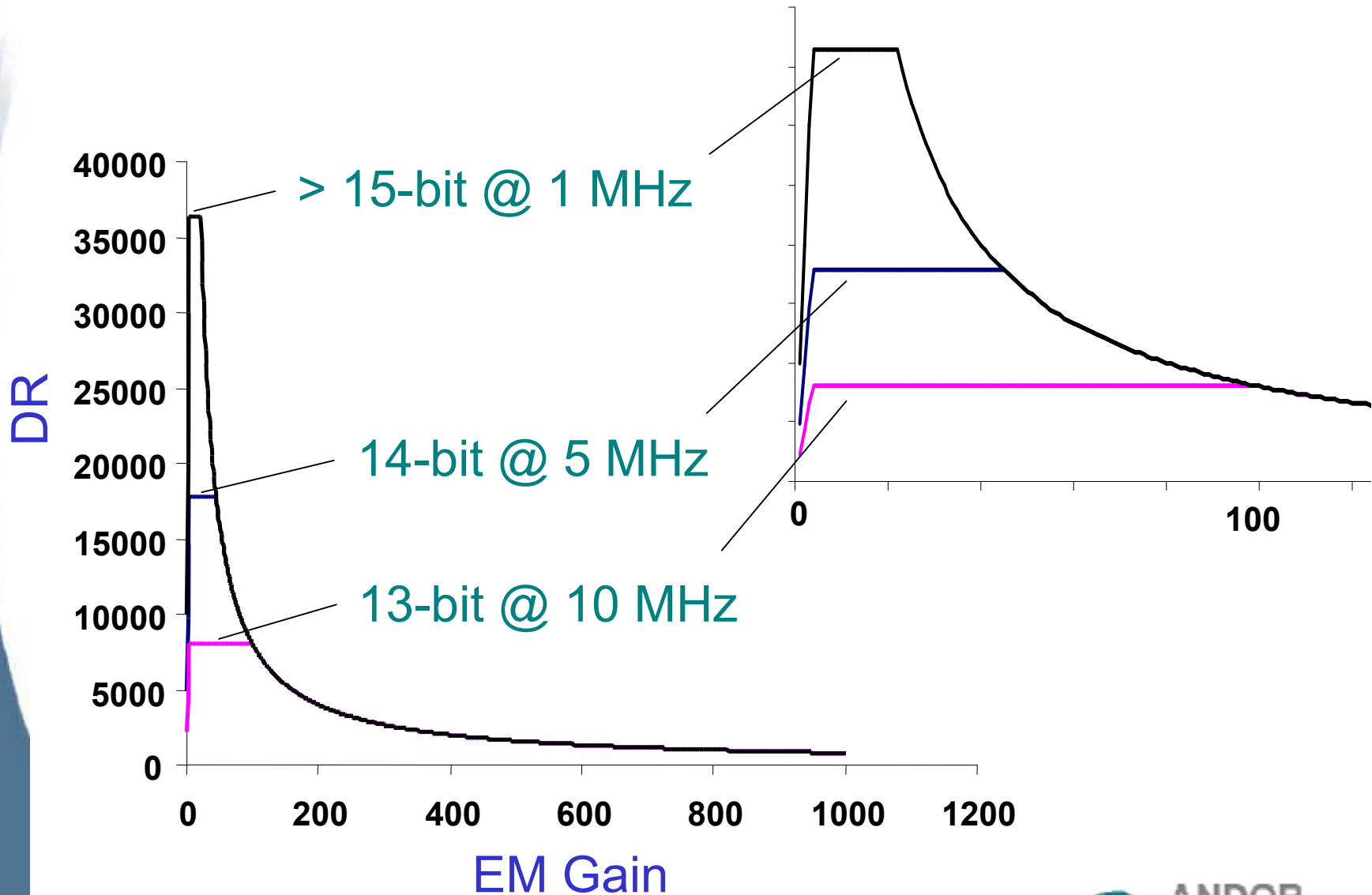
Dynamic Range varies with EM gain:

