Backside thinned, 2.5 e^-_{RMS}, BSI, 700fps, 1760x1760 pixels wave-front imager with 88 parallel LVDS output channels

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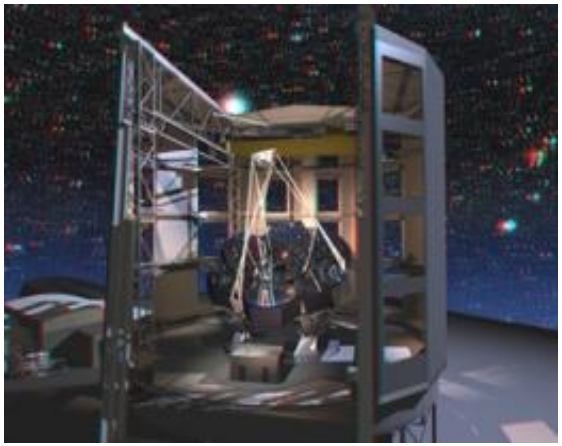
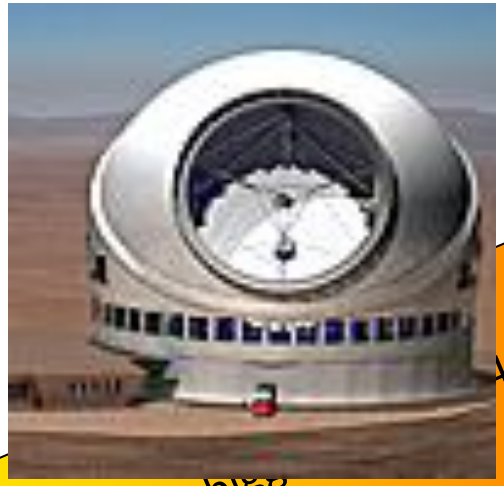
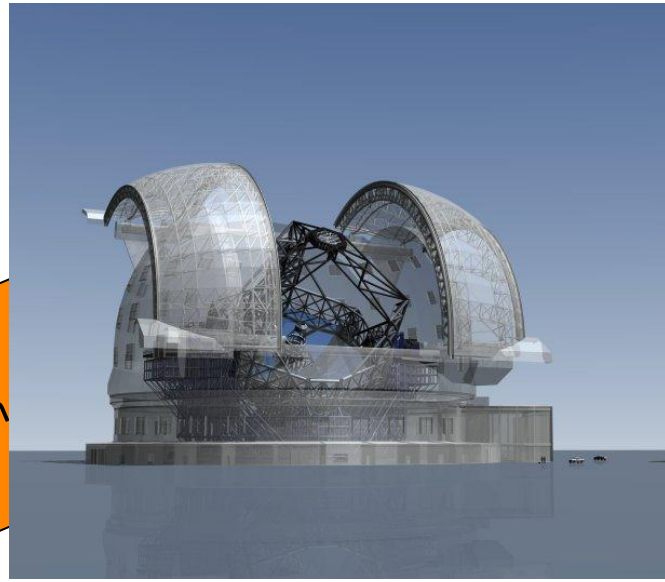
From: “Detectors for AO Wavefront Sensing”

Mark Downing, G. Finger, D. Baade, N. Hubin, J. Kolb, O. Iwert

Instrumentation Division ESO







Future Telescopes
GMT (24m), TMT (30m), E-ELT (42m)

Adaptive Optics (AO)

