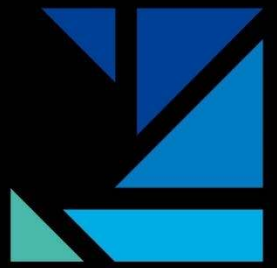
SAMSUNG

World Largest Mobile Image Sensor with All Directional Phase Detection Auto Focus Function

Hot Chips 33
August 22-24, 2021

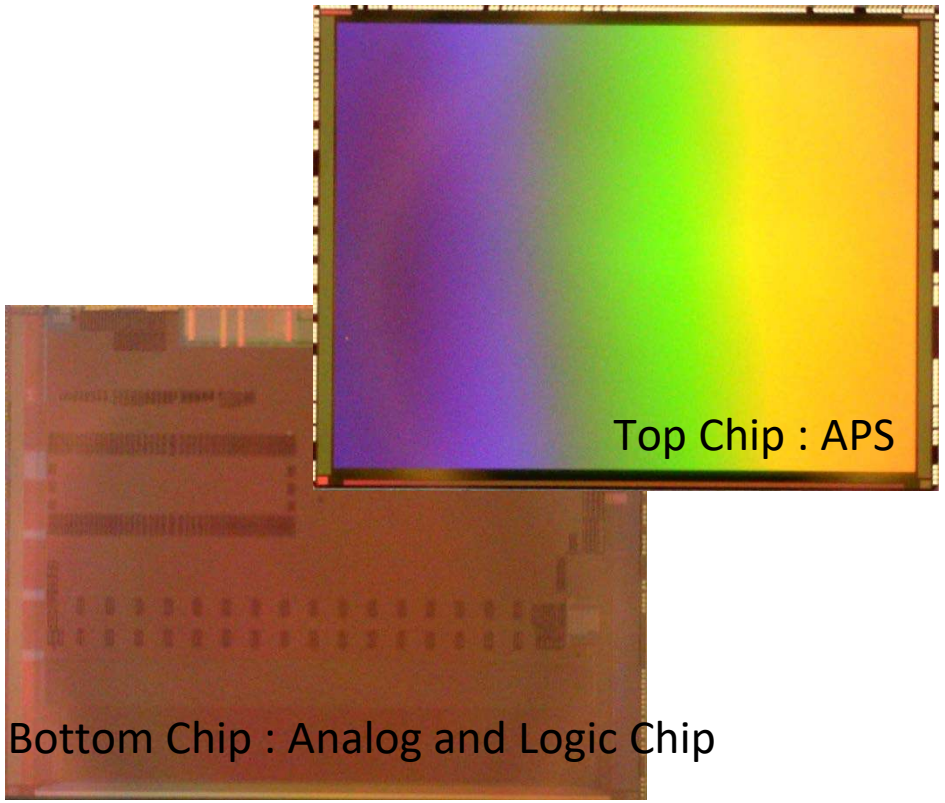


Sukki Yoon, Jungbin Yun, Yunhwan Jung, Ilyun Jeong,
Junghee Choi, Wooseok Choi, Jeongguk Lee, Hansoo Lee, Juhyun Ko

1/1.12-inch 1.4um 50Mp CMOS Image Sensor

- **Main features**

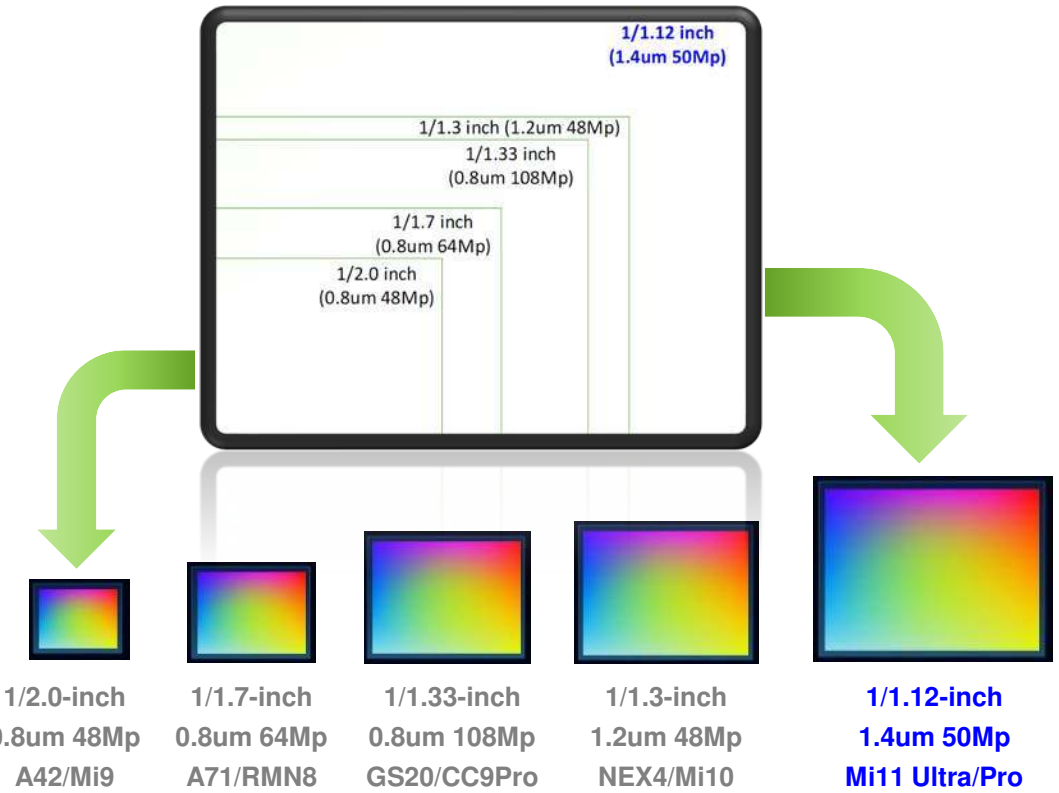
1. 1/1.12-inch 1.4um 50Mp Dual Pixel Pro
2. Output modes
   - 50 MP @ 20 fps/8K @ 24 fps/12.5 MP @ 120 fps/FHD @ 480 fps
3. Super Fast All-Directional AF with Dual Pixel Pro
4. HDR solutions
   - Smart ISO Pro
   - Staggered HDR
5. Low power ADC
   - 2.2V Analog power supply voltage
6. High speed interface
   - MIPI Combo(CPHY/DPHY) with EMI immunity

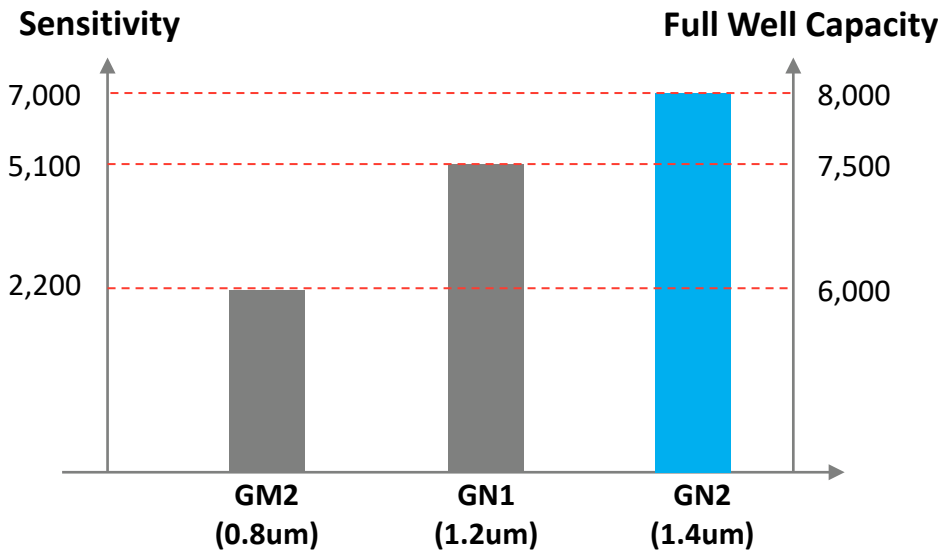


ISOCELL GN2 – The Largest Pixel

World Largest Mobile Sensor

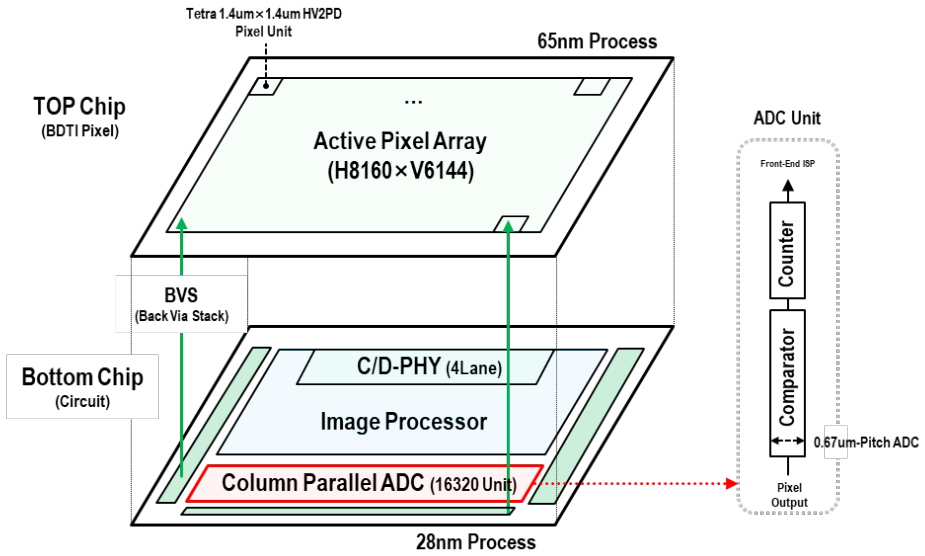
- **DSC-like Pixel area, Best shot even in the night scene**
  - Larger sensor gives the higher sensitivity and full well capacity
  - Better resolution in the bright scene, Brighter image in the dimming scene

