Solid State Division

Selection Guide
Aug. 2010

# FLAT PANEL SENSORS

Digital X-ray image sensors developed as key devices
for real-time X-ray imaging applications requiring high sensitivity and high image quality

HAMAMATSU

# Contents



# HAMAMATSU Flat Panel Sensor

HAMAMATSU has been a leading supplier of opto-semiconductor sensors of diverse types and categories including sensors for high energy physics, UV sensors, visible light sensors, infrared sensors, position sensors, and linear or image sensors since 1957. Over the last 20 years, intense research and development have been made into various techniques for capturing X-ray images with solid state image sensors and some remarkable results have been achieved. Besides being ideal for digital imaging, solid state image sensors are expected to replace conventional image acquisition methods based on ortho film or imaging tubes. After years of laboratory development, HAMAMATSU has deemed digital X-ray imaging is ready. A unique flat panel sensor based on the single crystal CMOS technologies was developed in 1987. Then a prototype of CMOS flat panel sensor was fabricated in 1993. This sensor had a large pixel size and still retained an analog interface, but it was a milestone in the digital radiography field. The dedicated world's first monolithic CMOS flat panel sensor with 12 cm photodiode array area was developed in 1999.
The latest line-up of flat panel sensor still inherits the advantages of single crystal Si yet has expanded analog and digital performances achieved through CMOS technology and outstanding scintillator.

## Line-up of Flat Panel Sensors

| Application | | Type No. | Scan mode | A/D (bits) | Pixel size (μm) | Photodiode area [(H) · (V) mm] | Frame rate *1 (frames/s) | Scintillator | Energy range | Top cover material (thickness) | CE marking *2 | Page No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radiology | Rotational radiography | C10900D | Fast | 13 | 200 | 124.8 · 124.8 | 35 | Direct deposition CsI | 20 kVp to 90 kVp | – | – | 3 |
| | | | Partial | | | | 70 | | | | | |
| | | | Fine | 12 | 100 | | 17 | | | | | |
| | | | Panoramic | | | | 280 | | | | | |
| | | C9252DK-14 | Whole | 13 | 200 | 249.6 · 124.8 | 30 | | | Carbon fiber (1.0 mm) | – | 5 |
| | | | Partial | 12 | 100 | | 146 | | | | | |
| | Biochemistry | C7942CK-22 | – | 12 | 50 | 120 · 120 | 2 | CsI FSP | 20 kVp to 80 kVp | Carbon fiber (1.0 mm) | ○ | 7 |
| | | C9730DK-10 | – | 14 | | 52.8 · 52.8 | 4 | Direct deposition CsI | 17 keV (Mo source) | | | |
| | | C9732DK-11 | – | | | 120 · 120 | 1 | | | | | |
| | Diffraction | C9728DK-10 | – | 14 | 50 | 52.8 · 52.8 | 3 | Direct deposition CsI | 18 keV Max. | Carbon fiber (1.0 mm) | ○ | 9 |
| | | C10158DK | Whole | 14 | 50 | 118.8 · 118.8 | 3 | | | | – | |
| | | | Partial | | | | 12 | | | | | |
| Non-destructive inspection (offline) *3 | General X-ray | C7921CA-29 | – | 12 | 50 | 52.8 · 52.8 | 4 | CsI FSP | 20 kVp to 100 kVp | Aluminum (1.0 mm) | ○ | 11 |
| | | C7942CA-22 | – | | | 120 · 120 | 2 | | | | | |
| | | C7943CA-22 | – | | 100 | 124.8 · 124.8 | 7 | | | | | |
| | High tube voltage | C7942SK-25 | – | 12 | 50 | 120 · 120 | 2 | GOS-deposited FOP | 20 kVp to 150 kVp | Carbon fiber (1.0 mm) | ○ | 13 |
| | | C9312SK-06 | – | | | 124.8 · 115.2 | 8 | | 20 kVp to 110 kVp | | | |

*1: Single operation
*2: Types marked with a circle (○) conform to the European EMC directives: EN61326-1 Class A.
*3: Not recommended for use in inline applications where large radiation damage may occur.

Note:
Please consult us for other energy ranges not listed above.
The HAMAMATSU flat panel sensor has not been legally approved for medical applications. This means that the flat panel sensor alone cannot be used as medical equipment. When incorporating the flat panel sensor in systems for medical applications, be sure to obtain any required legal approvals.