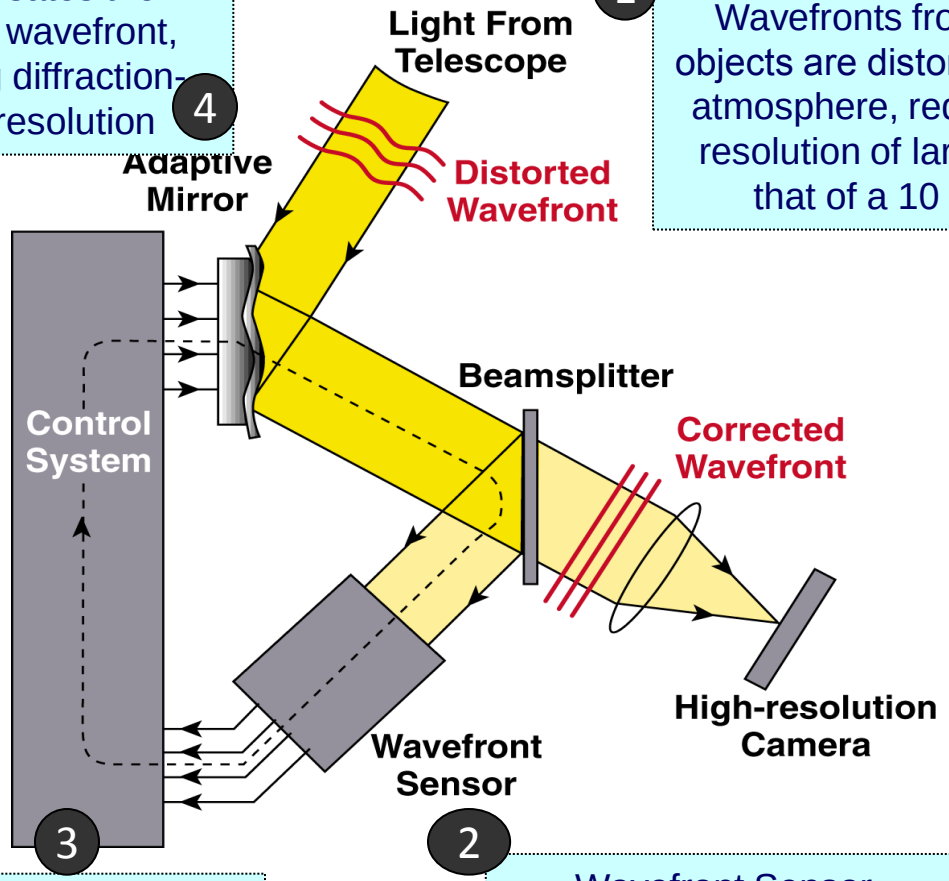
- removing the twinkle of the stars

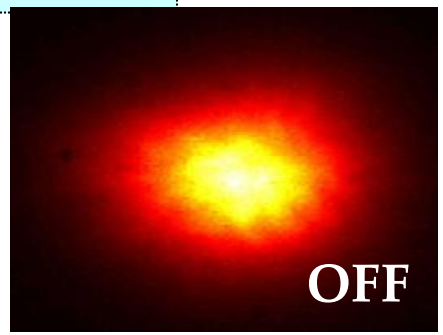
Deformable mirror compensates the distorted wavefront, achieving diffraction-limited resolution

4

1

Wavefronts from astronomical objects are distorted by the Earth's atmosphere, reducing the spatial resolution of large telescopes to that of a 10 cm telescope





3

Control System computes commands for the deformable mirror(s)