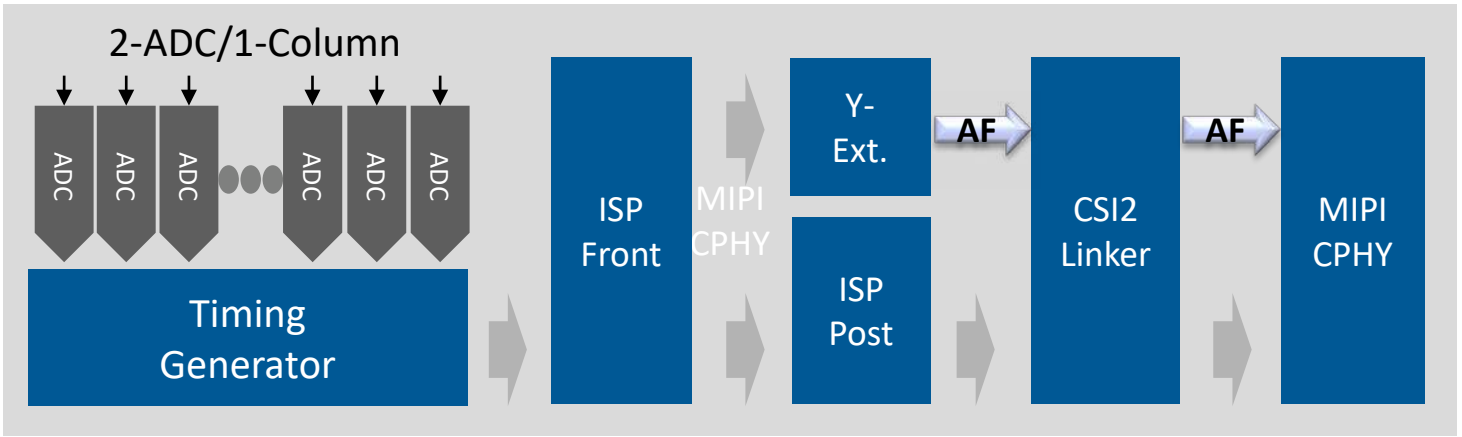




Stacked Image Sensor

- **Separation of Pixels from analog and logic Parts**
  - To realize small area and various functions
  - To enhance sensor performance by using pixel-only process
  - To realize manufacturing flexibility and various functions through separation of logic process

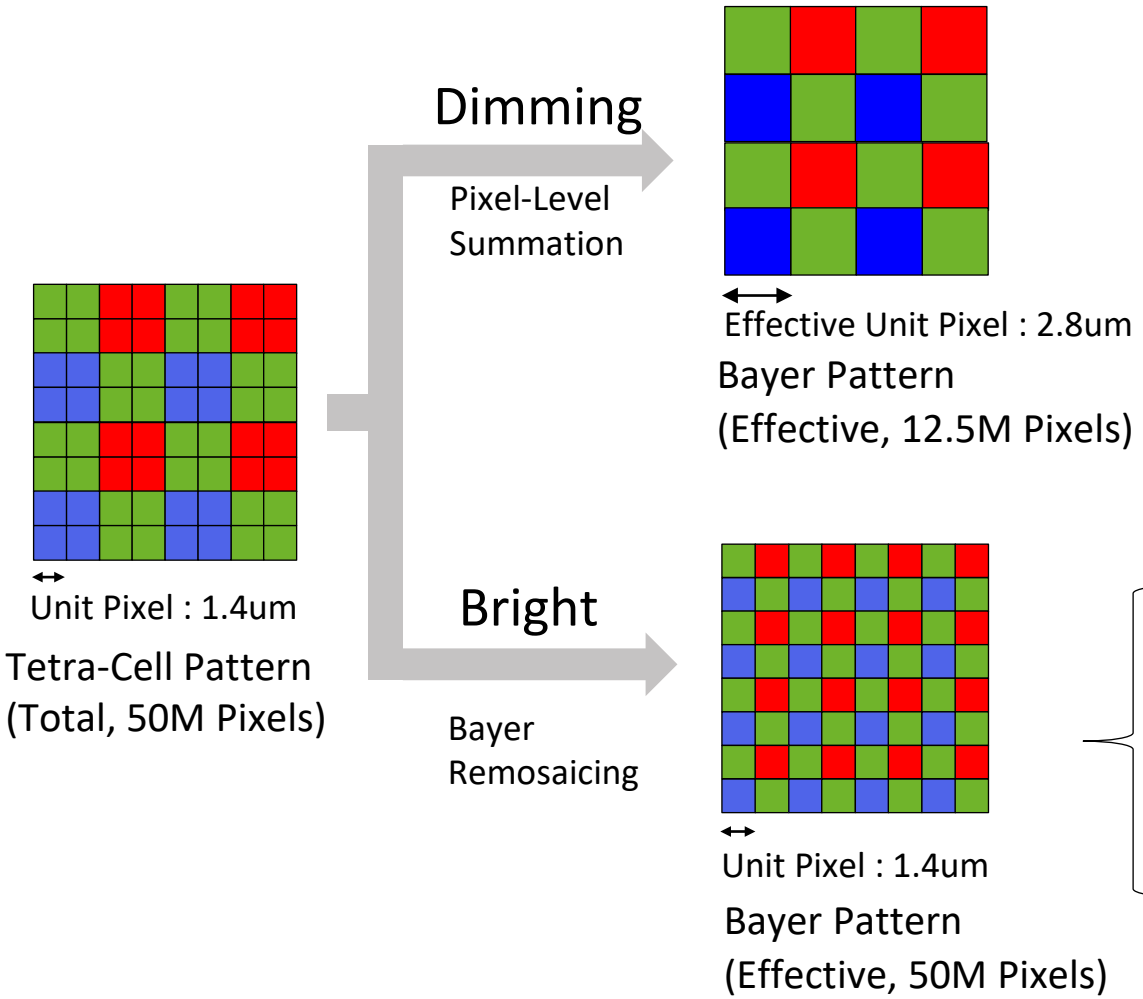




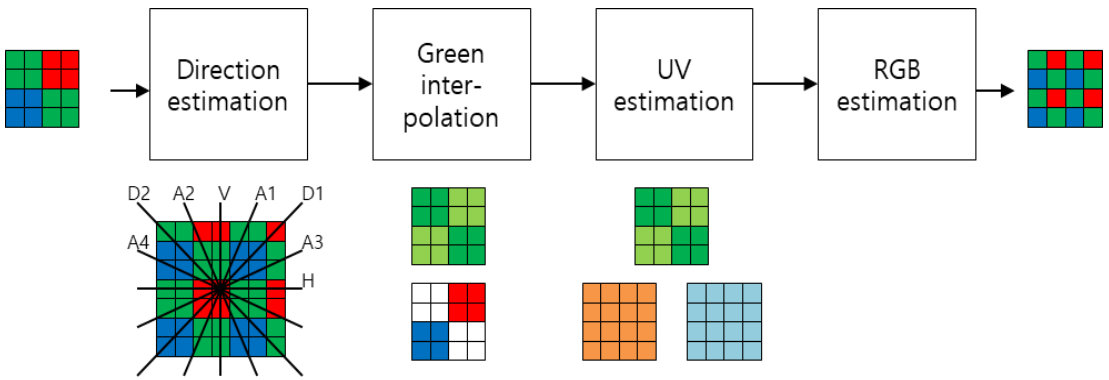
Bottom Chip : Analog + Logic

Adaptive Sensitivity Control with Tetra-Cell

- **Two Main Operation Modes**



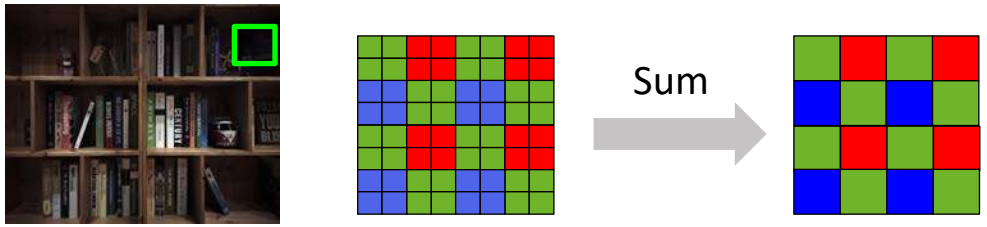
	Tetra-Cell (50M Pixels)	
Mode	Sum	Remosaic
Light Condition	Dimming	Bright
SNR	Ref. +6dB	Ref.
Resolution	12.5M Pixels 1/4	50M Pixels Full

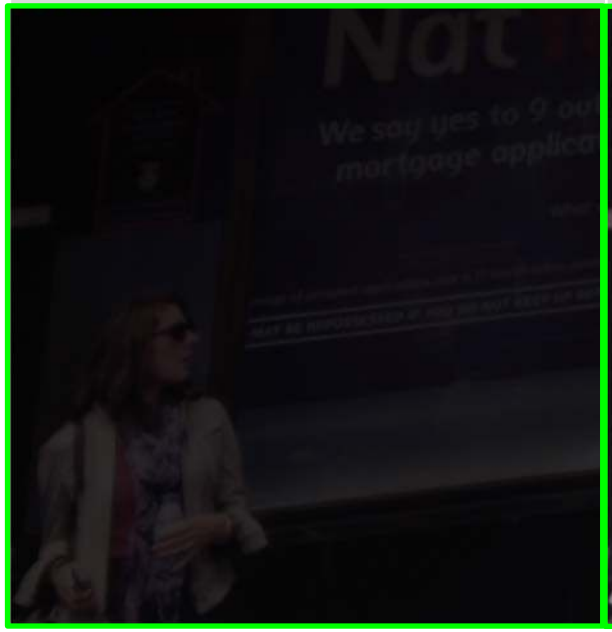


Tetra-to-Bayer Remosaicing algorithm

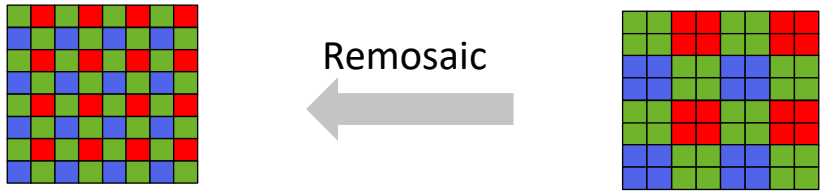
Tetra-Cell for vivid photos at any time

Higher SNR with summing image



Remosaic (50M)	4 Sum (12.5M)
	