# 1. X-ray Image Sensor Technology

## 1-1. CMOS Process Technology

HAMAMATSU develops and manufactures unique flat panel sensors with large area, low noise and high resolution for X-ray imaging field.
The latest Si process line realizes the world largest monolithic CMOS chip where optimized high performance electronics are obtained. HAMAMATSU can provide high-quality X-ray images for various X-ray imaging applications.

## 1-2. Scintillator Technology

HAMAMATSU has succeeded in developing an optimal and high-sensitivity X-ray device ideal for indirect X-ray detection. A CsI:Tl crystal plate with needle structure mounted on the largest formatted photodiode array allows the scintillation to propagate through the fiber-like-crystals. This structure offers advantages in light propagation over other scintillators of compound. Scintillator thickness has been optimized according to the application.

## 1-3. Assembly Technology

Assembling and packaging of flat panel sensor is of critical importance. It is considerably more challenging than for integrated circuits since flat panel sensors must interact with X-ray irradiation and other harsh environments in higher reliability. The latest robotics techniques were utilized to attain precision alignment, higher reliability assembling and stable quality in large size active area ranging from 5 · 5 cm to 12 · 24 cm.

Figure 1: Wire bonding

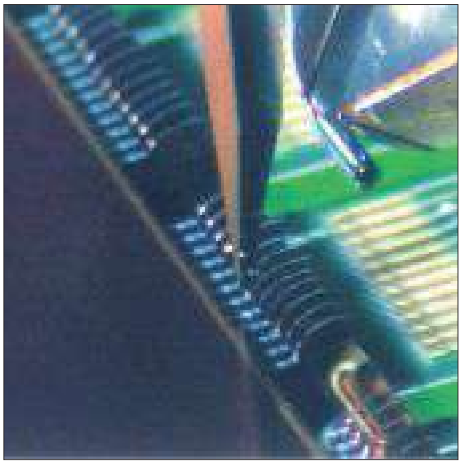
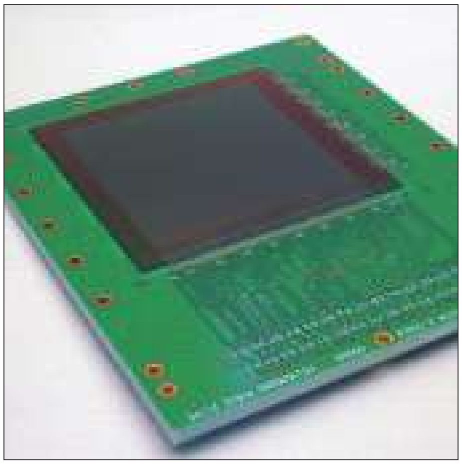


Figure 2: Sensor board assembly



## 1-4. IC Design Technology

In recent years, large formatted CMOS solid state image sensors of monocrystalline material have become available. These offer many options compared to amorphous Si and conventional imaging devices. We have developed many types of flat panel sensors that show the tremendous potential offered by large size image sensor devices made in a 0.6 μm standard CMOS process. These devices have an anti-blooming (overflow drain), a correlated double sampling (CDS) circuit, external frame start and binning functions.