- *Extra well capacity in gain register*
- *Detection limit = read noise, therefore decreases with increasing gain.*

e.g. at 5 MHz readout with 45 e<sup>-</sup> rms read noise:-



# Dynamic Range is readout speed dependent

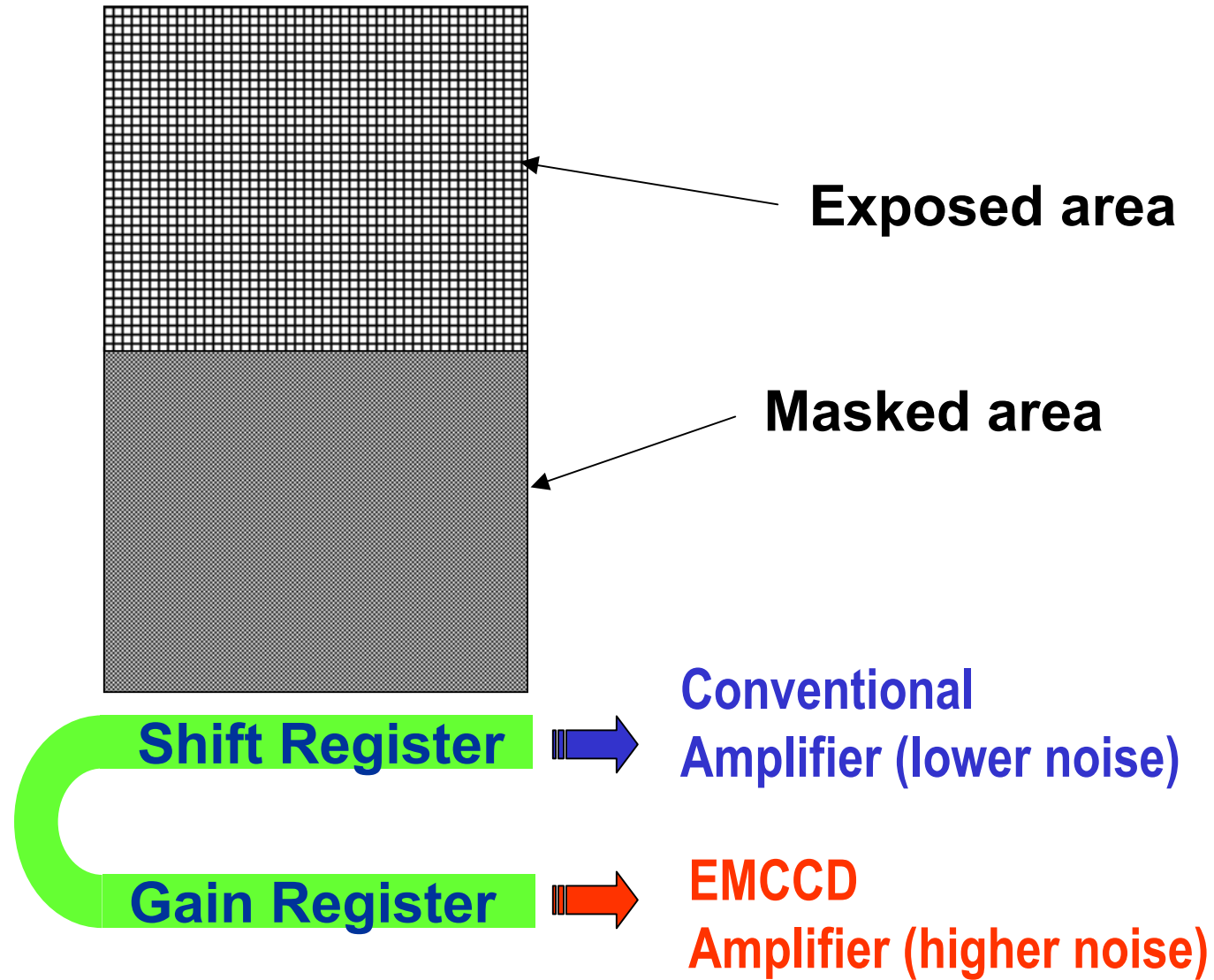




End

Thank you

# EMCCD and Conventional Amplifiers



e.g. Read noise values @ 1 MHz:

- through EMCCD Amplifier ~ 22 elec rms
- through Conventional Amplifier ~ 7 elec rms

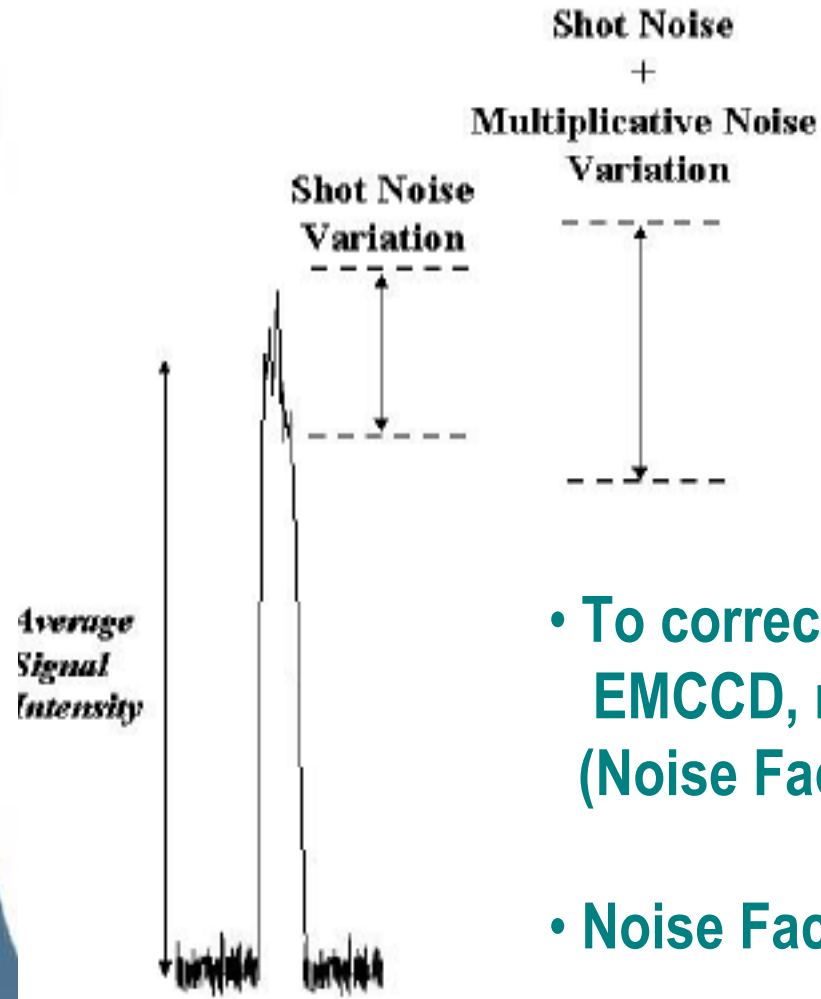
Therefore, max. dynamic range values are as follows:

- EMCCD (with x22 gain) = 36,364:1 (> 15 bit)  
*With 1 e<sup>-</sup> effective read noise*
- Conventional = 31,428:1 (> 15 bit)  
*With 7 e<sup>-</sup> read noise.*

The conventional amplifier achieves this dynamic range without any multiplication noise, therefore better shot noise performance.