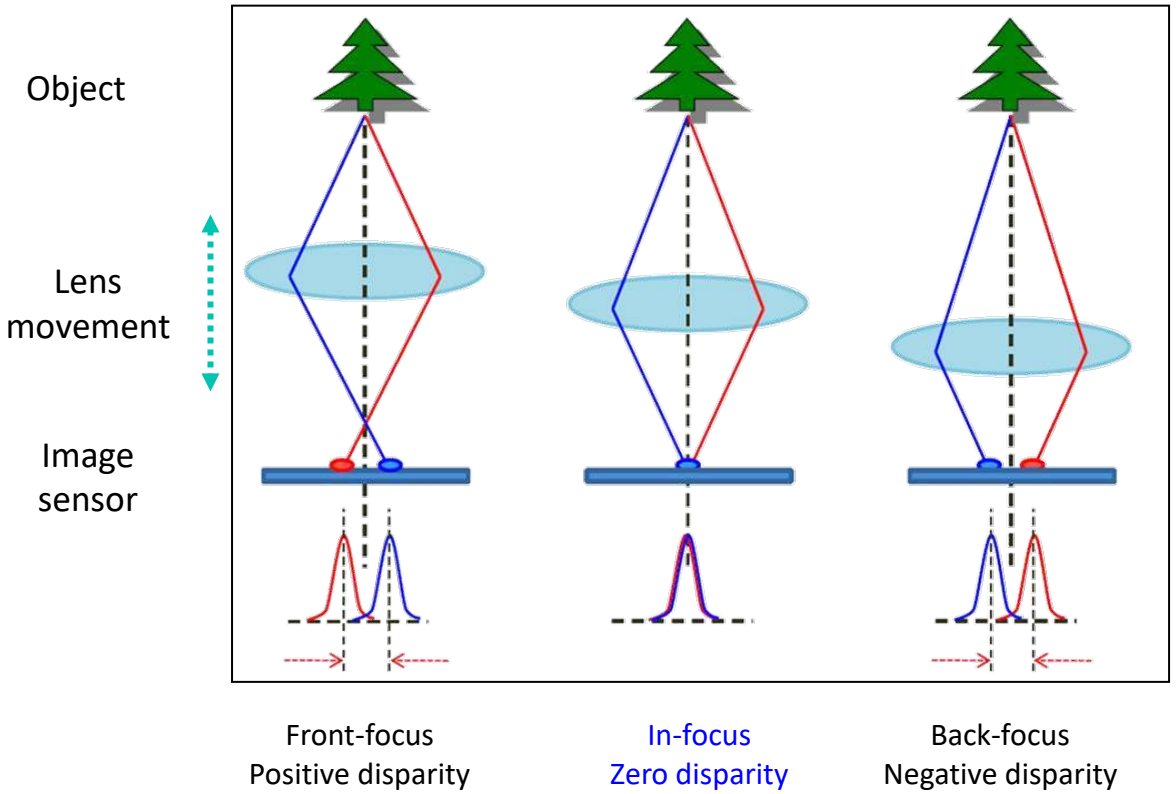
Better resolution with remosaic image

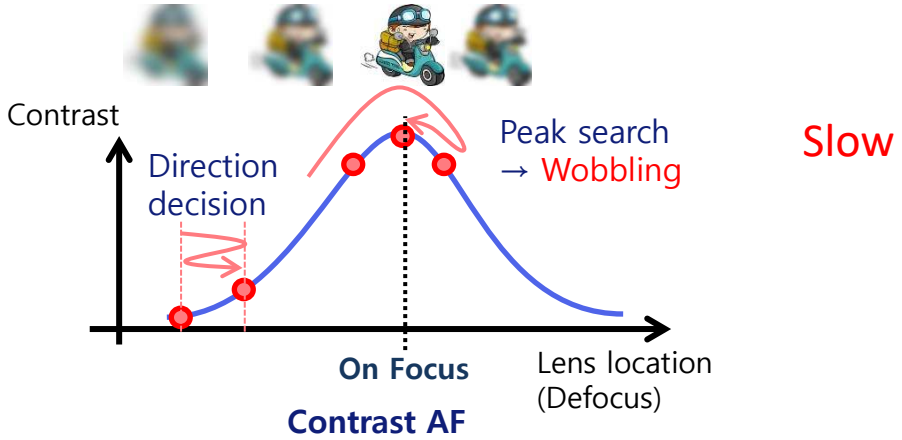


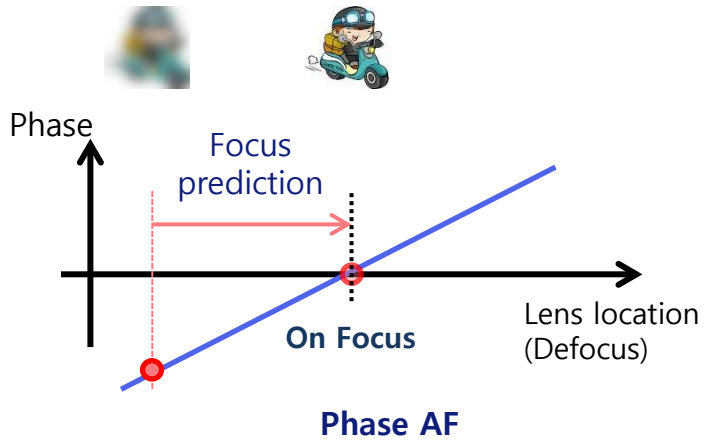
Remosaic (50M)	4 Sum (12.5M)
	

What is PDAF (Phase Detection Auto Focus) ?

- Provides better AF performance than “Contrast” AF





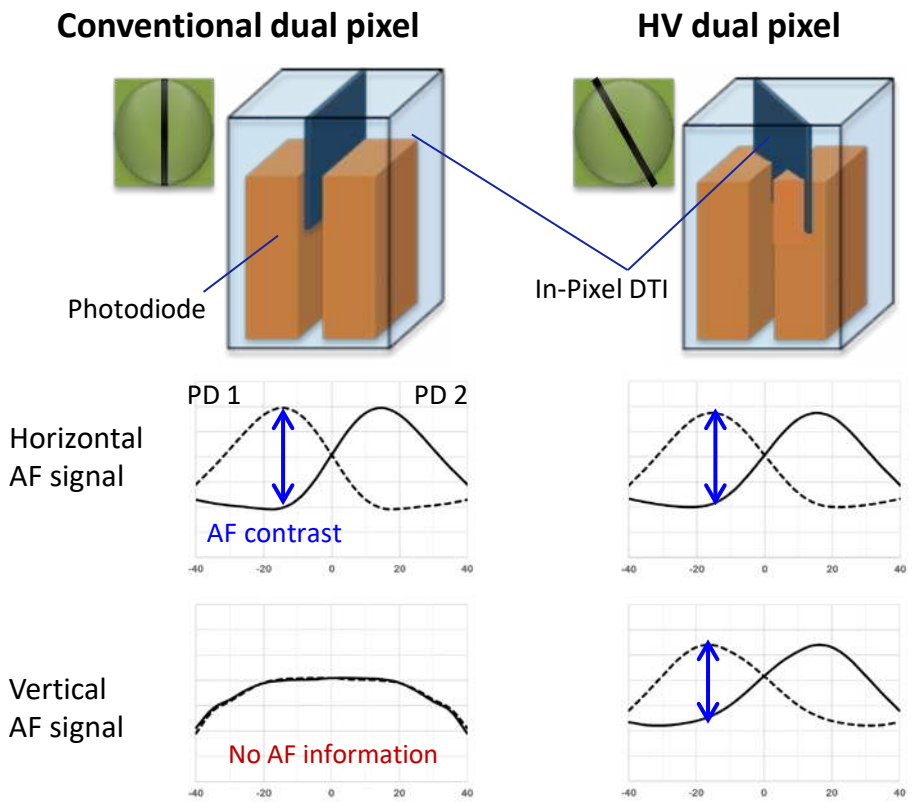


PDAF can predict the focus location with the single scene !

Pixel characteristics of Dual Pixel Pro

- HV dual pixel can provide all directional AF with good pixel performance.