Figure 3: CAD image of circuit design

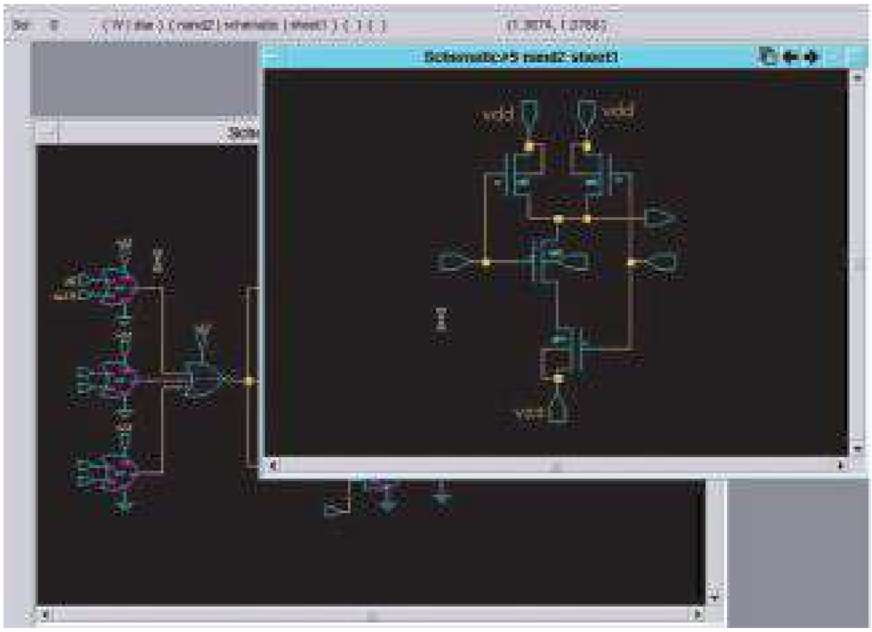
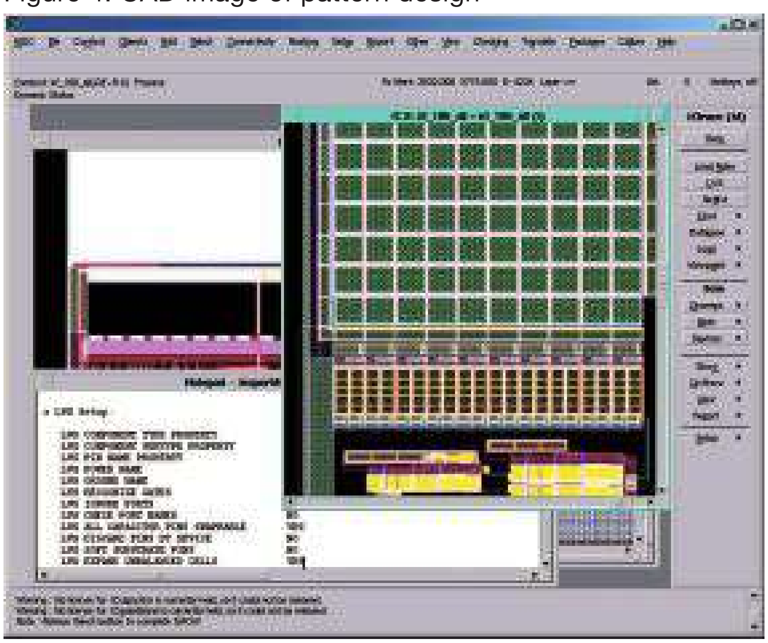