# Software Integration

# Effect of Multiplicative Noise:



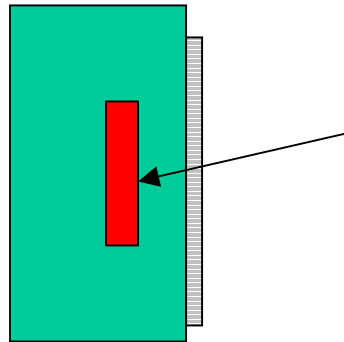
- To correct for Multiplicative Noise in EMCCD, multiply shot noise by x1.41 (Noise Factor).
- Noise Factor is significantly higher in ICCDs.

# Effective read noise with EM gain

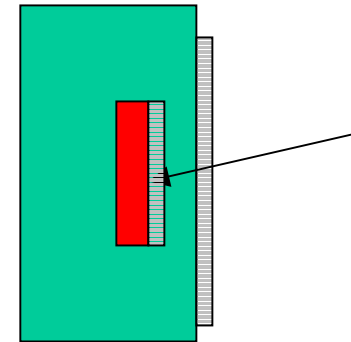
# Photon Loses

Beware of how many windows the light has to pass through!

**Andor**



**Other Cameras**

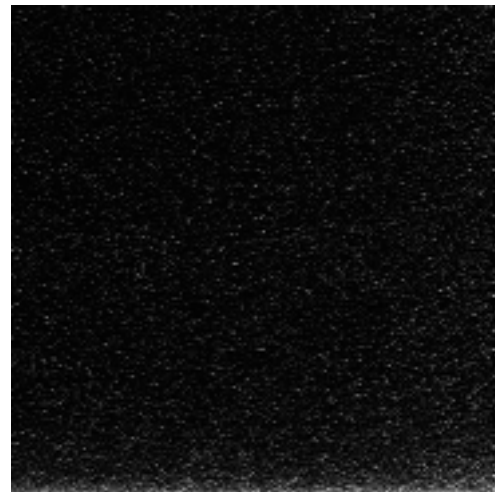


Also, ensure the windows have anti-reflection (AR) coatings.

## Horizontal Smearing 2

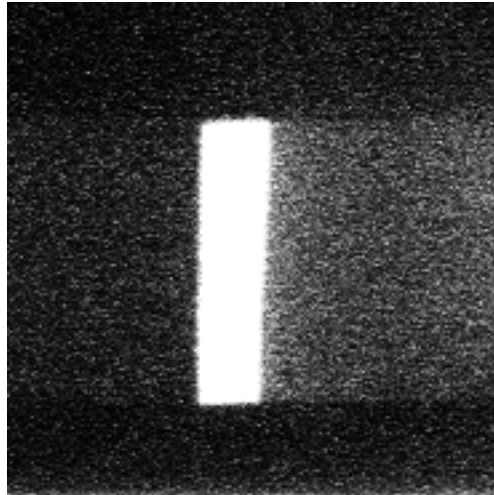


Bright image  
No gain

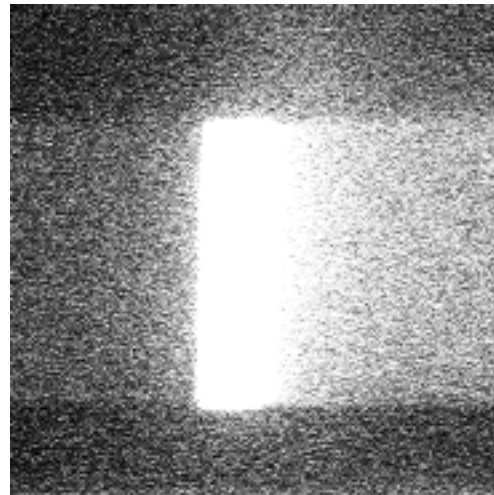


Dark image  
X2000 gain  
(CIC only)

# Horizontal Smearing 3



Saturated image  
at X2000 gain  
(Total smeared  
charge is about 50%  
of total image charge)



X10 Saturated image  
at X2000 gain