Item	Unit	Conventional dual pixel	HV dual pixel
Full well capacity	e-	8,000	8,000
G-sensitivity	e-/lux.sec	7,000	**7,200**
Crosstalk	%	16.3	16.1
PRNU	%	0.8	0.8
AF contrast @H	-	4.5	3.6
AF contrast @V	-	-	**2.3**

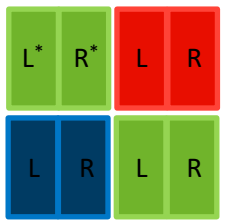


ISOCELL GN2 – Dual Pixel Pro

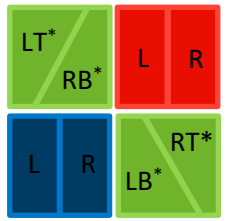
‘Dual Pixel Pro’ Gives Auto Focus of All Directions

- **Innovative Diagonal Pixel Divide**

  - Dual Pixel Pro adds Top/Bottom focusing capability to Dual Pixel’s already fast left/Right

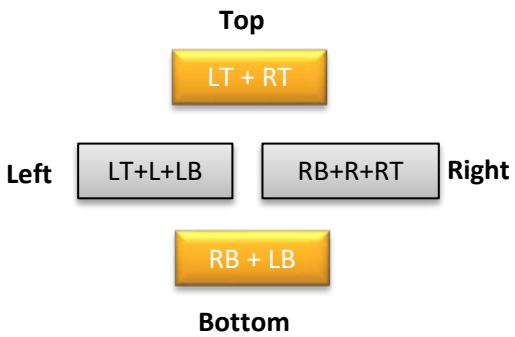


Dual Pixel
(Vertical Divide)



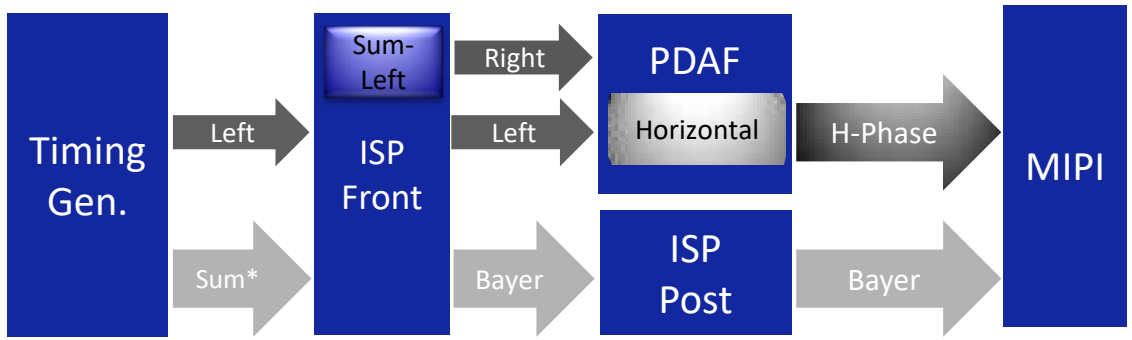
Dual Pixel Pro
(Vertical & Diagonal)

*L = Left pixel, R=Right pixel



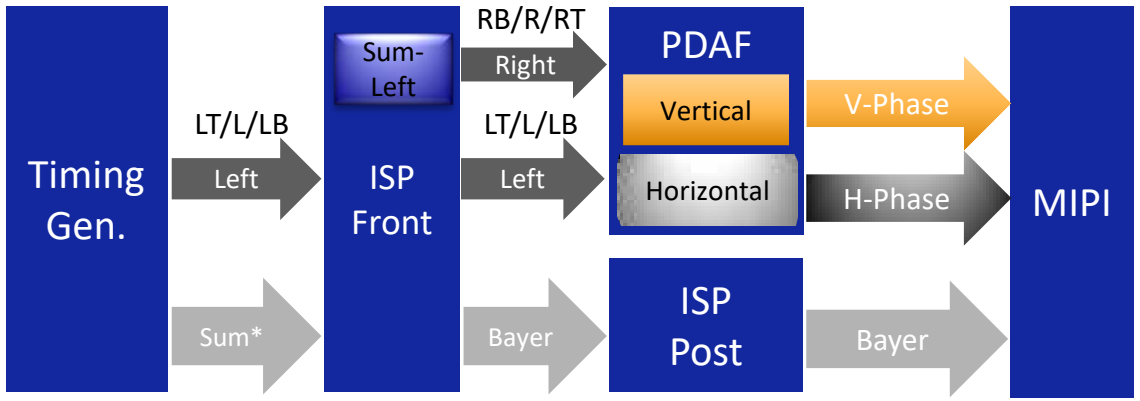
*LT = Left Top, RB = Right Bottom
LB = Left Bottom, RT = Right Top

- **Horizontal & Vertical Phase Difference Architecture**



*Sum= L+R

Conventional Dual Pixel Phase Generation



*Sum = LT+RB or L+R or LB+RT

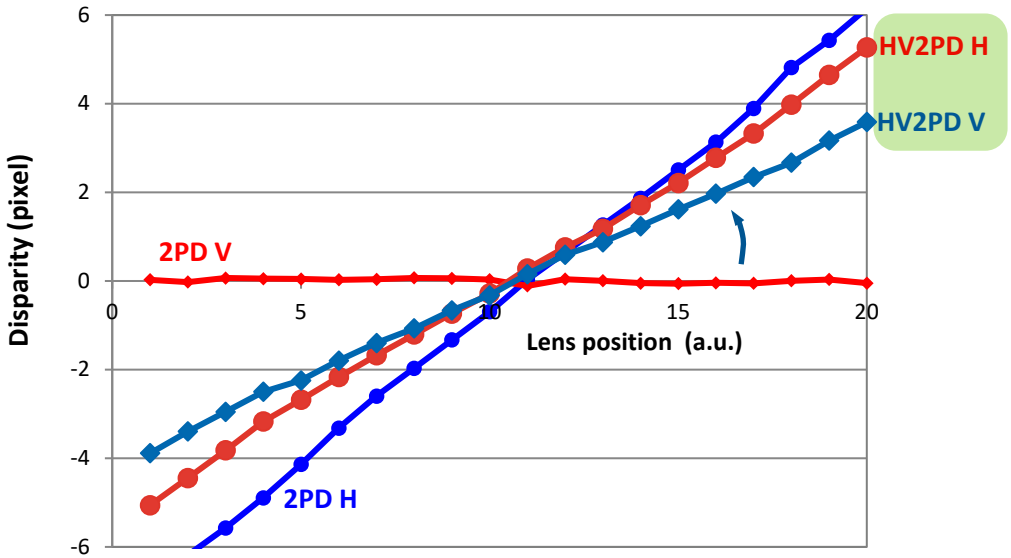
Dual Pixel Pro Phase Generation

ISOCELL GN2 – Dual Pixel Pro

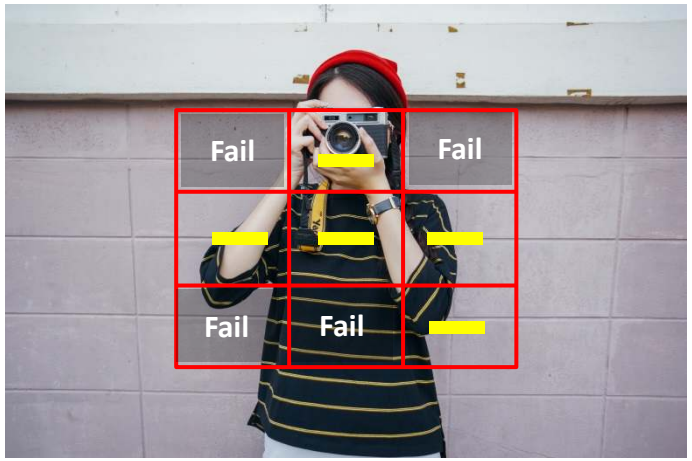
‘Dual Pixel Pro’ Gives Auto Focus of All Directions

- **Horizontal & Vertical Phase Difference AF data**
  - H & V direction AF information can be extracted from the combination of diagonal phase differences

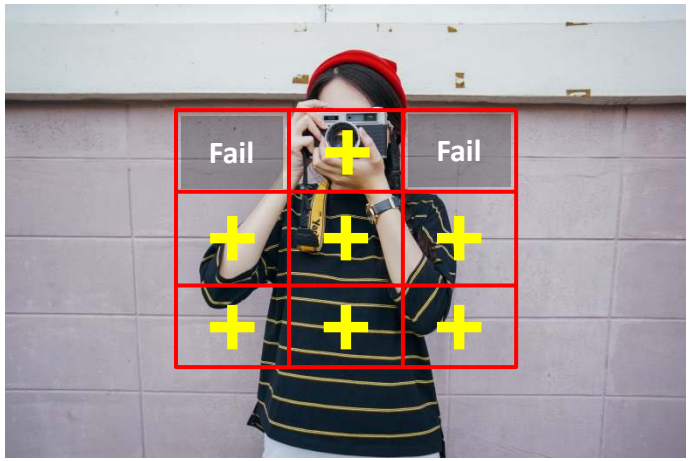
- **AF performance improvement**
  - It can make horizontal line focused