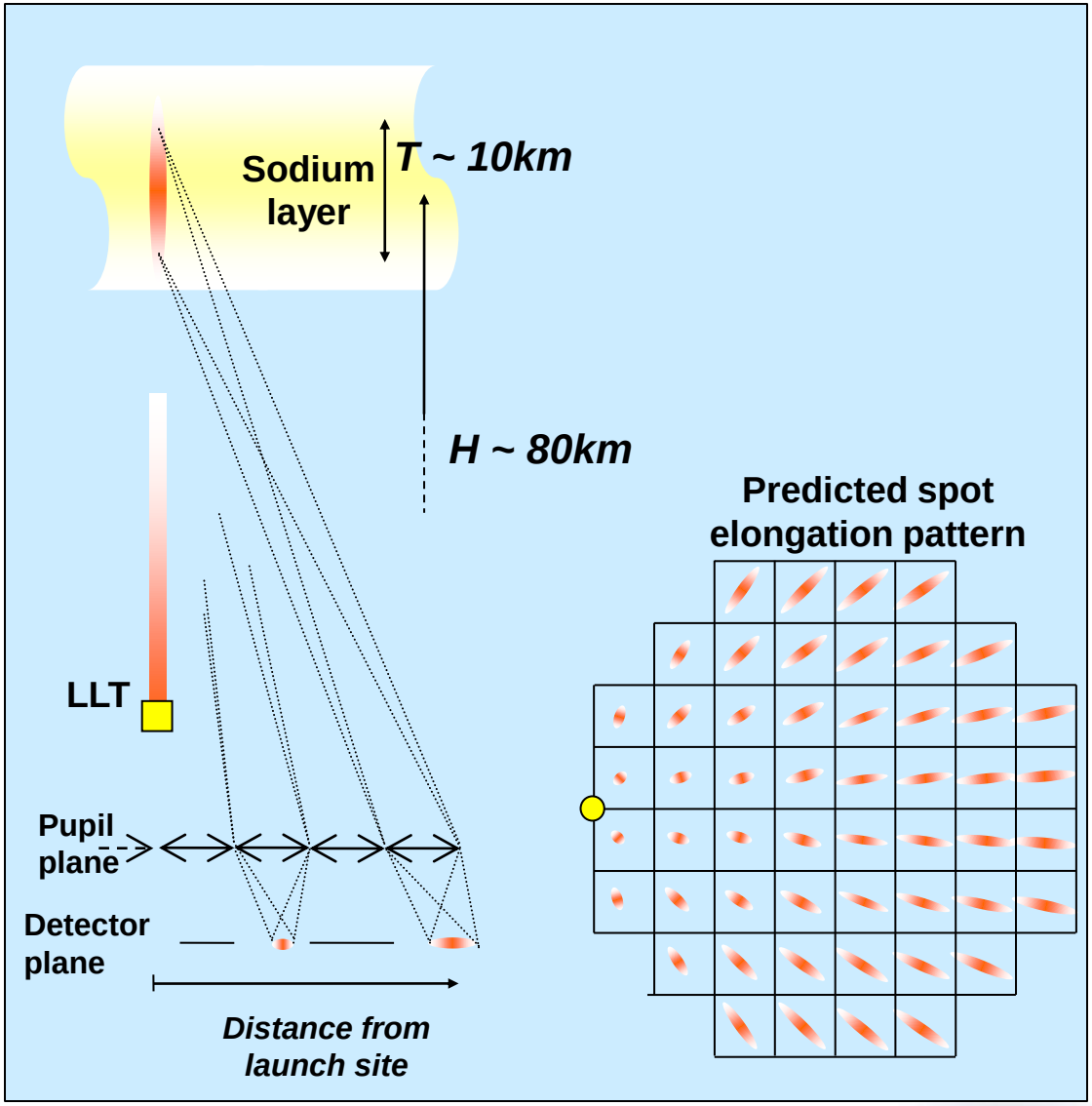
2

Wavefront Sensor measures deviation of wavefront from a flat (undistorted) wave

Large Visible AO WFS Detector needed to sample the spot elongation

Sodium Laser Guide Stars (589 nm)

- AO systems operate at ~1 kHz frame rate
- Bright “guide stars” are required
- Only 1% of the sky is accessible with natural guide stars
- Sodium layer at 80-90 km altitude can be stimulated to produce artificial guide stars anywhere on the sky
- Pulsed laser can be used to range gate to limit laser spot elongation



Outline

- Introduction: wavefront sensing
- Specifications of the E-ELT WFS
- Results of the previous generation sensor TVP
- The massive parallel data problem
  - A balanced clock tree for 88 LVDS channels
  - Optimal design

Specifications of the ELT WFS

Pixel array (including dark reference pixels)	Stitched design for two versions: 880x840 pixels (“NGSD”) or 1760x1760 pixels (“LGSD”)
Technology	backside illuminated CMOS 0.18µm
Pixel pitch	24µm
Pixel topology	4T pinned photodiode pixel
Array architecture	1680x1680 pixels organized in 84x84 time coherent “sub arrays” of 20x20 pixels, with a total LGSD image size of 4x4cm
Shutter	Rolling shutter in chunks of 20 rows, so that within a sub-array (20 rows x 20 columns) detection is synchronous.

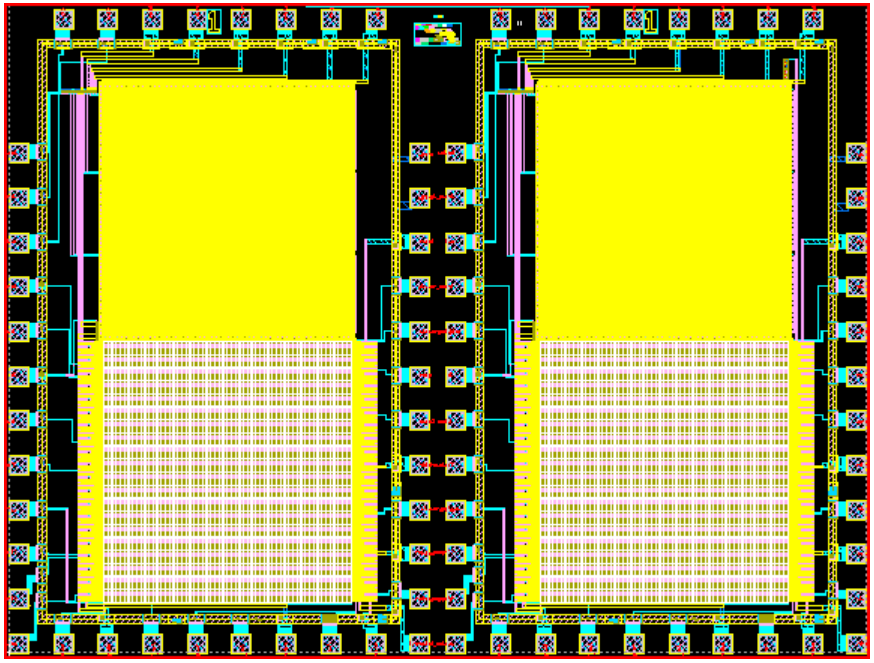
Specifications of the ELT WFS

Responsivity	100 to 160 µV/electron in TVP pixel variants
Pixel full well Q_{FW}	4000 e- (on TVP)
Read noise including ADC	$2.5e^-_{RMS}$ (on TVP)
QE	QE above 90%, for 24x24µm, backside illuminated (BSI) pixels over the visible range *or* optimized for the wavelength of the laser guide star.
Image lag	<0.1 % (TVP)
MTF	ideal and symmetric in X and Y by design

