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

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ISOCELL GN2 - Overview

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

Top Chip : APS

Bottom Chip : Analog and Logic Chip
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
ISOCELL GN2 - Stack Sensor

**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
ISOCELL GN2 – Tetra-Cell

Adaptive Sensitivity Control with Tetra-Cell

- Two Main Operation Modes

**Dimming**
- Pixel-Level Summation
- Effective Unit Pixel: 2.8μm
- Bayer Pattern (Effective, 12.5M Pixels)

**Bright**
- Bayer Remosaicing
- Unit Pixel: 1.4μm
- Bayer Pattern (Effective, 50M Pixels)

<table>
<thead>
<tr>
<th>Tetra-Cell (50M Pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Light Condition</td>
</tr>
<tr>
<td>SNR</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Tetra-to-Bayer Remosaicing algorithm
ISOCELL GN2 – Tetra-Cell

Tetra-Cell for vivid photos at any time

Higher SNR with summing image

Better resolution with remosaic image

<table>
<thead>
<tr>
<th>Remosaic (50M)</th>
<th>4 Sum (12.5M)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Remosaic Image" /></td>
<td><img src="image2" alt="4 Sum Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Remosaic (50M)</th>
<th>4 Sum (12.5M)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Remosaic Image" /></td>
<td><img src="image4" alt="4 Sum Image" /></td>
</tr>
</tbody>
</table>
ISOCELL GN2 – Auto Focus

What is PDAF (Phase Detection Auto Focus) ?

- Provides better AF performance than “Contrast” AF

PDAF can predict the focus location with the single scene!
ISOCELL GN2 – Dual Pixel Pro

Pixel characteristics of Dual Pixel Pro

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Conventional dual pixel</th>
<th>HV dual pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full well capacity</td>
<td>e-</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td>G-sensitivity</td>
<td>e-/lux.sec</td>
<td>7,000</td>
<td>7,200</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>%</td>
<td>16.3</td>
<td>16.1</td>
</tr>
<tr>
<td>PRNU</td>
<td>%</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>AF contrast @H</td>
<td>-</td>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>AF contrast @V</td>
<td>-</td>
<td>-</td>
<td>2.3</td>
</tr>
</tbody>
</table>
‘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

- **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

*L* = Left pixel, *R* = Right pixel
*LT* = Left Top, *RB* = Right Bottom
*LB* = Left Bottom, *RT* = Right Top
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
ISOCELL GN2 – Smart ISO

‘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

<table>
<thead>
<tr>
<th>Luminance</th>
<th>Pixel Output [mV]</th>
<th>ADC Input Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Luminance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Luminance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th></th>
<th>Reset Sampling</th>
<th>Signal Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>Conversion Gain</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Smart ISO Pro</td>
<td>Double</td>
<td>Double</td>
</tr>
<tr>
<td>Conversion Gain</td>
<td>High, Low</td>
<td>Low, High</td>
</tr>
</tbody>
</table>

* Conversion Gain ratio 1:4

![SNR Comparison Diagram](image)

- High ISO SNR
- Low ISO SNR

Dynamic Range Extension

- High ISO AG1x: C.G xV/e, AG 1x (RN e)
- Low ISO AG1x: 4*C.G xV/e, AG 1x (4* RN e)
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

  ![Diagram](image)

  **① High ISO/Low ISO Signal Normalization**

  ![Diagram](image)

  **② Conversion Gain Mismatch Correction**

  ![Diagram](image)

  **③ Adaptive Merging Weight Control**

  ![Diagram](image)

  **Merging weight :**

  \[ \text{Output @ Mingling Point} = \text{HighISO} \times (\alpha) + \text{LowISO} \times (1 - \alpha) \]

  **Merging Threshold**

  ![Diagram](image)

  **YSNR(dB)**

  ![Diagram](image)

  **No motion artifact in Smart ISO Pro HDR**

  ![Image](image)

  **No SNR dip in Smart ISO Pro HDR**

  ![Image](image)

  **Smart ISO Pro HDR**

  ![Image](image)

  **Multi-frame HDR**

  ![Image](image)

  **Patch#**

  ![Image](image)

  **HDR merge map**

  (Red: High ISO, Blue: Low ISO)
ISOCELL GN2 – Staggered HDR

‘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

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[Diagram of the Staggered HDR Technology]

- Short 1\textsuperscript{st} Readout
- Long 1\textsuperscript{st} Readout
- Middle 1\textsuperscript{st} Readout

Move
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

**Less motion blur**
- Reduce the time difference between adjacent frames
- The big pixels require shorter shutter time reducing motion blur

**High image quality**
- Longer exposure time @ 30fps

<table>
<thead>
<tr>
<th>30fps @12.5Mp</th>
<th>Conventional</th>
<th>Staggered HDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>100%</td>
<td>&lt;101%</td>
</tr>
</tbody>
</table>

![Power Comparison](image)

![Motion Blur Comparison](image)
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
ISOCELL GN2 – Low Power

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**
- PD substrate = 0V
- PD
- FD
- Pixel voltage
- Signal loss
- 2.2V
- 2.8V

**ADC-side : limitation of ADC input range**
- VDDA = 2.8V
- Load Tr V_DS
- Input Tr V_DS
- Current source Tr V_DS
- GND
- Input Range
- Input Range

※ Required V_DS for saturation ∝ V_th
Low Analog Supply Voltage Scheme

Solutions

**Pixel** : Potential level shift using negative substrate voltage

![Diagram of Pixel Voltage and Potential Level Shift](image)

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

**ADC** : Development of low Vth transistor

![Diagram of ADC and Power Reduction](image)

- Required $V_{DS}$ for saturation $\propto V_{th}$

Power Reduction

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

![Power Reduction Graph](image)
ISOCELL GN2 – High Speed Interface

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

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

![Diagram showing MIPI Combo (CPHY/DPHY) Structure with sensor high speed interface, solutions of combo PHY, and test result.](image-url)

**Adaptive BW PLL**

**Combo & LEGO structure**

**Equipment embedded Channel Model**

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

**Improvement of driver characteristics to satisfy the performance of all MIPI’s standard channels**
**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.

**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.

**SSCG function can lower EMI peak tone by 10dB**

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**Example of the Frequency Hopping method**

Dynamic Frequency change

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EMI Issue state

Frequency Hopping !!
ISOCELL GN2 – Summary

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.