International Image Sensor Workshop (IISW)
Vaals, Netherlands
8-11 June 2015

Science & Technology Facilities Council
Technology

Notes about the limits of ultra-high speed solid-state imagers

Dr Renato Turchetta
STFC - Rutherford Appleton Laboratory (RAL)
Oxfordshire, UK
E-mail: renato.turchetta@stfc.ac.uk

International Image Sensor Society

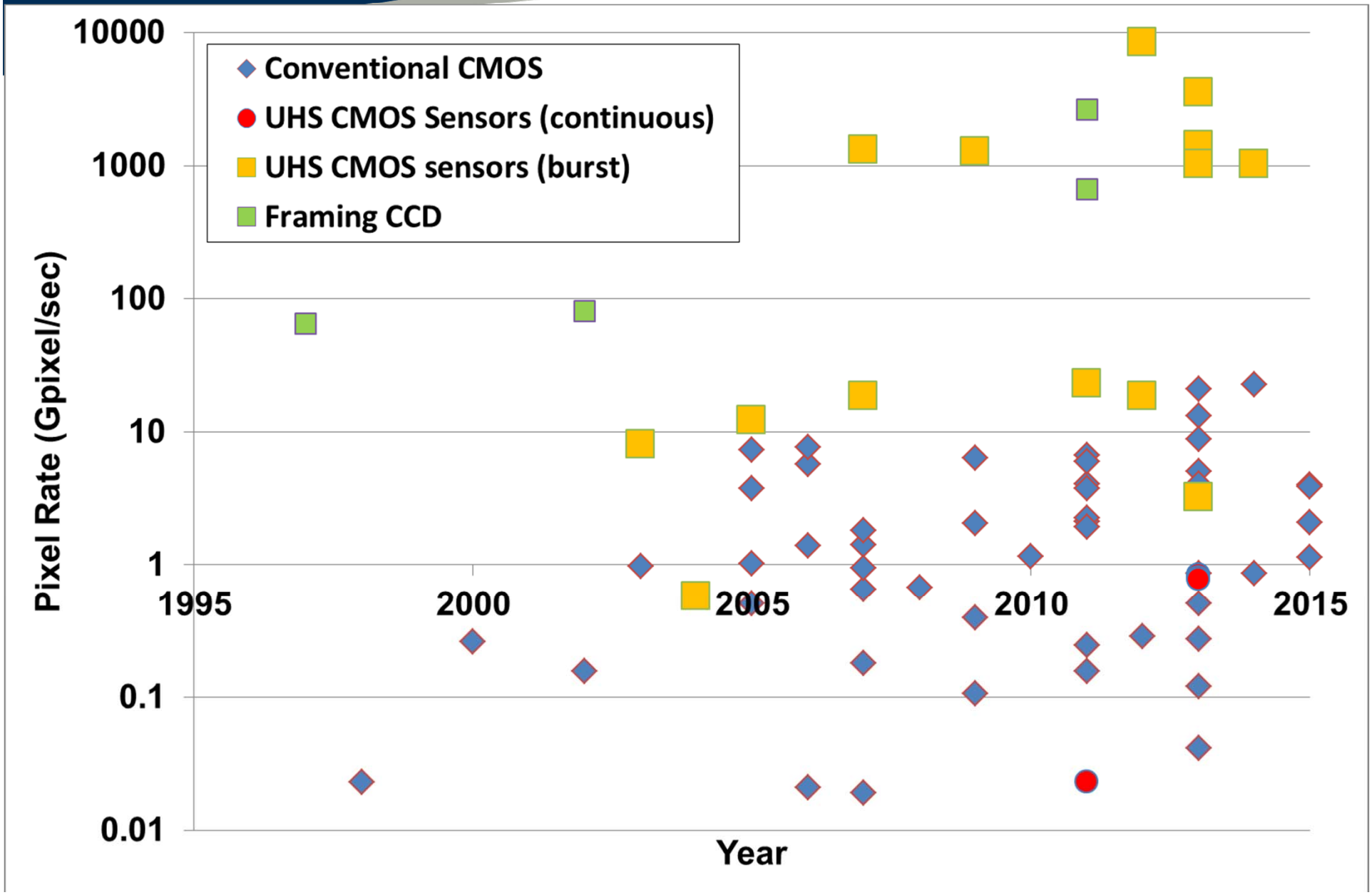
Science & Technology Facilities Council

Outline

- Current signal at high-speed → the Shockley-Ramo's theorem
- Dead time limit for photon counting devices