Specifications of the ELT WFS

Number of rows read in parallel	40 (LGSD) or 20 (NGSD) rows over 20 parallel column lines per column of pixels
Number of ADC's	40x1760 (LGSD) or 20x880 (NGSD)
Number of parallel LVDS channels	22 (NGSD) or 88 (LGSD)
LVDS channel bit rate	210 Mb/s baseline, up to 420 Mb/s (desired)
Frame rate	between 700 and 1000fps or 2 to 3 Gpixel/s or 20 to 30 Gb/s over 88 parallel LVDS channels
Power dissipation (spec)	Maximum 5W overall, including the 88 LVDS drivers
Actual LVDS driver dissipation per channel	6.0 mW @ at maximum data rate. 4.5 mW in sub-LVDS

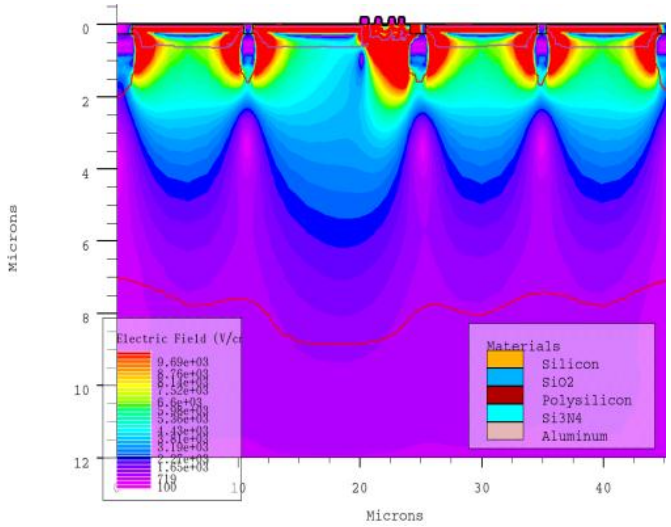
TVP predecessor performance



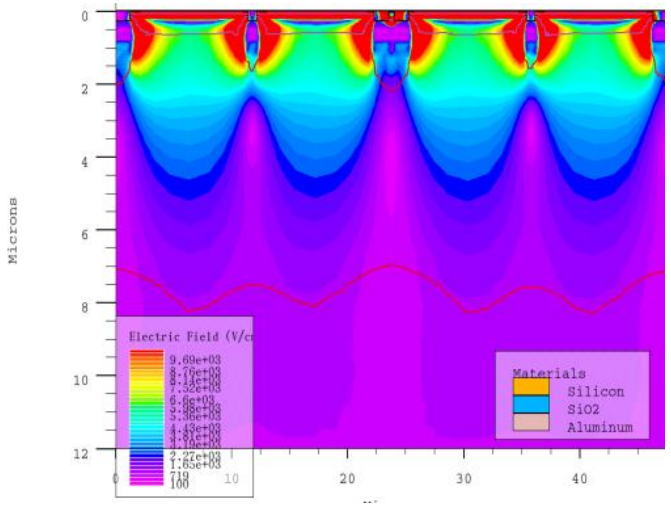
Nov 2010

- In a nutshell
  - All features of NGSD/LGSD
  - 60x60 pixels, 12 variants
  - Same pixel and ADC driving
  - 1200 (60x20) column ramp ADCs
  - >700 fps
- Key performance tested
  - Perfectly symmetric MTF
  - 2.5 e^-_{RMS}
  - Full well 4000...8000 e-
  - Conversion gains 100...160 µV/e-
- Not tested in TVP:
  - Massive parallelism
  - Array of LVDS IO
  - BST/BSI