The phase difference characteristic



Auto focus with H only AF direction

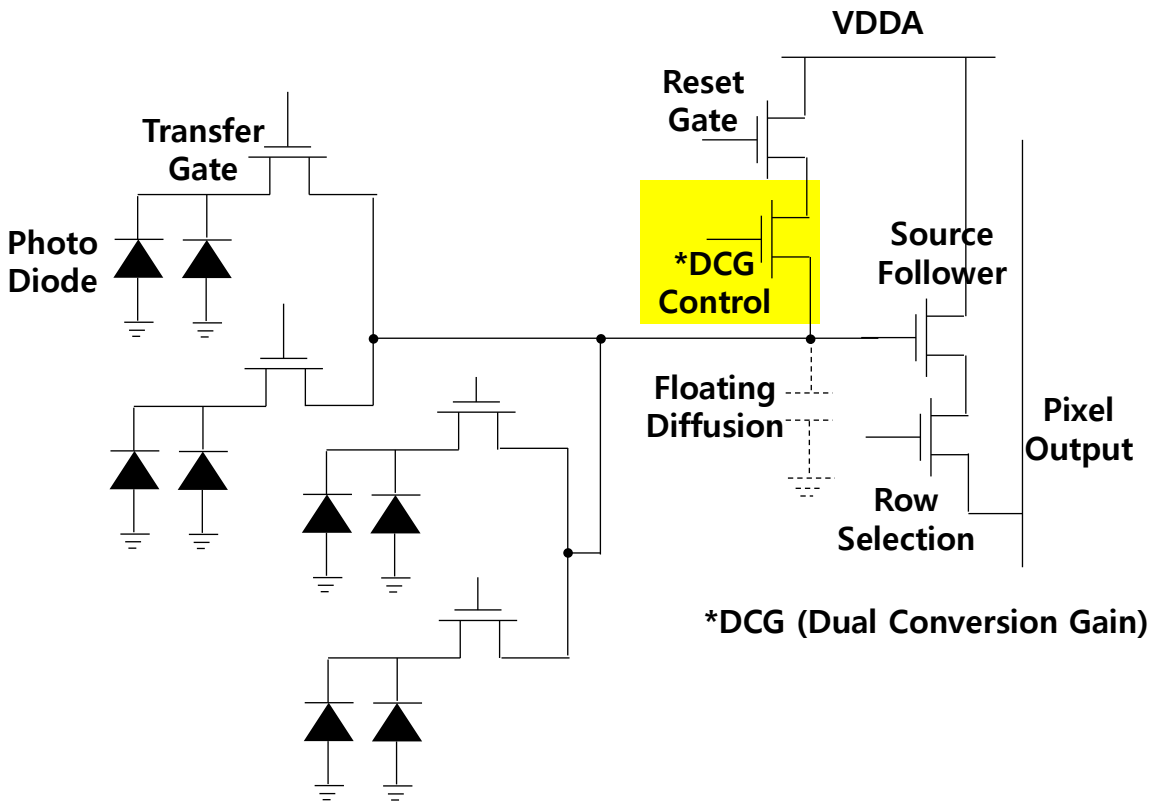


Auto focus with H/V AF direction

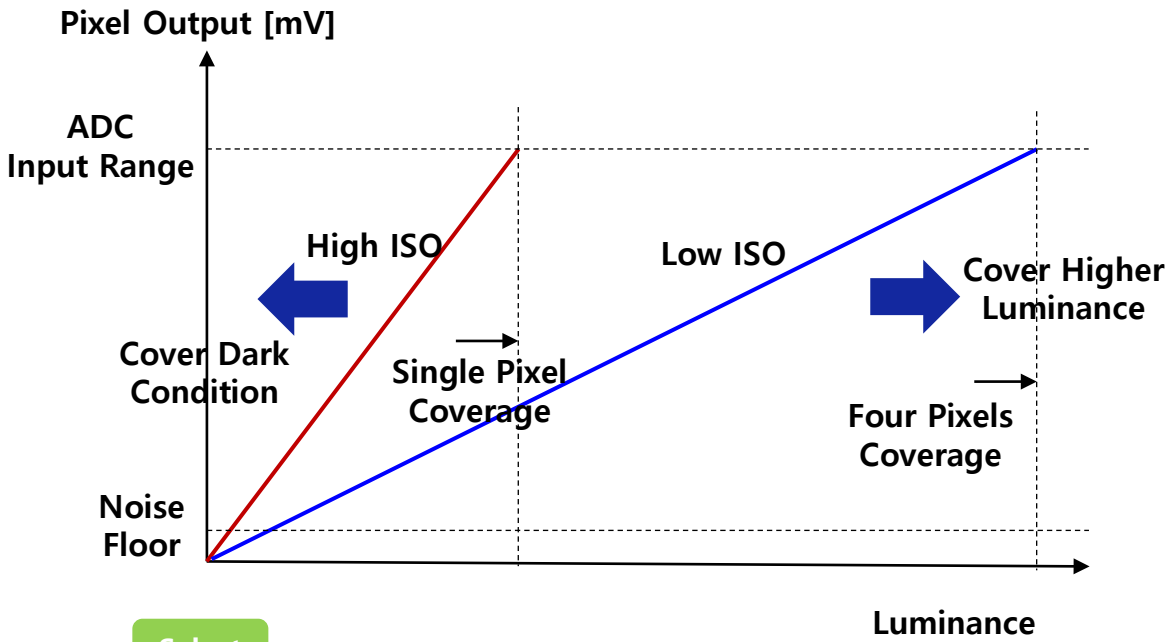
‘Smart ISO’ HDR Technology

- **Adaptive High or Low ISO Selection to Environment Luminance**

  - High ISO for Low Luminance Condition and Low ISO for High Luminance Condition by Controlling DCG Switch



*DCG (Dual Conversion Gain)



Select

	High ISO	Low ISO
Pros	Better noise level in low code	100% FWC available
Cons	25% *FWC available	Worse noise level in low code

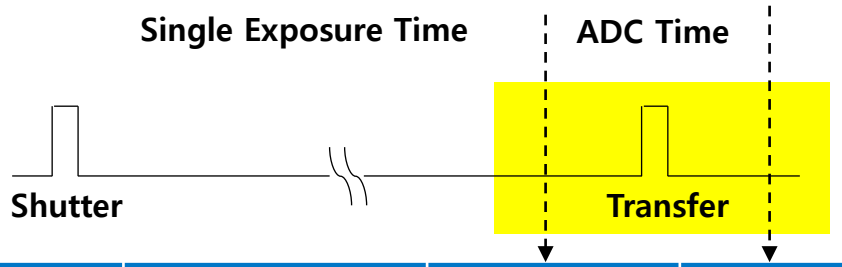
*FWC (Full Well Capacity)

ISOCELL GN2 – Smart ISO Pro

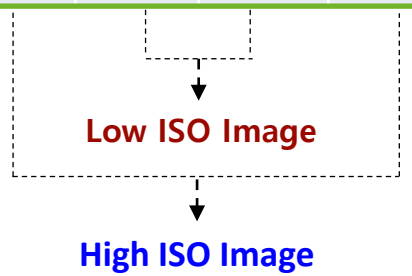
‘Smart ISO Pro’ HDR Technology

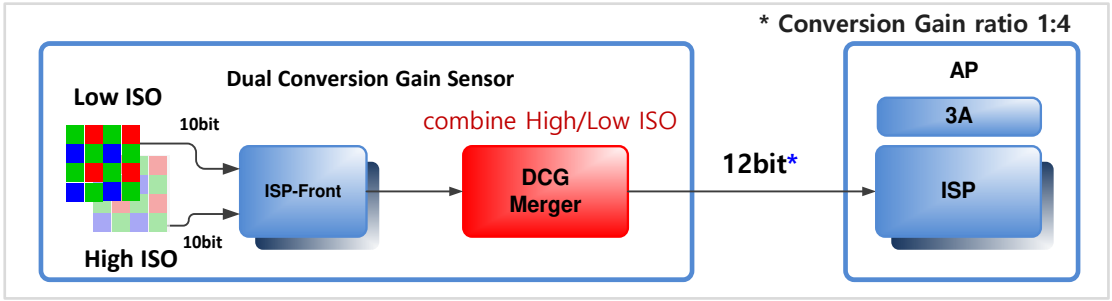
- **Double ADCs & Internal Merging with High and Low ISO images**

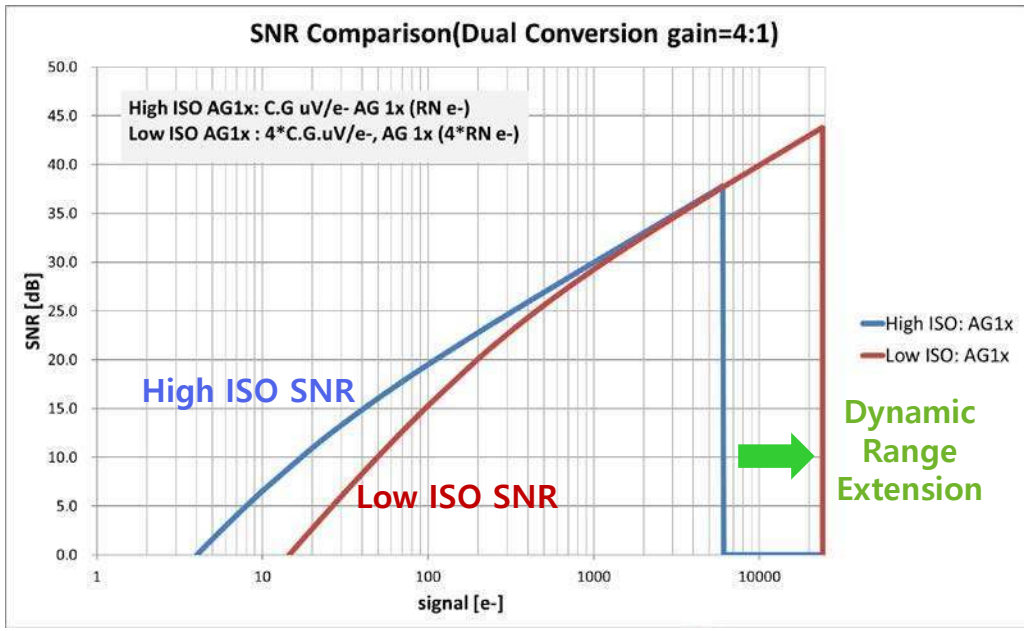
  - No motion artifact and no SNR Dip thanks to the single exposure



		Reset Sampling		Signal Sampling	
Conventional	Sampling	Single		Single	
	Conversion Gain	High		High	
Smart ISO Pro	Sampling	Double		Double	
	Conversion Gain	High	Low	Low	High





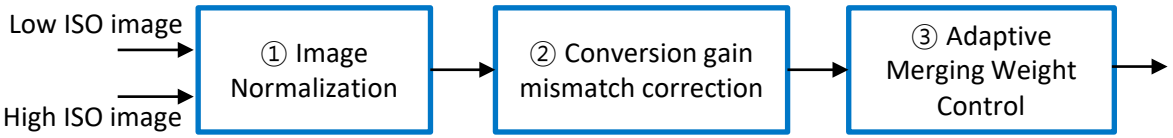


ISOCELL GN2 – Smart ISO Pro

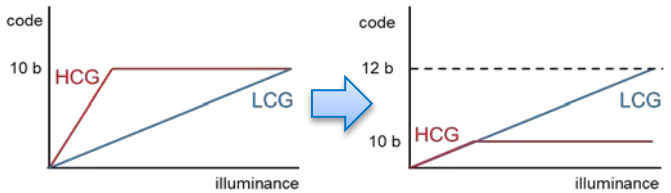
‘Smart ISO Pro’ Without Motion Artifact & SNR Dip

- In Sensor HDR Processing

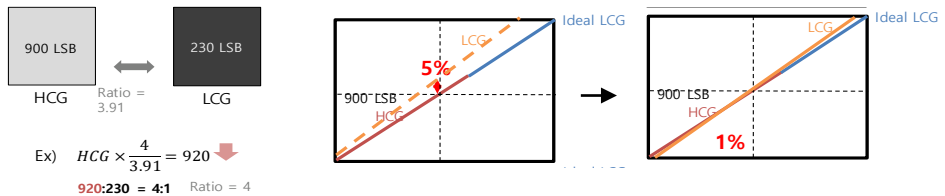
  - Embedded High ISO/Low ISO merger inside of the sensor