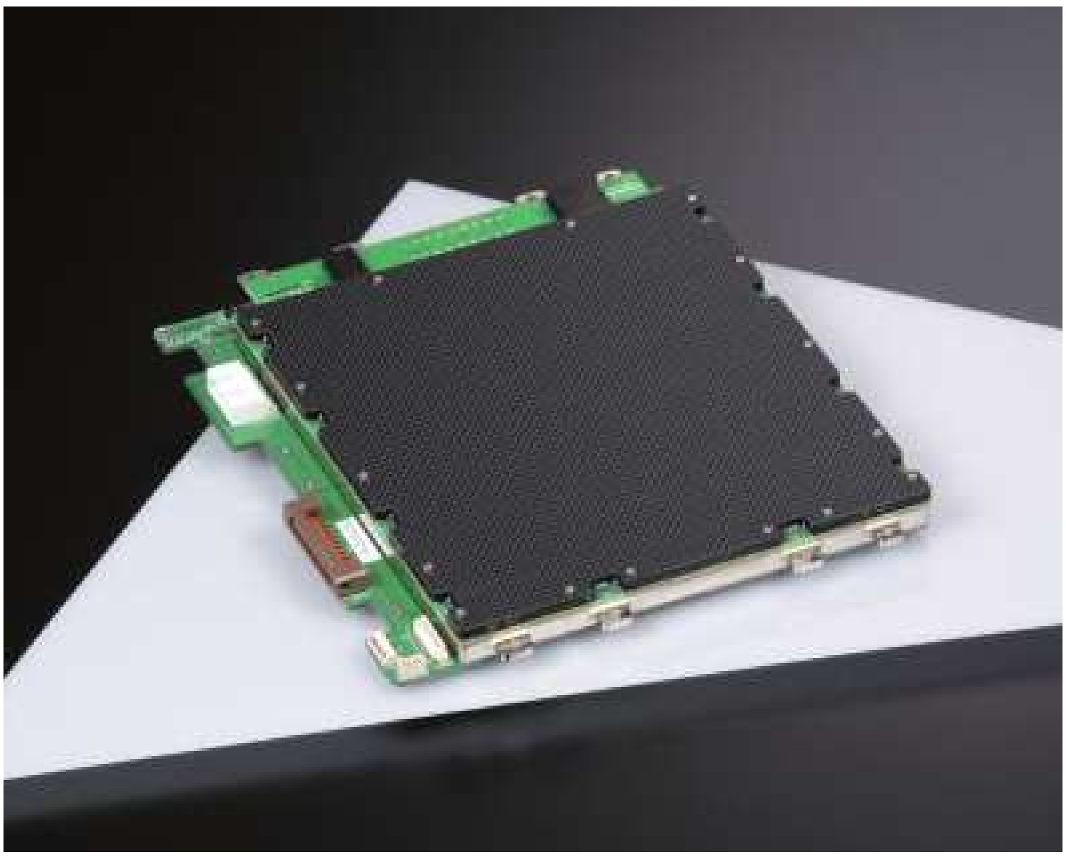

Figure 4: CAD image of pattern design



# Rotational radiography

## 2-1. Radiology

The C10900D was developed for CT and panoramic imaging. It operates in 4 selectable scan modes to capture X-ray images: "Fast mode" and "Partial mode" with a pixel size of 200 · 200 μm, and “Fine mode” and "Panoramic mode" with a pixel size of 100 · 100 μm.



### Features

- Four selectable scan mode
- High sensitivity
- High-speed frame rate: 280 frames/s (panoramic mode)
- Flat panel structure without image distortion
- Scintillator: direct deposition CsI
- For assembly into equipment: supplied without case

### Applications

- Cone beam CT, etc.
- Digital radiography, etc.

(Ta=25 ˚C, Typ. unless otherwise noted)

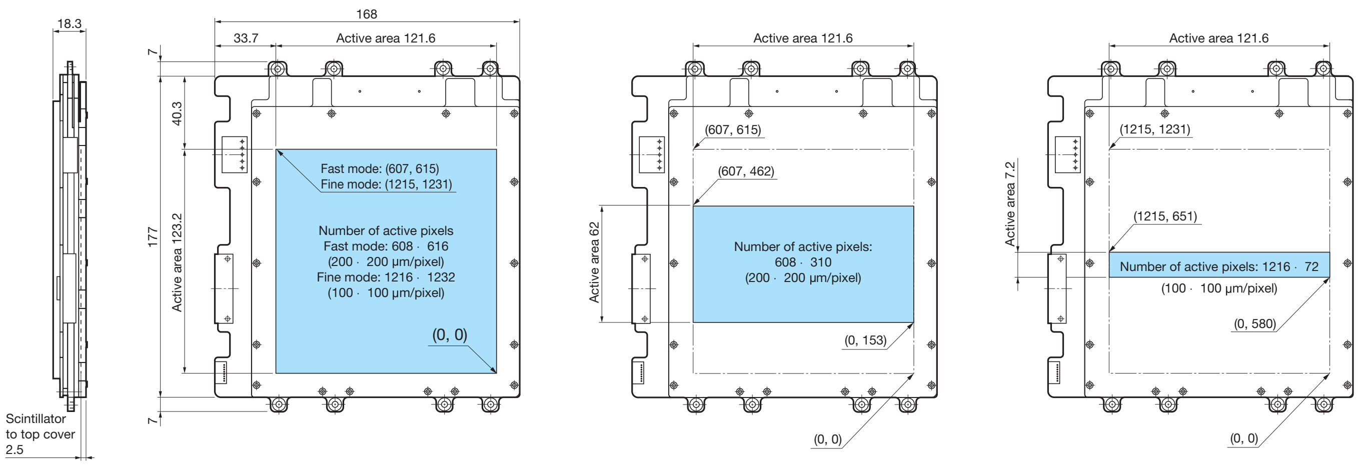
| Parameter | C10900D | | | | Unit |
|---|---|---|---|---|---|
| Scan mode | Fast mode | Partial mode | Fine mode | Panoramic mode | |
| Pixel size | 200 | | 100 | | μm |
| Photodiode area | 124.8 (H) · 124.8 (V) | | | | mm |
| Number of pixels | 624 (H) · 624 (V) | | 1248 (H) · 1248 (V) | | pixels |
| Number of active pixels | 608 (H) · 616 (V) | 608 (H) · 310 (V) | 1216 (H) · 1232 (V) | 1216 (H) · 72 (V) | pixels |
| Frame rate | 35 | 70 | 17 | 280 | frames/s |
| Frame rate external | Sf(int)*1 to 10 | | Sf(int)*1 to 10 | Sf(int)*1 to 50 | frames/s |
| Noise *2 | 2900 | | 1300 | | electrons |
| Sensitivity *3 | 6000 | | 3500 | | LSB/mR |
| Saturation charge | 10.5 | | 2.3 | | M electrons |
| Resolution *4 | 2.5 | | 4.5 | | line pairs/mm |
| Dynamic range | 3600 | | 1700 | | - |
| Defect line *5 | 8 Max. | | | | lines |
| X-ray tube voltage | 20 to 90 | | | | kVp |
| Digital output (interface) | 13 (LVDS differential) | | 12 (LVDS differential) | | bits |
| Scintillator | Direct deposition CsI | | | | - |