Science & Technology Facilities Council

Introduction



Science & Technology Facilities Council

Towards Gfps

10s of Mega frames per second already available

Going towards Giga frames per second

Carrier transit time comparable with sampling time

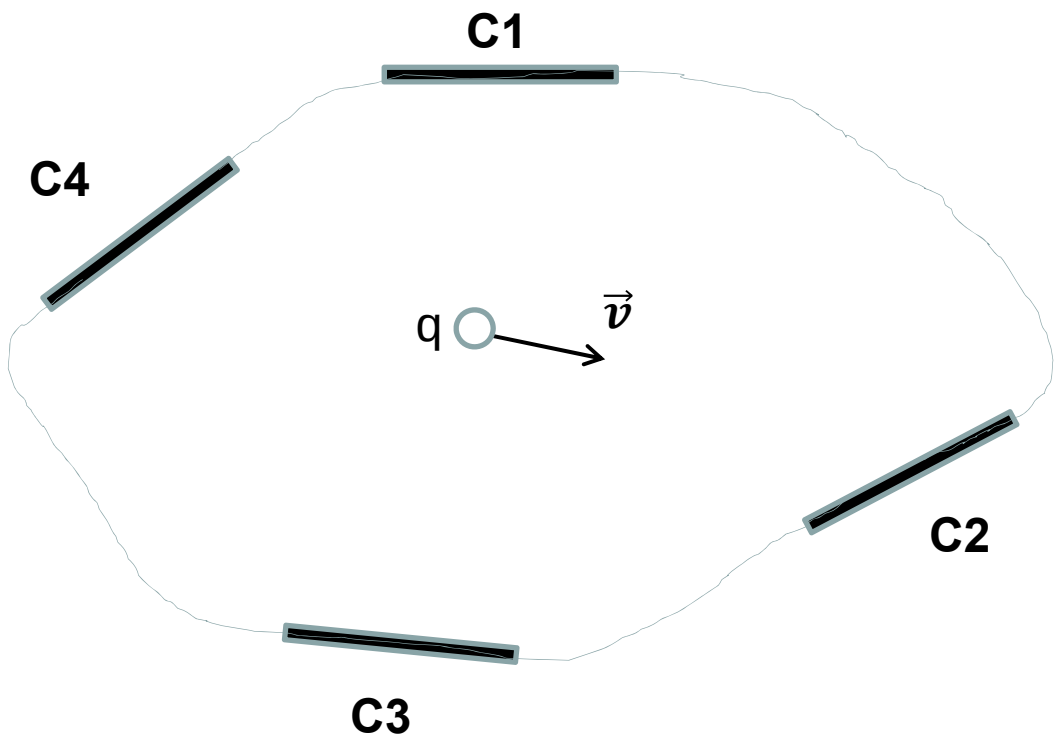
How do we calculate the charge signal?

Science & Technology Facilities Council

Vacuum tubes

Transit time of electrons comparable with frequency response of tubes.

What is the signal on the k-th electrode due to the movement of a carrier with charge q?



Science & Technology Facilities Council

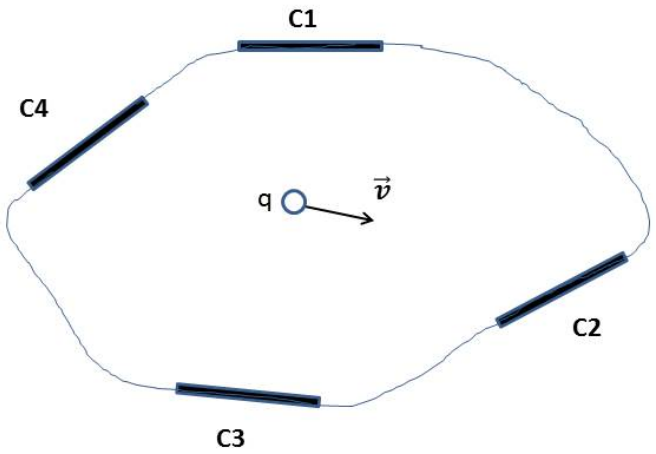
Shockley-Ramo's theorem

Current i(t) on one electrode due to a charge q moving with speed v(t) at point x

$$i_k(t) = q\,\vec{v} \cdot \overrightarrow{E_W}$$

$E_w(x)$ is the electric field obtained by setting the selected electrode at unit potential, all other electrodes at zero potential.
(Shockley 1938, Ramo 1939)