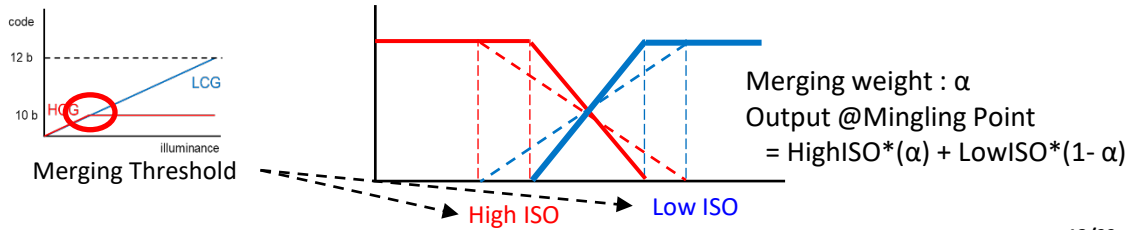
① High ISO/Low ISO Signal Normalization



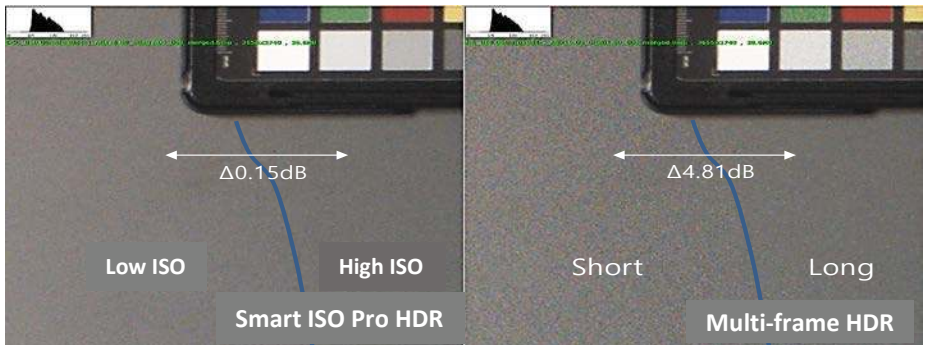
② Conversion Gain Mismatch Correction



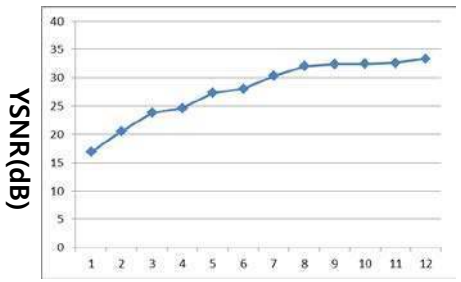
③ Adaptive Merging Weight Control

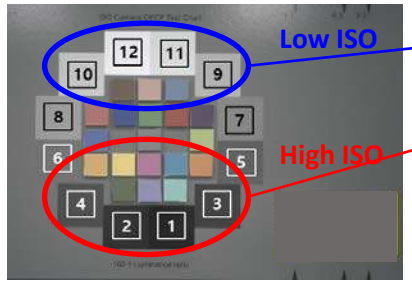


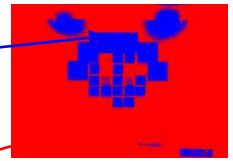
No motion artifact in Smart ISO Pro HDR



No SNR dip in Smart ISO Pro HDR





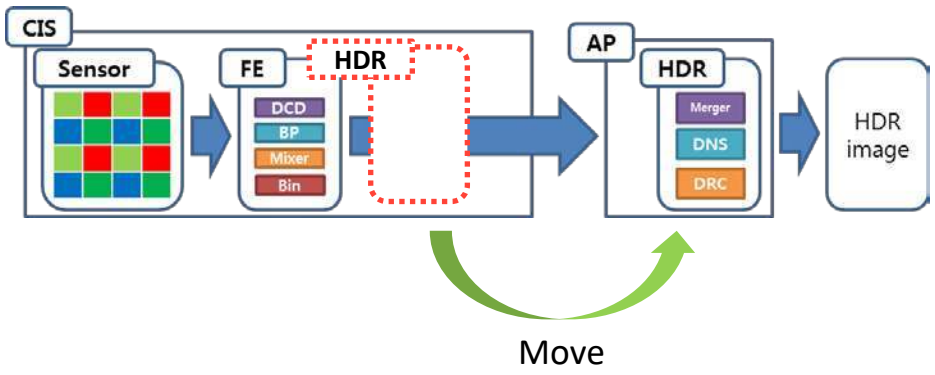


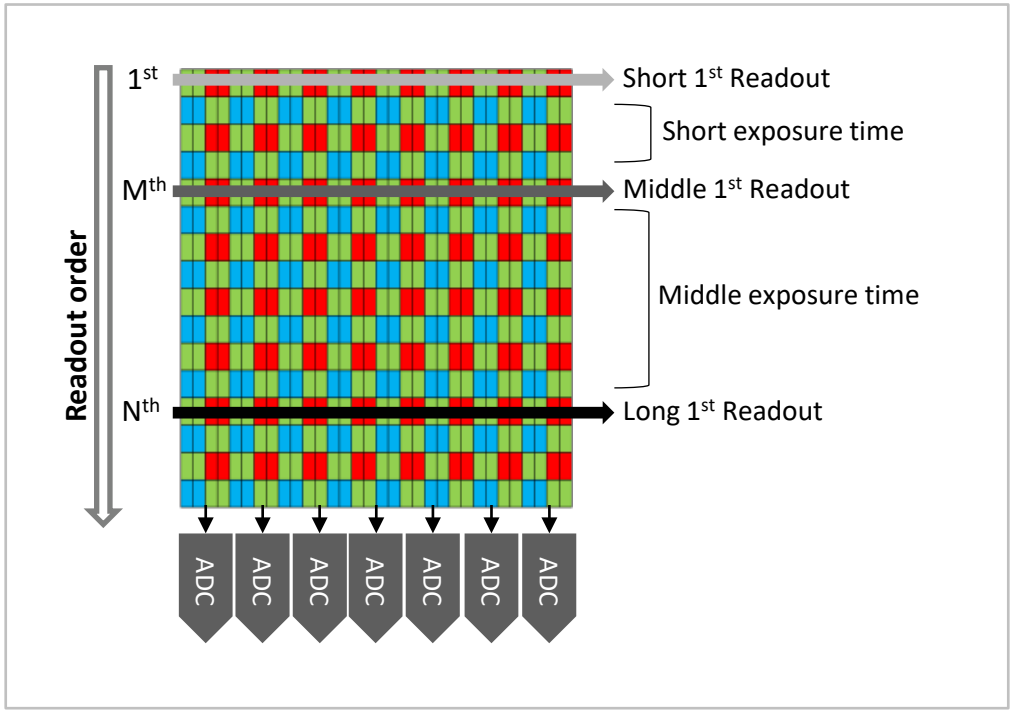
HDR merge map
(Red: High SO, Blue: Low ISO)

‘Staggered HDR’ Technology

A time-multiplexed HDR technology that uses rolling shutters over the same pixel arrays to capture multiple frames in short, middle, and long exposures

- Out of Sensor HDR Processing
- Cost-effective implementation
- Less motion blur
- High low-light image quality



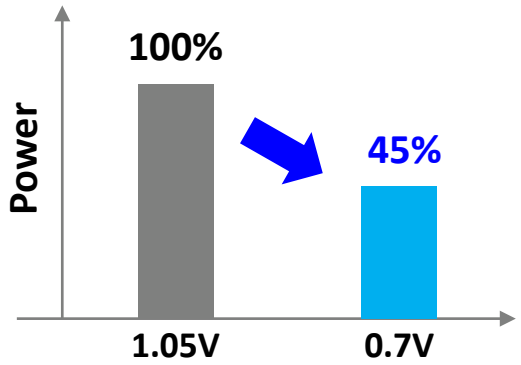


ISOCELL GN2 – Staggered HDR

Staggered HDR Key advantages

Low power & Cost effective

- Sensor 1.05V@28nm vs. AP 0.7V@AP

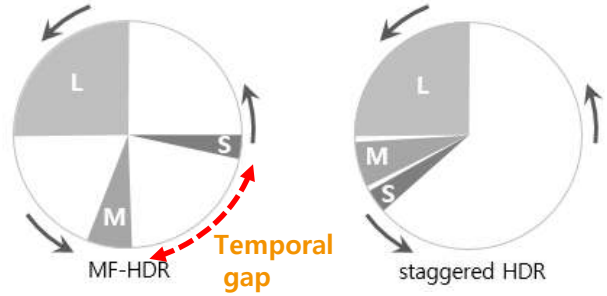


- Cost-effective HDR solution
  - Replace In-sensor HDR logic/SRAM with AP Merger and LPDDR memory

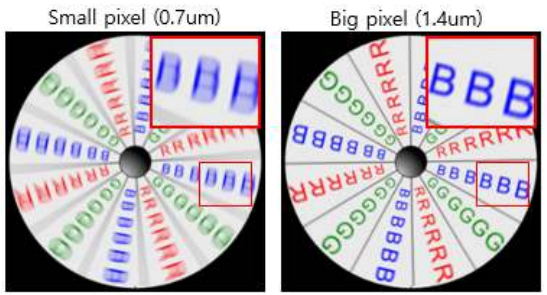
30fps @12.5Mp	Conventional	Staggered HDR
Area	100%	<101%

Less motion blur

- Reduce the time difference between adjacent frames



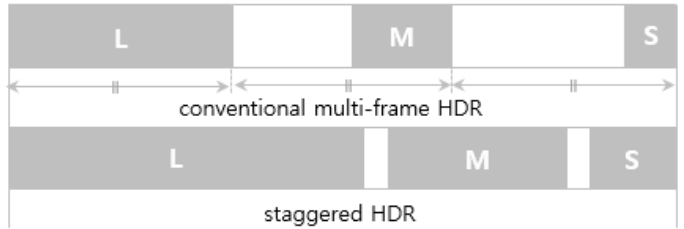
- The big pixels require shorter shutter time reducing motion blur