pixel design for best centroiding performances, TCAD simulations



Y / center



X

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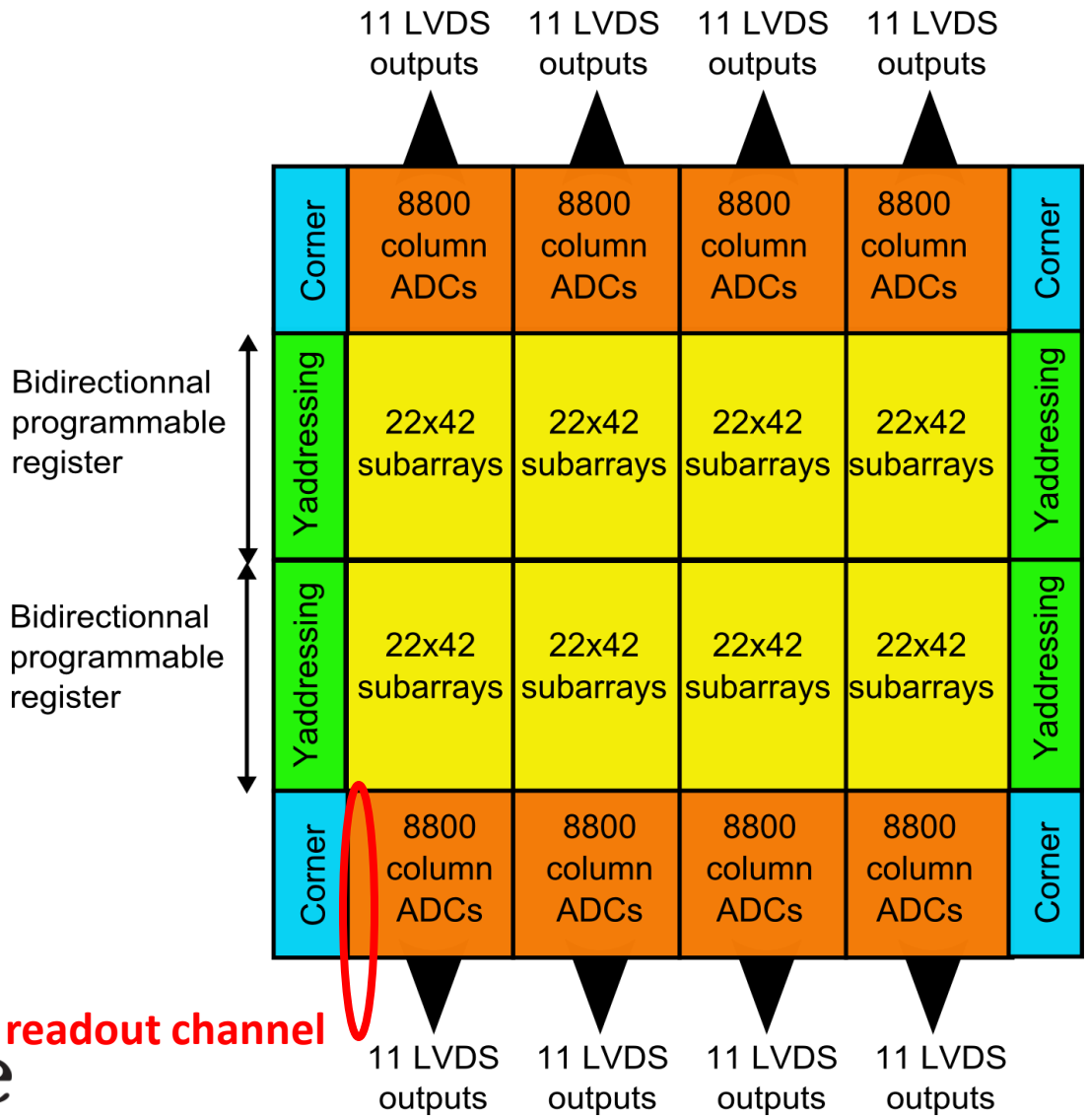
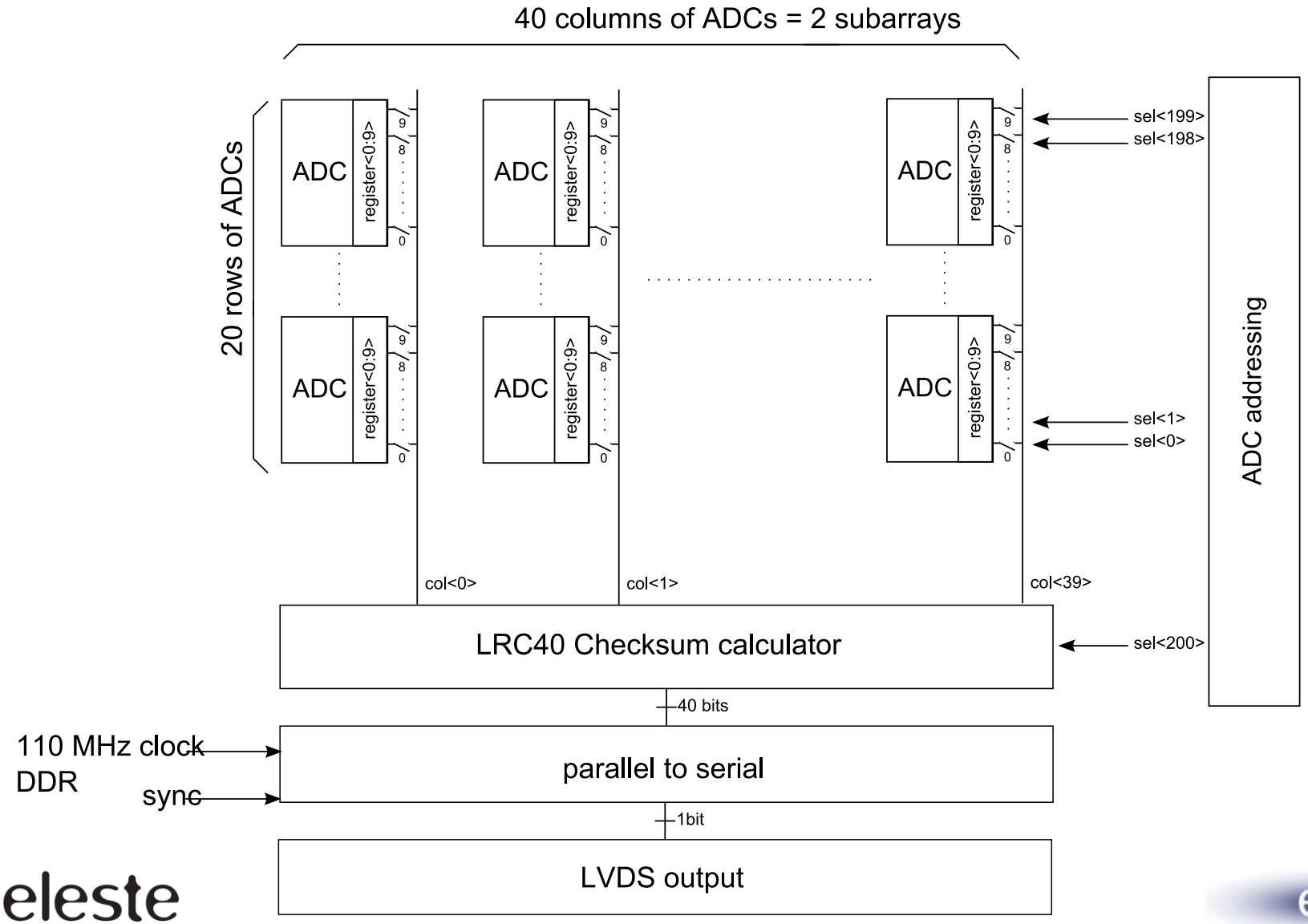
LGSD/NGSD floorplan (stitching)