$E_w(x)$ calculated after removing all space charge .
(Cavalleri et al. 1971)



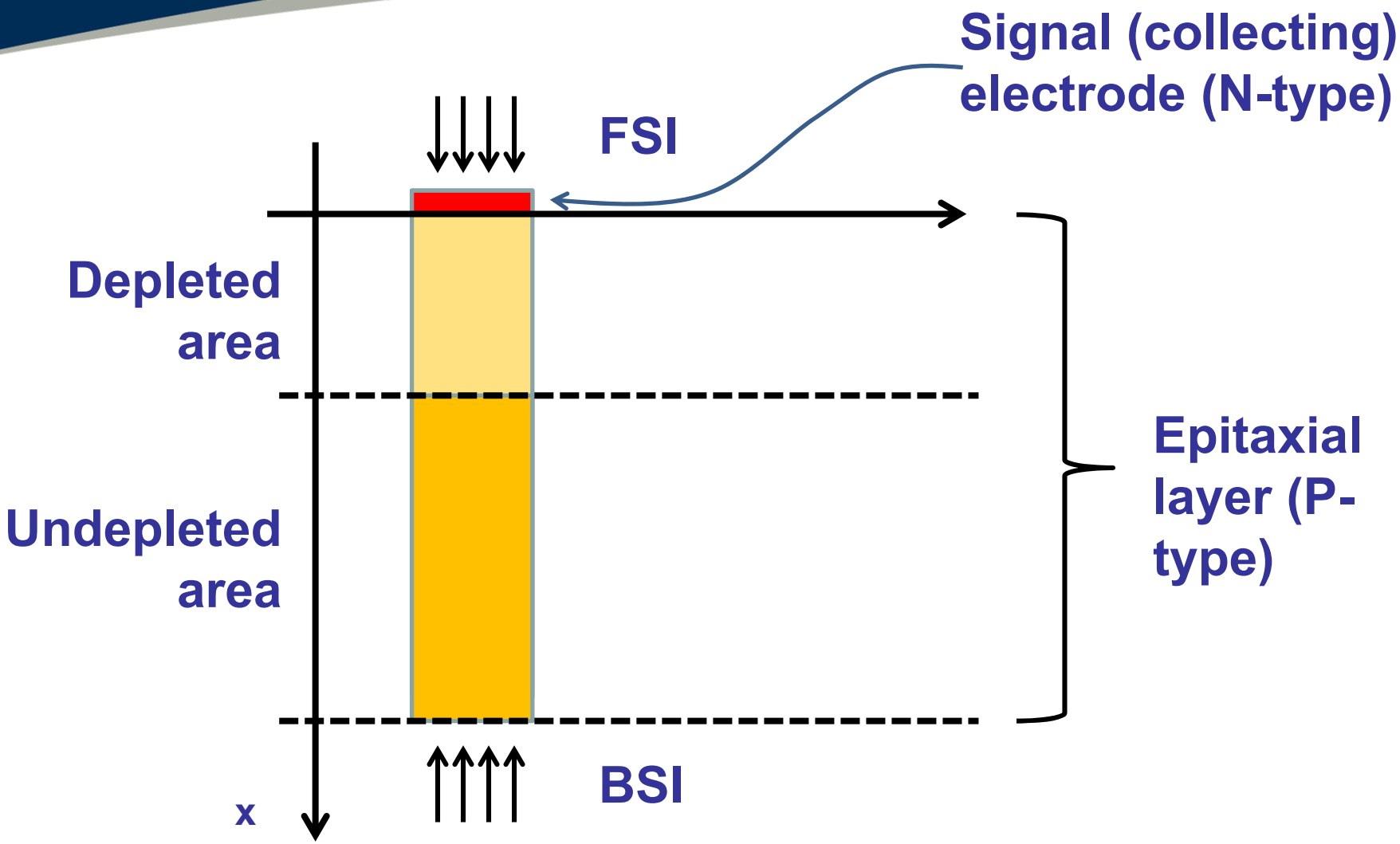
Science & Technology Facilities Council

Consequences

- The current signal is induced by the movement of charge
- In semiconductor there are two types of carriers, electrons and holes, hence two current components
- The two components are summed to give the total current
- The integral of the total (sum) current is equal to the collected charge