*1: Frame rate for internal mode
*2: Internal trigger mode
*3: At 80 kVp, acrylic filter 170 mm
*4: Spatial frequency at CTF=5 %
*5: Adjacent defect lines are not allowed. For the definition of defect line, see Chapter 3, “Description of Terms”.

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outlines (unit: mm, tolerance: ±1 mm)

Fast mode, Fine mode | Partial mode | Panoramic mode

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# Rotational radiography

## 2-1. Radiology

This flat panel sensor was developed for CT and panoramic imaging application up to 90 kVp. C9252DK-14 has a tiling construction for large image area capability. C9252DK-14 is whole scan and partial scan selectable for CT and panorama application respectively.

### Features

- High sensitivity
- High-speed frame rate
- Flat panel structure without image distortion
- Scintillator: direct deposition CsI
- Large area size with tiling construction
- Partial scan and whole scan selectable

### Applications

- Panoramic imaging
- CT imaging, etc.

(Ta=25 ˚C, Typ. unless otherwise noted)

| Parameter | C9252DK-14 | Unit |
|---|---|---|
| Pixel size | 200 | µm |
| Photodiode area | 249.6 (H) · 124.8 (V) | mm |
| Number of pixels | 1248 (H) · 624 (V) | pixels |
| Number of active pixels | 1216 (H) · 616 (V) | pixels |
| Frame rate | 30 | frames/s |
| Frame rate external | Sf (int)*1 to 10 | frames/s |
| Noise *2 | 2600 | electrons |
| Sensitivity *3 | 6000 | LSB/mR |
| Saturation charge | 8.3 | M electrons |
| Resolution *4 | 2.5 | line pairs/mm |
| Dynamic range | 3200 | - |
| Defect line *5 | 20 | lines |
| X-ray tube voltage | 20 to 90 | kVp |
| Digital output (interface) | 13 (LVDS differential) | bits |
| Scintillator | Direct deposition CsI | - |
| Top cover material (thickness) | Carbon fiber (1.0 mm) | - |
| Suitable frame grabber cable | A8406-6* series | - |

*1: Frame rate for internal mode *2: Internal trigger mode *3: At 80 kVp, acrylic filter 170 mm *4: Spatial frequency at CTF=5 %
*5: Adjacent defect lines are not allowed. For the definition of defect line, see Chapter 3, “Description of Terms”.

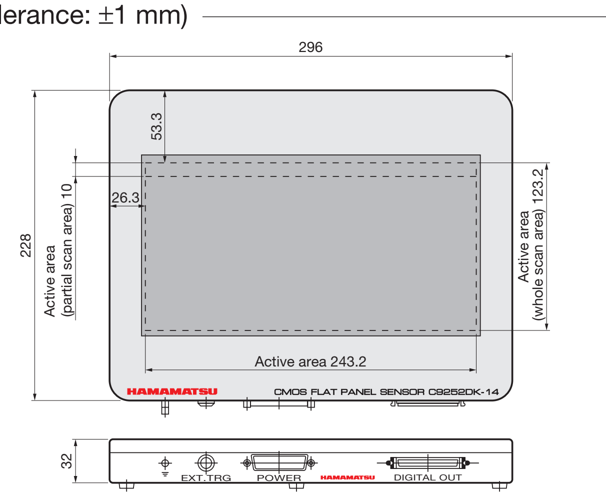
■ Partial scan

| | | |
|---|---|---|
| Pixel size | 100 | µm |
| Number of active pixels *6 | 2432 (H) · 100 (V) | pixels |
| Partial frame speed | 146 | frames/s |
| Noise | 1300 | electrons |
| Saturation charge | 4.2 | M electrons |
| Sensitivity *7 | 1500 | LSB/mR |
| Dynamic range | 3200 | - |
| Resolution | 4.5 | line pairs/mm |
| Digital output (Interface) | 12 (LVDS differential) | bits |