One readout channel (of 88)



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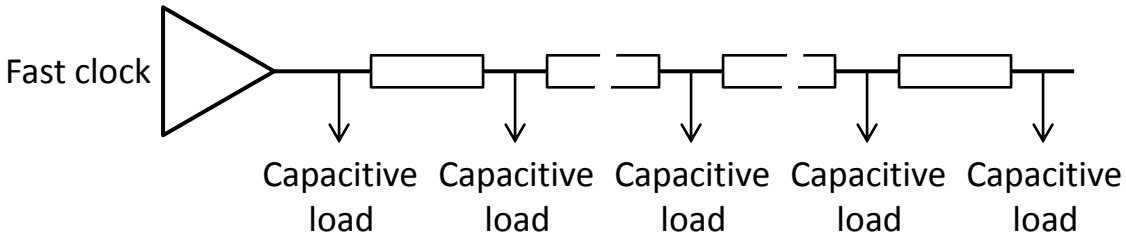
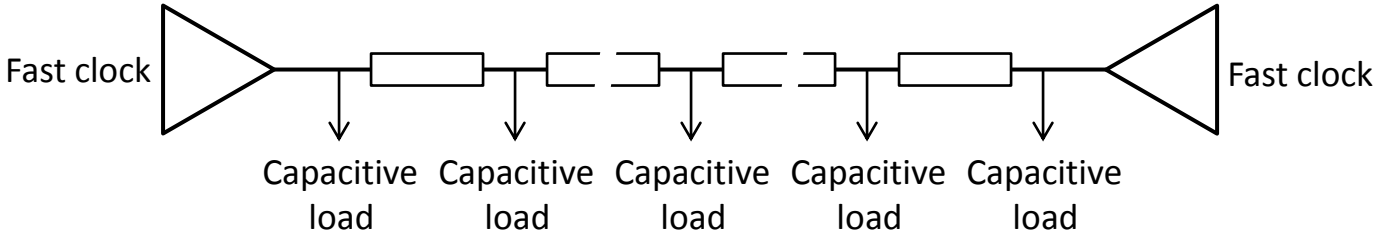
How to drive 210 MHz over 4cm?