Science & Technology Facilities Council

MonteCarlo simulation



$E_0(x) = 1/w$

2000 e-h pair generated

Science & Technology Facilities Council

Induced current

Epi w = 5 µm

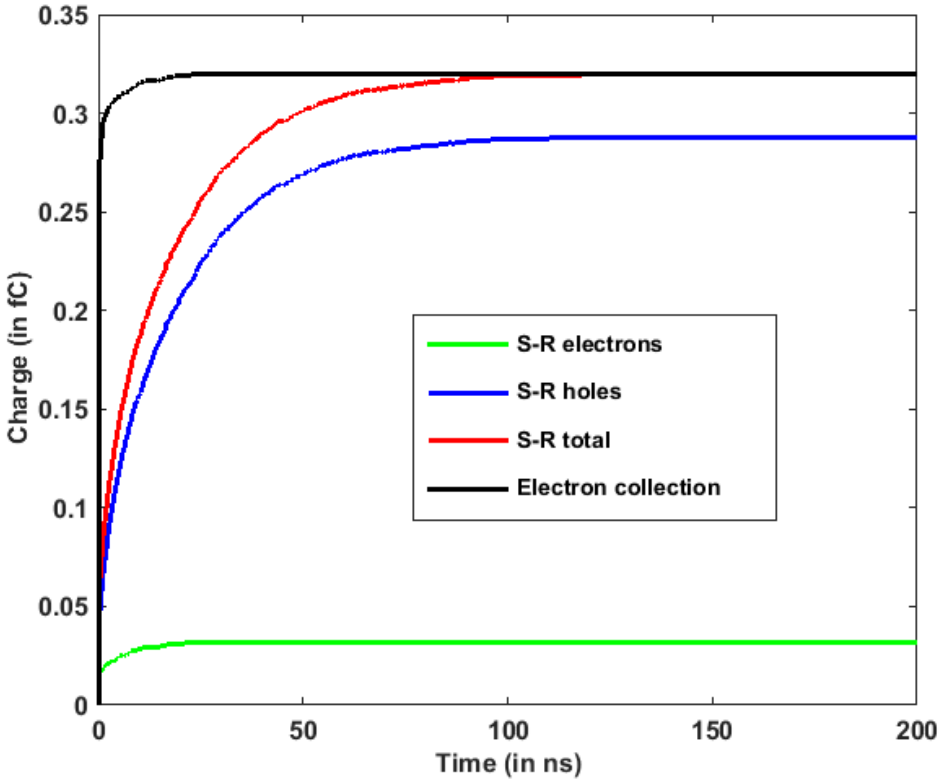
$N_D = 10^{18}$ cm^{-3}

$N_A = 2*10^{15}$ cm^{-3}

V_{bias} = 1.5V

FSI

w.l. = 450 nm

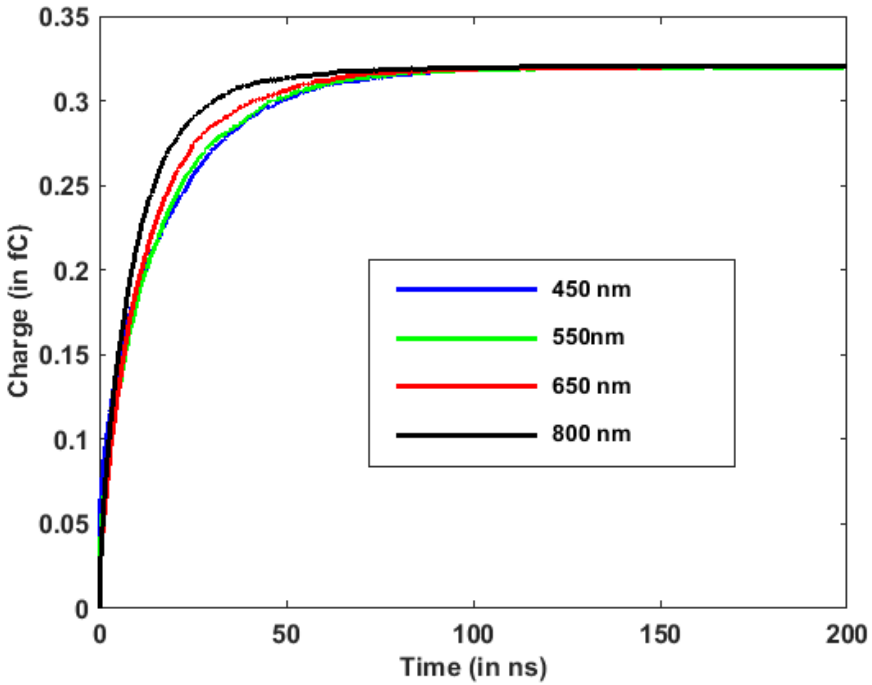


Ramo-Shockley gives a very different result!