*6: The position of the active area under the partial scan mode is described in dimensional outline *7: 80 kVp, acrylic filter 170 mm

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outline (unit: mm, tolerance: ±1 mm)



# Biochemistry

## 2-1. Radiology

The biochemical application series C9730DK-10 and C9732DK-11 have fine 50 μm pixel pitch and directly deposited CsI scintillator onto a large formatted photodiode array optimized to 17 keV radiation. They have a cassette shape with a carbon fiber top cover.
C7942CK-22 installs CsI flipped scintillator plate (FSP) which is optimized for low absorption material radiography of less than 80 kVp energy range.

### Features

- High resolution
- No dead area (insensitive area) due to seamless structure
- Scintillator: CsI flipped scintillator plate (C7942CK-22)
  direct deposition CsI (C9730DK-10, C9732DK-11)
- Top cover material: carbon fiber

### Applications

- Soft X-ray radiography
- X-ray imaging, etc.
  (C9730DK-10, C9732DK-11: optimized to 17 keV)

(Ta=25 ˚C, Typ. unless otherwise noted)

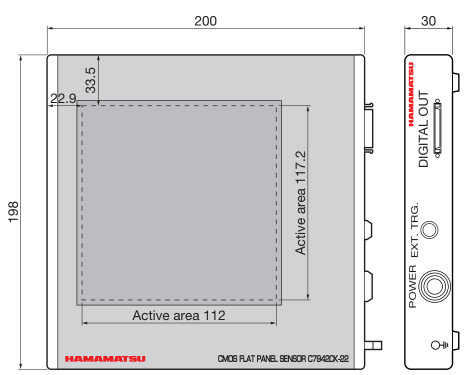
| Parameter | C7942CK-22 | C9730DK-10 | C9732DK-11 | Unit |
|---|---|---|---|---|
| Pixel size | 50 | 50 | 50 | µm |
| Photodiode area | 120 (H) · 120 (V) | 52.8 (H) · 52.8 (V) | 120 (H) · 120 (V) | mm |
| Number of pixels | 2400 (H) · 2400 (V) | 1056 (H) · 1056 (V) | 2400 (H) · 2400 (V) | pixels |
| Number of active pixels | 2240 (H) · 2344 (V) | 1032 (H) · 1032 (V) | 2368 (H) · 2340 (V) | pixels |
| Frame rate (single operation) | 2 | 4 | 1 | frames/s |
| Frame rate (2 · 2 binning) | 4 | - | - | frames/s |
| Frame rate (4 · 4 binning) | 9 | - | - | frames/s |
| Frame rate external (single operation) | Sf (int)*1 to 0.1 | Sf (int)*1 to 0.5 | Sf (int)*1 to 0.5 | frames/s |
| Noise *2 | 1100 | 1250 | 1250 | electrons |
| Sensitivity | 35 *3 | 65 *4 | 65 *4 | LSB/mR |
| Saturation charge | 2.2 | 6.4 | 6.4 | M electrons |
| Resolution *5 | 8 | 10 | 10 | line pairs/mm |
| Dynamic range | 2000 | 5100 | 5100 | - |
| Defect line | 20 Max. *6 | 10 Max. *6 | 16 Max. *7 | lines |
| X-ray tube voltage | 20 kVp to 80 kVp | Less than 35 kVp (17 keV Mo source) | | - |
| Digital output (interface) | 12 (RS-422 differential) | 14 (USB 2.0) | | bits |
| Scintillator | CsI flipped scintillator plate | Direct deposition CsI | | - |
| Top cover material (thickness) | Carbon fiber (1.0 mm) | | | - |
| Suitable frame grabber cable | A8406-5* series | - | | - |

*1: Frame rate for internal mode
*2: Internal trigger mode and single operation
*3: At 80 kVp, without filter
*4: At Mo target 30 kVp, without filter
*5: Spatial frequency at CTF=5 %
*6: Adjacent defect lines are not allowed. For the definition of defect line, see Chapter 3, “Description of Terms”.
*7: Only one pair of adjacent defect lines is allowed. For the definition of defect lines, see Chapter 3, “Description of Terms”.