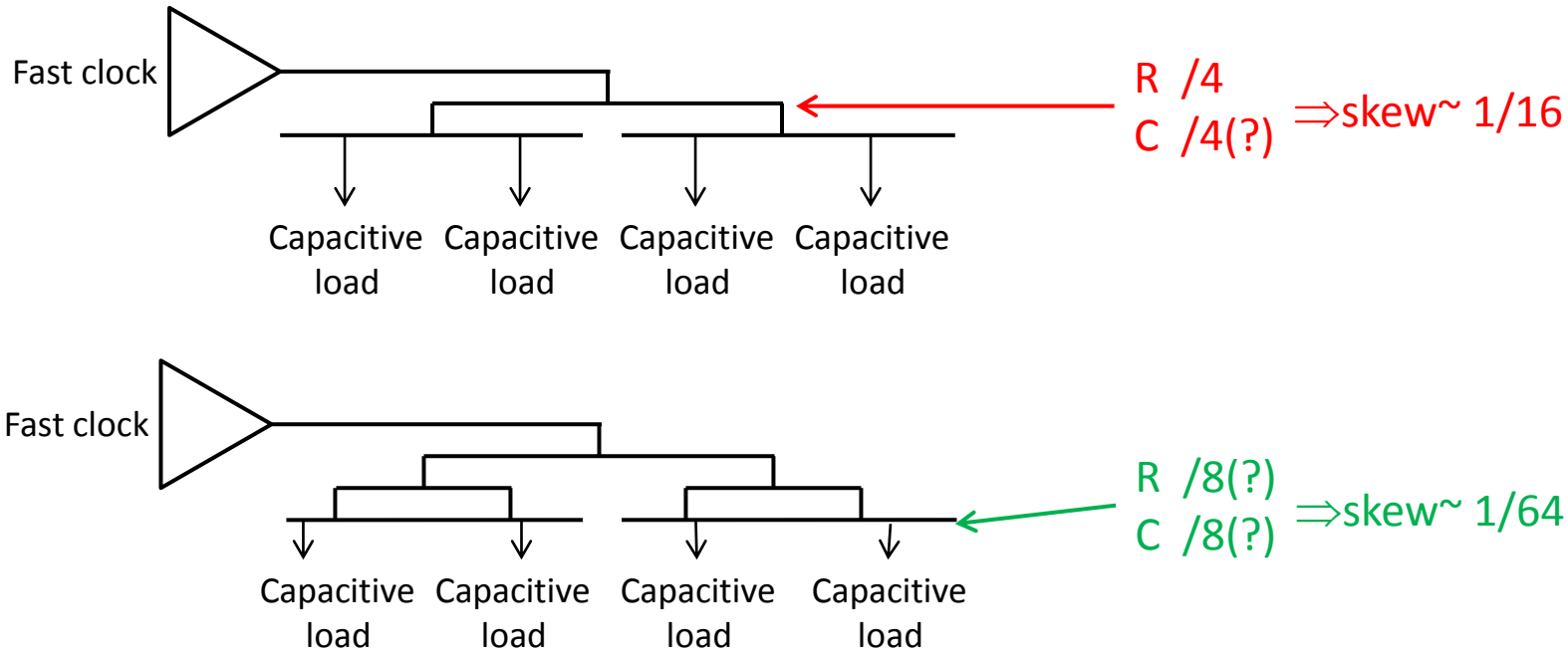
Reference case for speed and skew

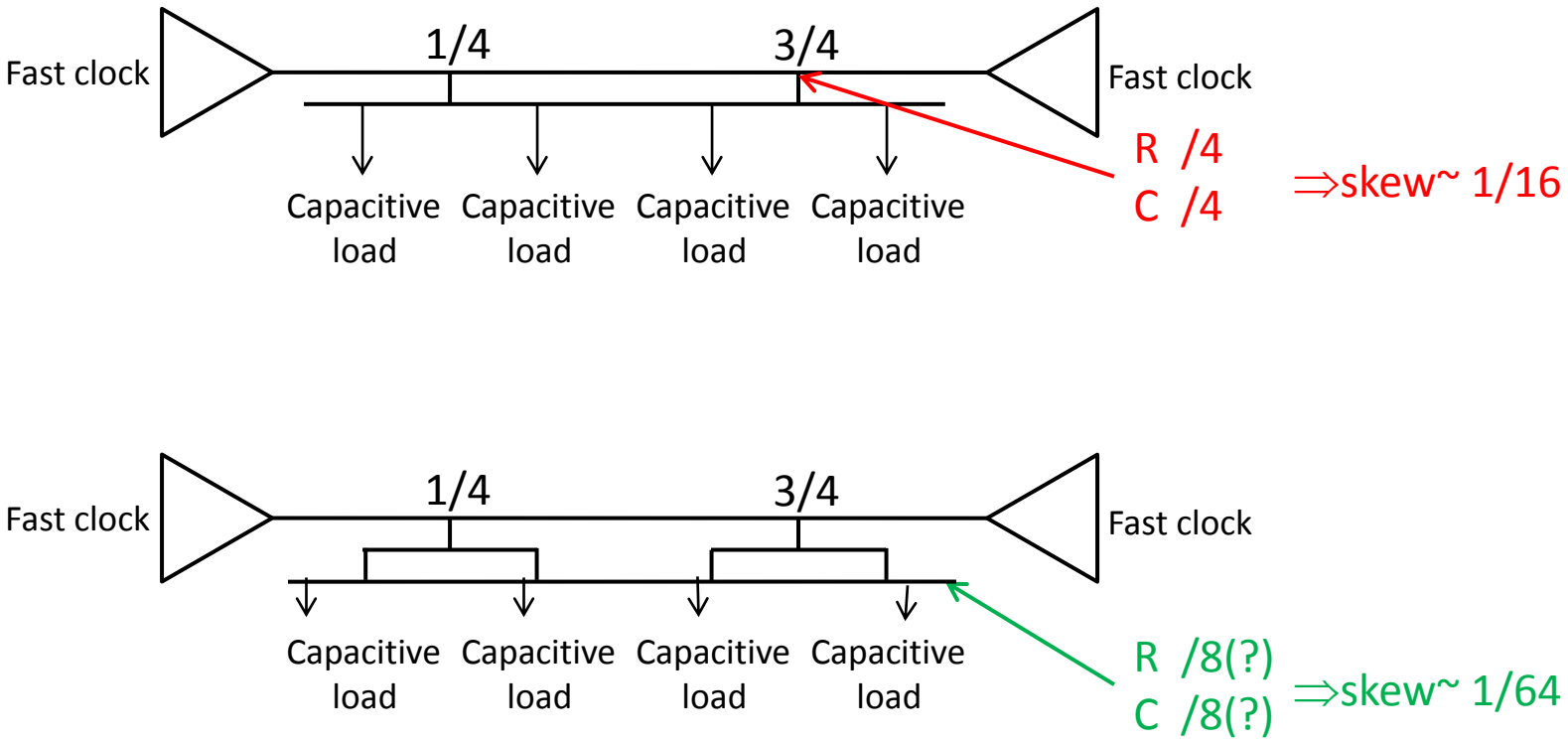
Skew>2ns



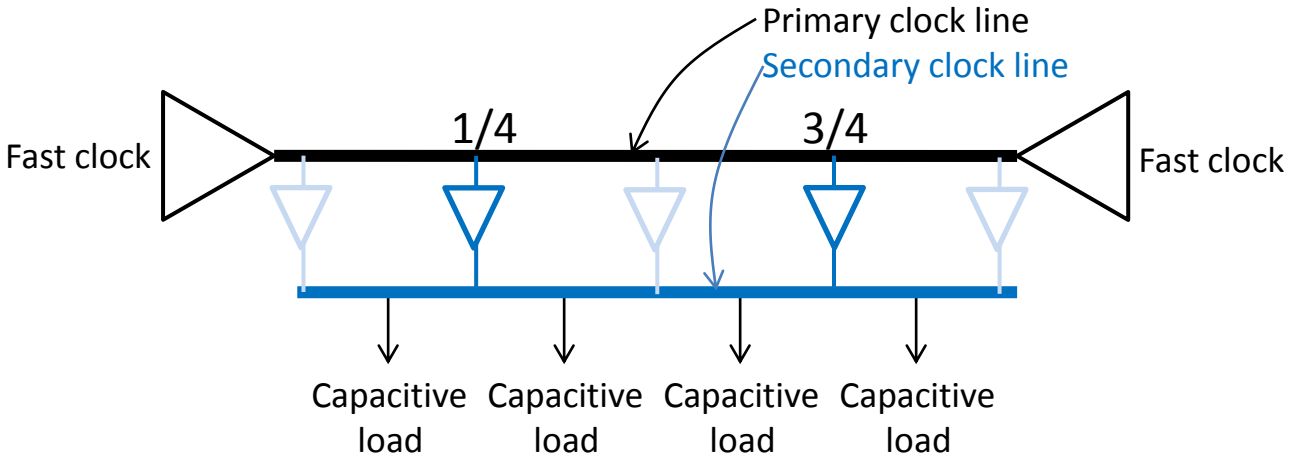
R /2 ⇒Speed~ *4

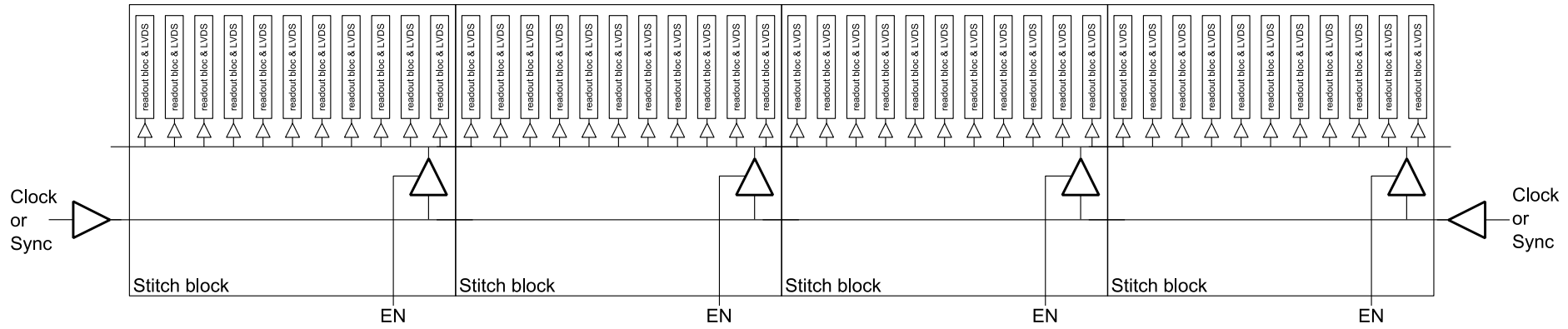
C /2 ⇒Skew~ /4


Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R /4
C /4(?)
⇒skew~ 1/16
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R /8(?)
C /8(?)
⇒skew~ 1/64


Fast clock
1/4
3/4
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R /4
C /4
⇒skew~ 1/16
Fast clock
1/4
3/4
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R /8(?)
C /8(?)
⇒skew~ 1/64

How to implement this when stitching?





Thank you!

Acknowledging Mark Downing & team, ESO

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