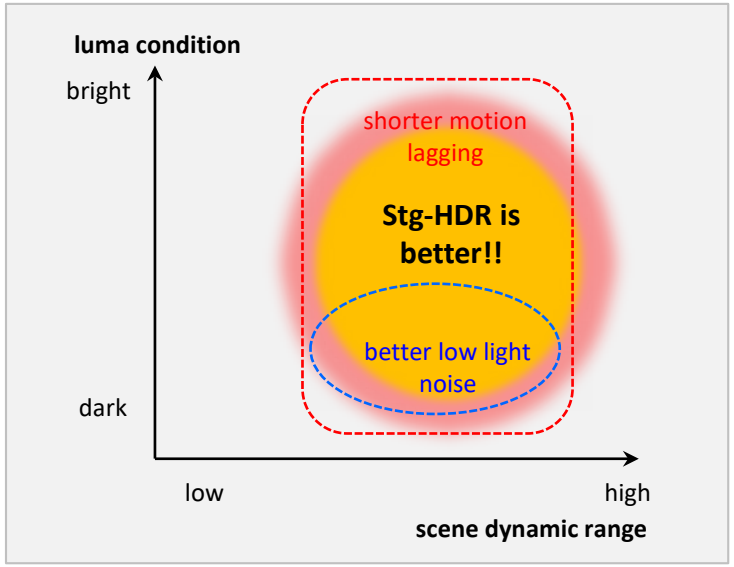


motion blur comparison
(100rpm, Tetra:8.3ms, staggered:2.0ms)

High image quality

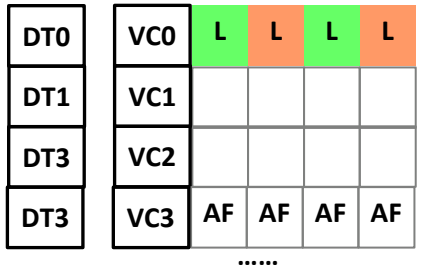
- Longer exposure time @ 30fps

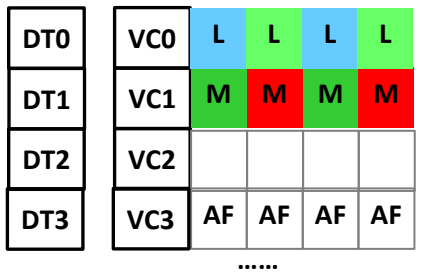


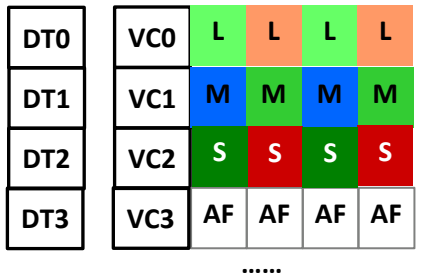


Staggered HDR output format

Each line is transferred to AP by using MIPI virtual channel or data type.





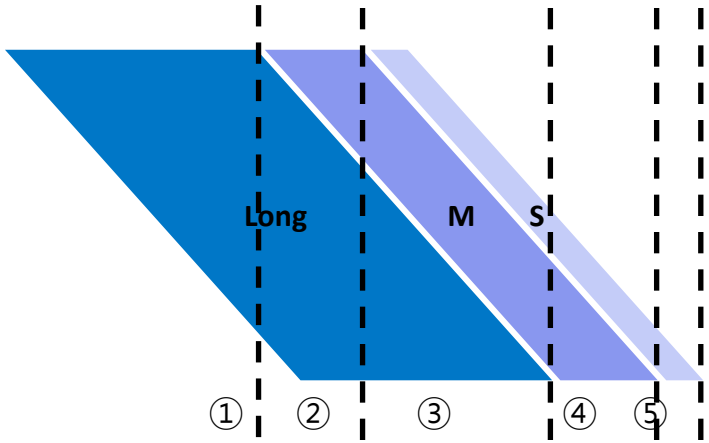


Notes)

① L/M/S, AF can be configured as independent DT's, VC's, or their combination

② AF can be outputted from one of L/M/S frame or all of them

③ AF data can be selected among L/M/S frames without stream-on/off



①	②	③	④	⑤
L only	L & M	L/ M/ S	M & S	S only

SAMSUNG

Low Analog Supply Voltage Scheme

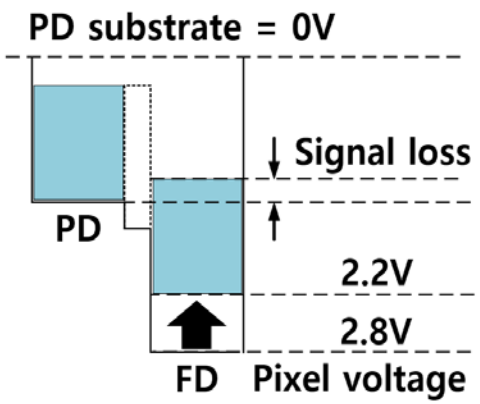
Sensor supply voltage

- The technology shrinkage has lowered the digital supply voltage by about 20 percent over the past decade, but the analog supply voltage has remained at 2.8V.

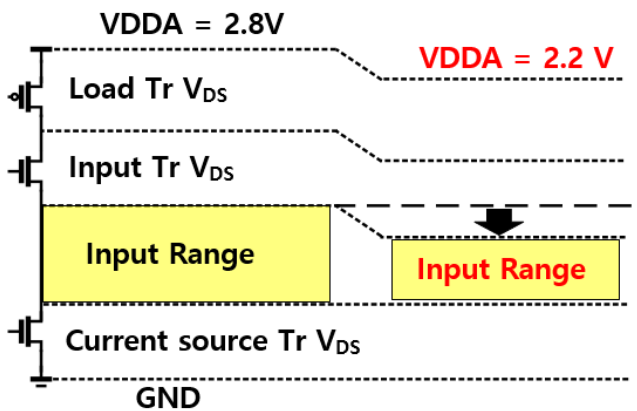
Limitations of low supply voltage

- Lower supply voltage degrades the signal transfer capability of pixels and limits the input range of ADC, resulting in signal loss and code clipping.

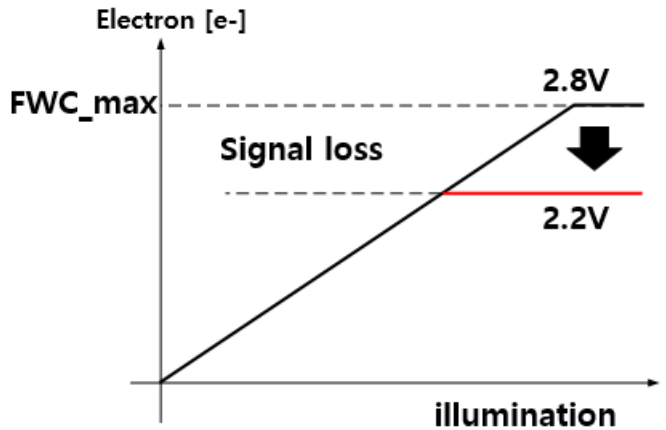
Pixel-side : signal loss



ADC-side : limitation of ADC input range



※ Required V_{DS} for saturation ∝ V_{th}



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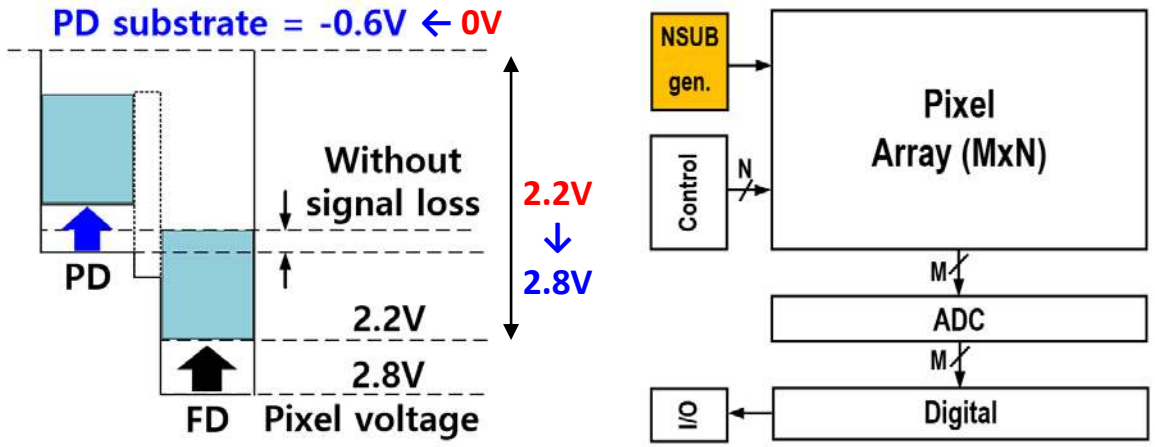
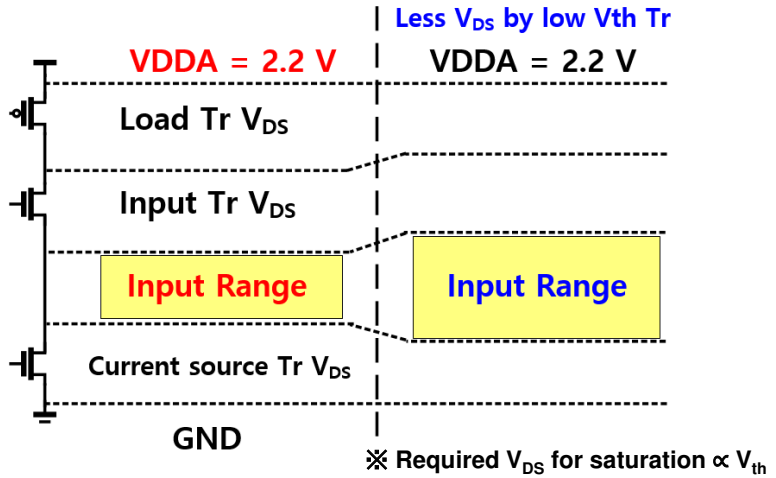
Low Analog Supply Voltage Scheme