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outlines (unit: mm, tolerance: ±1 mm)

### C7942CK-22

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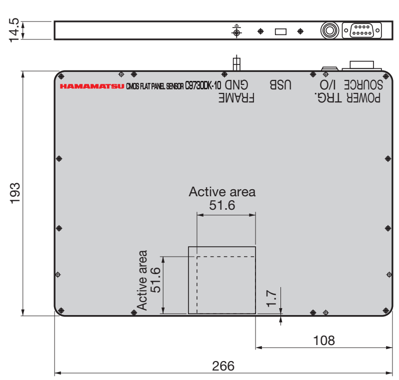
### C9730DK-10

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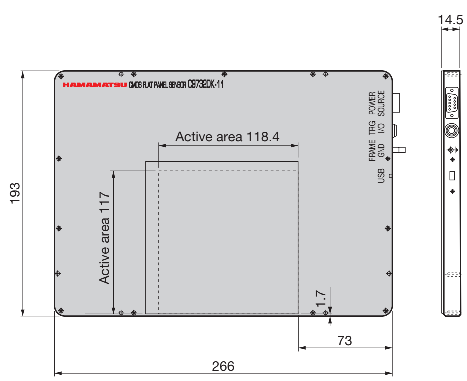
### C9732DK-11

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# Diffraction

## 2-1. Radiology

These flat panel sensors feature a low noise and direct deposition CsI scintillator for applications where diffraction is critical.

### Features

- Active pixel sensor
- Low noise: 80 electrons (C9728DK-10)
- High quality image
- With USB 2.0 interface (C9728DK-10)
- Scintillator: direct deposition CsI
- Top cover material: carbon fiber
- Partial scan and whole scan selectable (C10158DK)

### Applications

- Diffraction
- Radiography, etc.

(Ta=25 ˚C, Typ. unless otherwise noted)

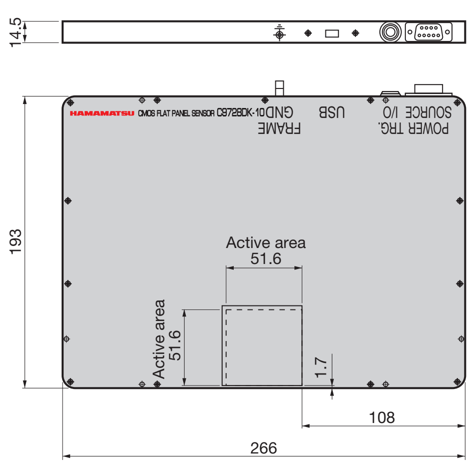
| Parameter | C9728DK-10 | C10158DK | | Unit |
|---|---|---|---|---|
| Pixel size | 50 | 50 | | μm |
| Photodiode area | 52.8 (H) · 52.8 (V) | 118.8 (H) · 118.8 (V) | | mm |
| Number of pixels | 1056 (H) · 1056 (V) | 2376 (H) · 2376 (V) | | pixels |
| Number of active pixels | 1032 (H) · 1032 (V) | Whole scan | 2352 (H) · 2352 (V) | pixels |
| | | Partial scan | 2352 (H) · 528 (V) | |
| Frame rate | 3 | Whole scan | 3 | frames/s |
| | | Partial scan | 12 | |
| Frame rate external | Sf (int)*1 to 0.1 | Sf (int)*1 to 1.0 | | frames/s |
| Noise *2 | 80 | 180 | | electrons |
| Sensitivity *3 | 450 | 220 | | LSB/mR |
| Saturation charge | 0.45 | 1.1 | | M electrons |
| Resolution *4 | 10 | 10 | | line pairs/mm |
| Dynamic range | 5600 | 6000 | | - |
| Defect line *5 | 10 Max. | 30 Max. | | lines |
| Adjacent defect line | 0 Max. | 2 Max. | | lines |
| X-ray energy range | 18 Max. | 18 Max. | | keV |
| Digital output (interface) | 14 (USB 2.0) | 14 (LVDS) | | bits |
| Scintillator | Direct deposition CsI | | | - |
| Top cover material (thickness) | Carbon fiber (1.0 mm) | | | - |
| Suitable frame grabber cable | - | A8406-5* series | | - |

*1: Frame rate for internal mode
*2: Internal trigger mode
*3: At Mo target 25 kVp, without filter
*4: Spatial frequency at CTF=5 %
*5: For the definition of defect line, see Chapter 3, “Description of Terms”.