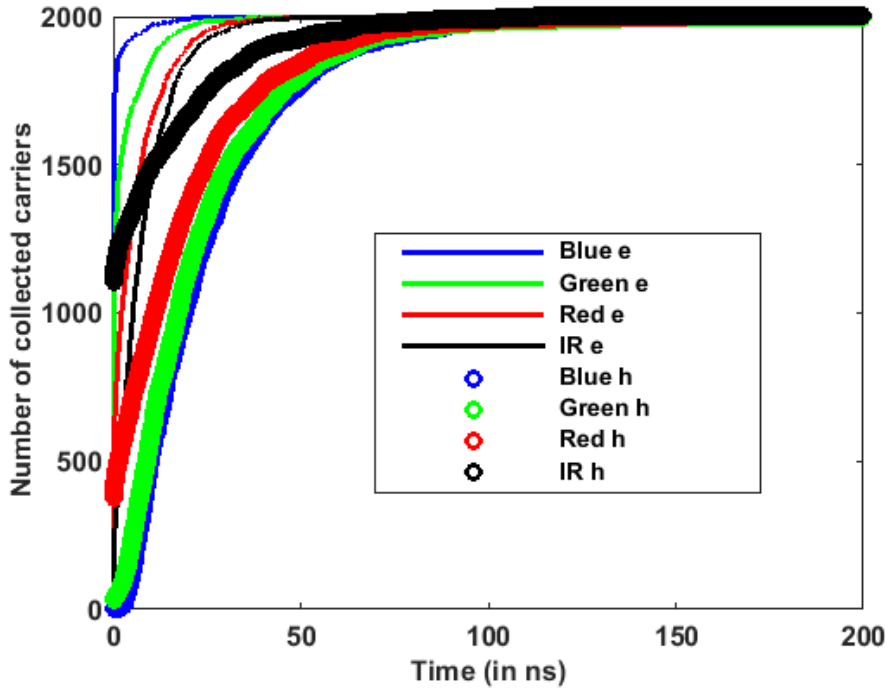
Science & Technology Facilities Council

Temporal colour cross-talk

Ramo-Shockley



Carrier collection

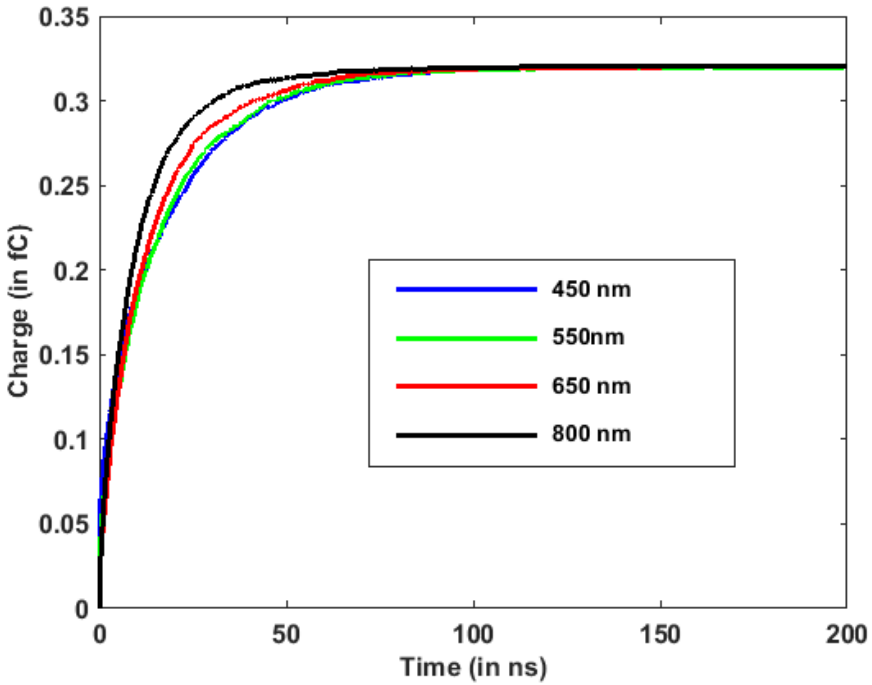


Thin epi. Low resistivity.