Solutions

Pixel : Potential level shift using negative substrate voltage

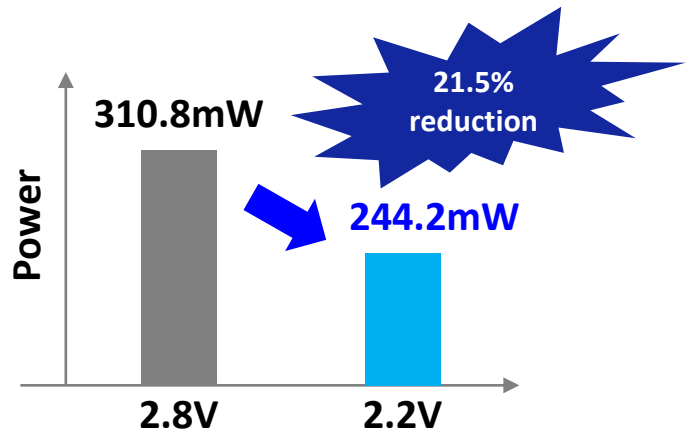


ADC : Development of low Vth transistor



Power Reduction

- Applying 2.2V analog power supply resulted in 21.5% power reduction



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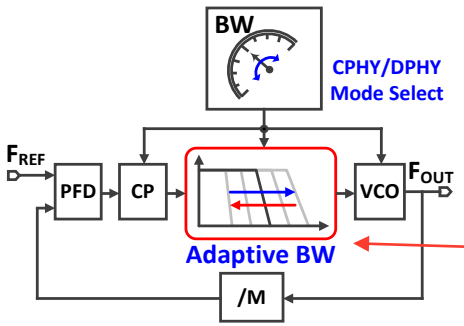
MIPI Combo (CPHY/DPHY) Structure

Sensor High Speed Interface

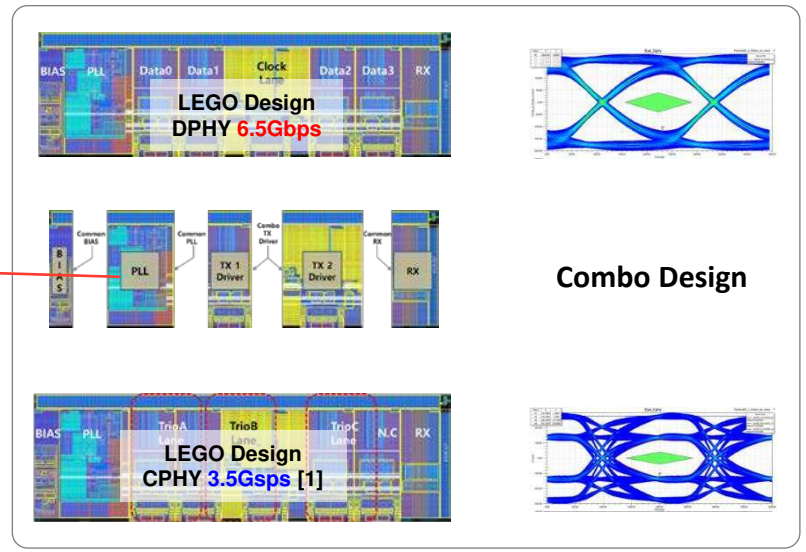
- The GN2 sensor implemented CPHY + DPHY interface to support all interfaces supported by the AP.

Solutions of Combo PHY

- The two interface IPs are implemented with Combo & LEGO concept



Interface mode can be simply selected according to the user's selection

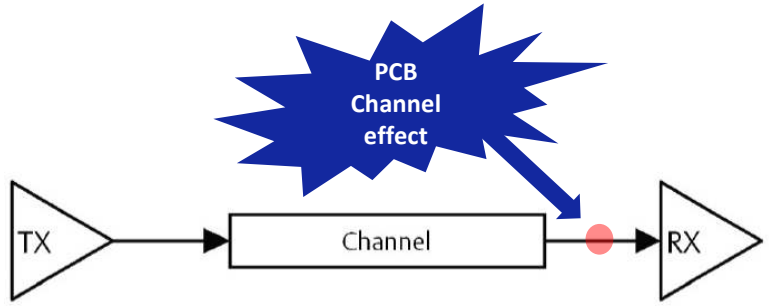


Adaptive BW PLL

Combo & LEGO structure

Test result

- All the measurement results of CPHY/DPHY interface output signal meet the specification (with channel model)



Equipment embedded Channel Model

Interface Mode	Channel Model embedding		
	Non – Channel	Short – Channel	Std - Channel
DPHY 6.5Gbps	Pass	Pass	Pass
CPHY 3.5Gsps	Pass	Pass	Pass

Improvement of driver characteristics to satisfy the performance of all MIPI's standard channels

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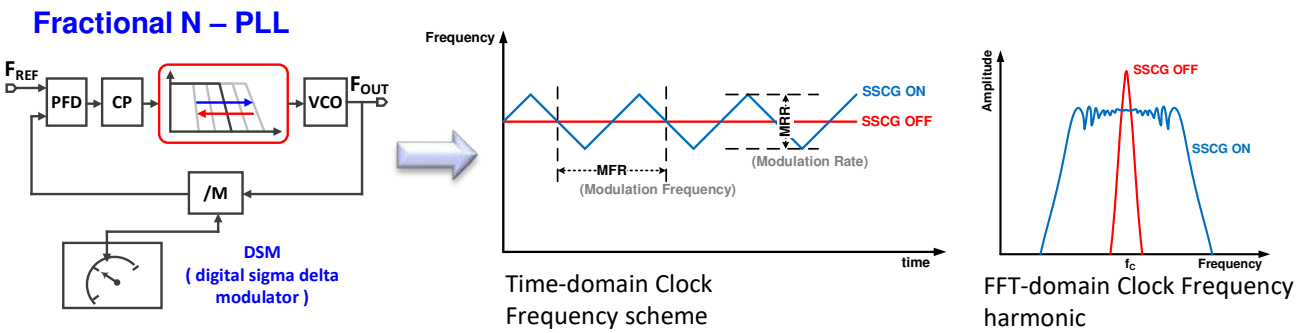
MIPI Special Functions for EMI Immunity

Proposal

EMI problems are getting serious in mobile products, and special features have been added to GN2 products for this purpose.

1st Spread Spectrum Clock Generation

SSCG is a method of suppression of EMI by PLL to shape its clock spectrum itself and reducing its peak.



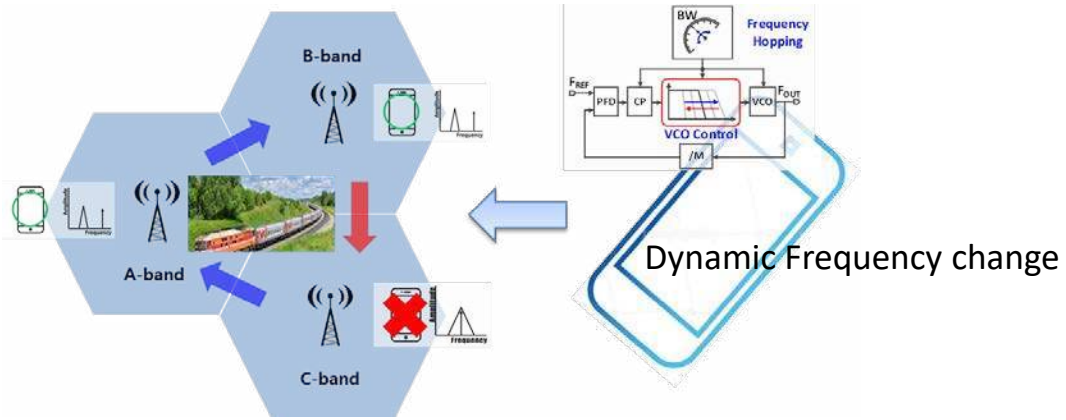
Time-domain Clock Frequency scheme

FFT-domain Clock Frequency harmonic

SSCG function can lower EMI peak tone by 10dB

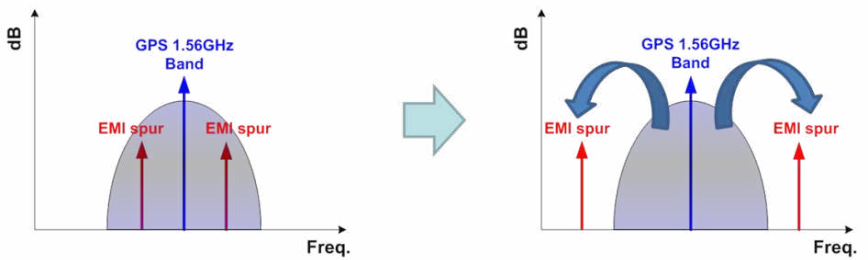
2nd Frequency Hopping without PLL reset

Frequency-hopping is a method of transmitting radio signals by rapidly switching a carrier among many frequency, using a PLL Divider sequence change with out IP's Reset signal.



Dynamic Frequency change

Example of the Frequency Hopping method



EMI Issue state

Frequency Hopping !!

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CONCLUSION REMARKS

The world largest mobile image sensor

The large Tetra-Cell pixel guarantees DSR-like image with higher SNR in the dark and better resolution in the bright

Dual Pixel Pro

All directional phase detection auto focus function can improve the AF performance

Smart ISO Pro

High dynamic range solution without no motion artifact and merging function in AP

Staggered HDR

Provide cost-effective high dynamic range image without the motion blue

The innovative low power scheme

Provide the lower analog power consumption on 2.2V supply voltage

Flexible high-speed interface

MIPI combo can provide the user flexibility with EMI immunity

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