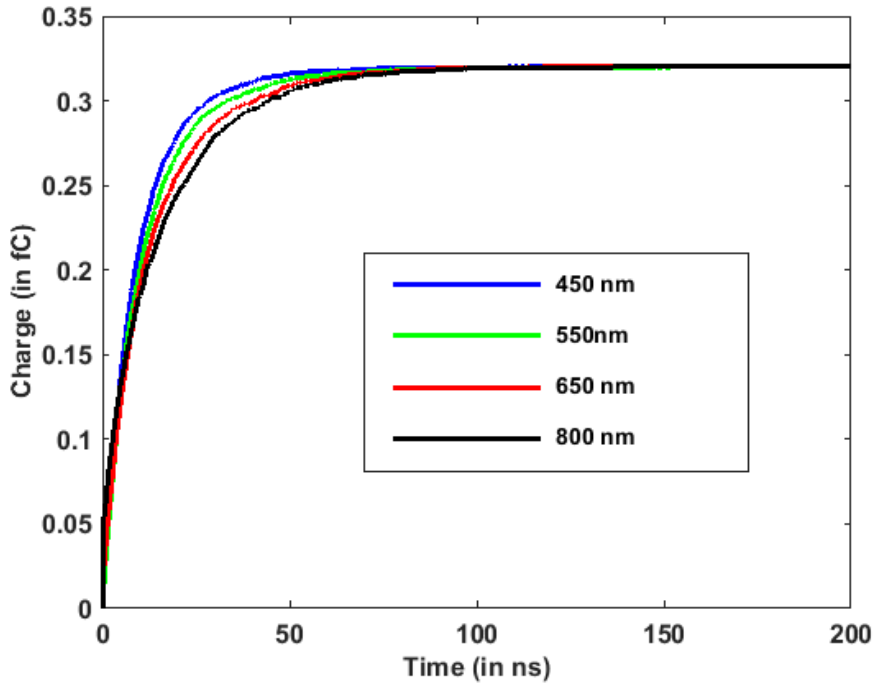
Science & Technology Facilities Council

FSI vs BSI

FSI



BSI

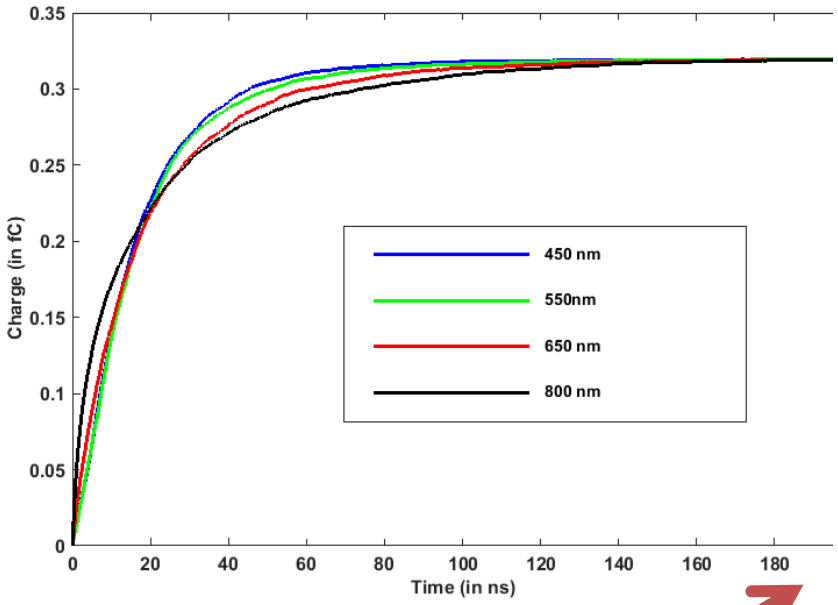


Thin epi. Low resistivity.

Science & Technology Facilities Council

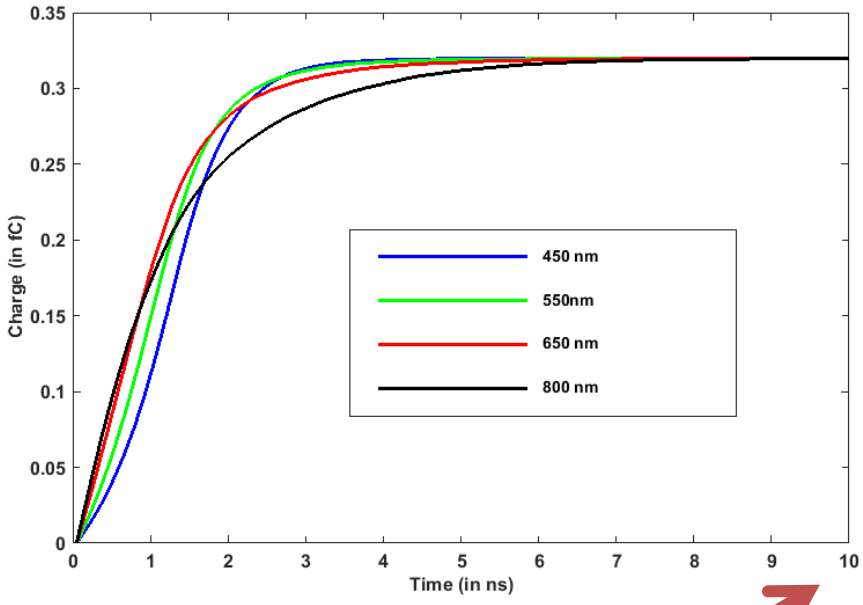
Thick epi. High res. BSI.

V_{bias} = 1.5V



200 ns

V_{bias} = 5V

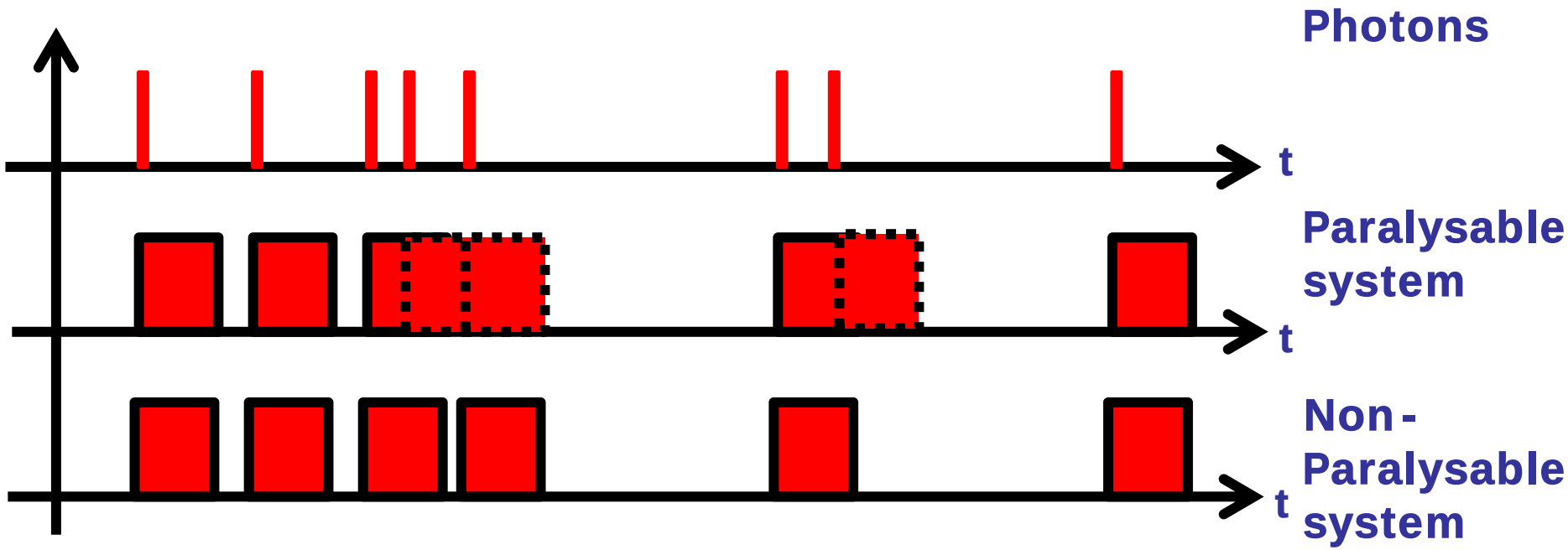


10 ns

Science & Technology Facilities Council

Deadtime

Deadtime in counting systems. Basic models: paralysable and non-paralysable



Science & Technology Facilities Council

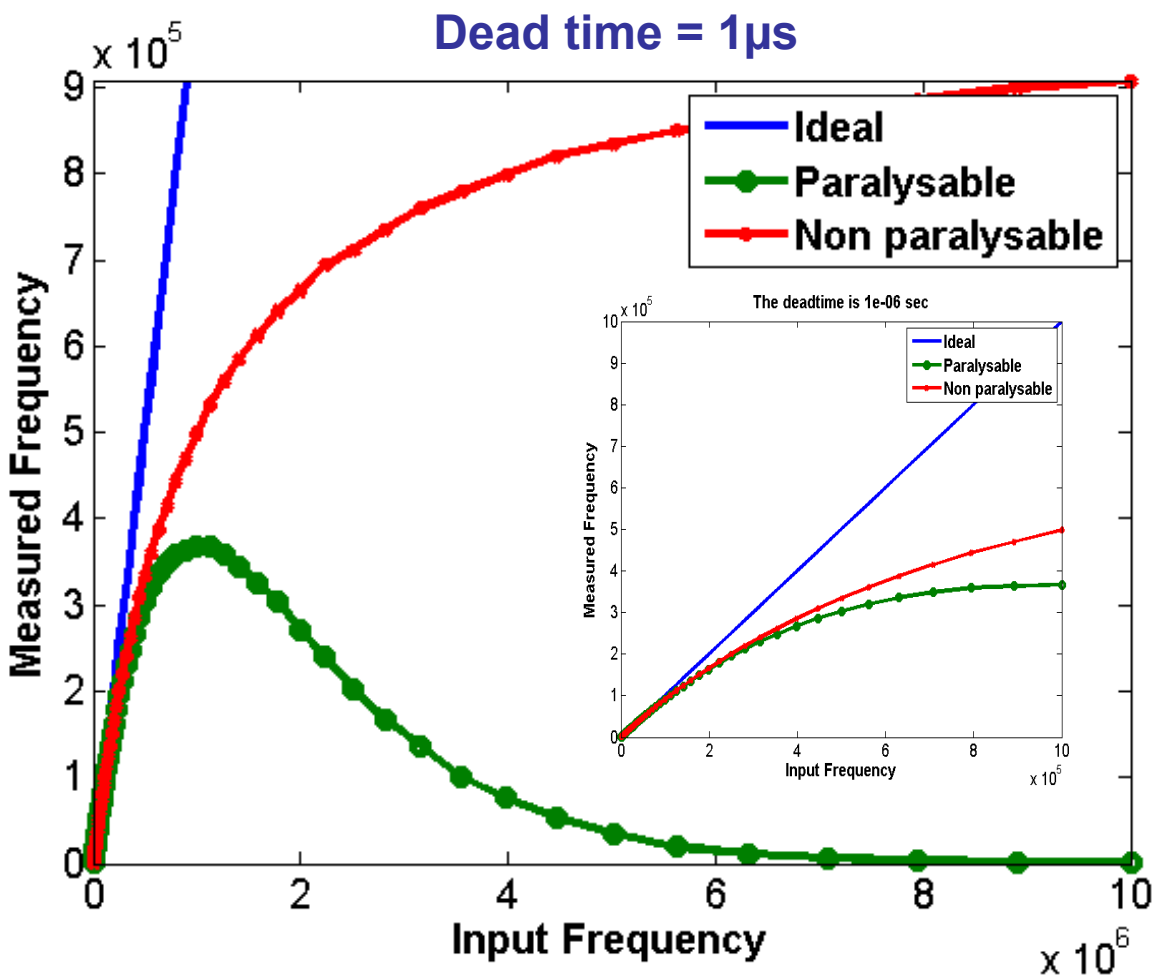
Counting curves

Maximum count rate set by dead time

Frame rate ↑↓

Maximum count ↓↓

Bit depth



Science & Technology Facilities Council

Conclusions

- Shockley-Ramo's theorem → current induced by the movement of charge
- Careful design to avoid temporal colour cross-talk at ultra-high speed
- Dead time to set trade-offs between amplitude and time resolution for photon counting sensors