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outlines (unit: mm, tolerance: ±1 mm)

### C9728DK-10

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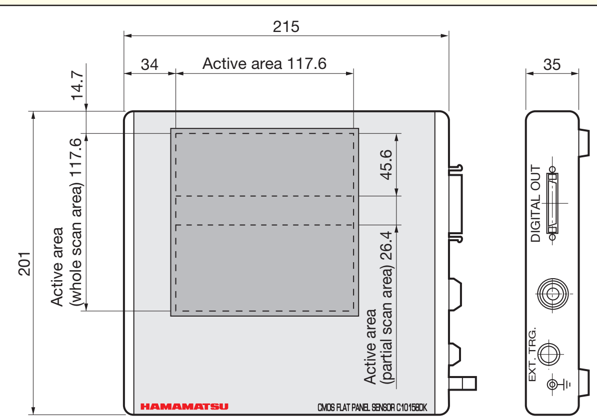
### C10158DK

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# General X-ray application

## 2-2. Non-destructive Inspection

These flat panel sensors install high quality CsI flipped scintillator plate (FSP) and aluminum top cover. These flat panel sensors offer 50 or 100 μm pixel size and high resolution of 8 or 5 line pairs/mm for general X-ray applications. Maximum radiation energy is less than 100 kVp and guaranteed dose is $10^6$ Roentgens. These flat panel sensors are available to use with microfocus X-ray sources having energy range up to 100 kV.

### Features

- High quality image
- Wide dynamic range
- High-speed imaging
- Flat panel structure without image distortion
- Scintillator: high quality CsI flipped scintillator plate
- Top cover material: aluminum

### Applications

- Non-destructive inspection
- Biochemical imaging
- X-ray microscopy
- Digital X-ray photography, etc.

(Ta=25 ˚C, Typ. unless otherwise noted)

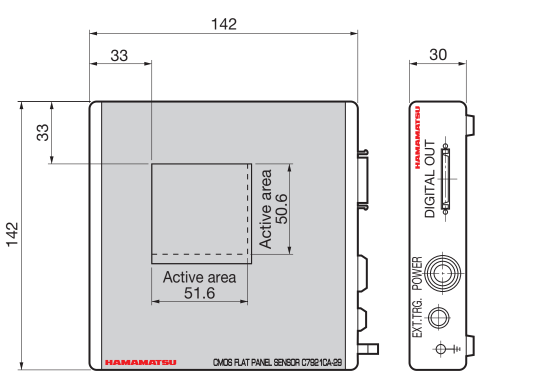
| Parameter | C7921CA-29 | C7942CA-22 | C7943CA-22 | Unit |
|---|---|---|---|---|
| Pixel size | 50 | 50 | 100 | µm |
| Photodiode area | 52.8 (H) · 52.8 (V) | 120 (H) · 120 (V) | 124.8 (H) · 124.8 (V) | mm |
| Number of pixels | 1056 (H) · 1056 (V) | 2400 (H) · 2400 (V) | 1248 (H) · 1248 (V) | pixels |
| Number of active pixels | 1032 (H) · 1012 (V) | 2240 (H) · 2344 (V) | 1216 (H) · 1220 (V) | pixels |
| Frame rate (single operation) | 4 | 2 | 7 | frames/s |
| Frame rate (2 · 2 binning) | 8 | 4 | 15 | frames/s |
| Frame rate (4 · 4 binning) | 16 | 9 | 30 | frames/s |
| Frame rate external (single operation) | Sf (int)*1 to 0.1 | Sf (int)*1 to 0.1 | Sf (int)*1 to 0.1 | frames/s |
| Noise *2 | 1000 | 1100 | 2300 | electrons |
| Sensitivity *3 | 18 | 25 | 28 | LSB/mR |
| Saturation charge | 2.9 | 2.2 | 10 | M electrons |
| Resolution *4 | 8 | 8 | 5 | line pairs/mm |
| Dynamic range | 2900 | 2000 | 4300 | - |
| Defect line *5 | 10 Max. | 20 Max. | 10 Max. | lines |
| Power source | A.vdd=+5.0 V, D.vdd=+5.0 V | A.vdd=+5.0 V, D.vdd=+5.0 V, V (±7.5)=±7.5 V | | - |
| X-ray tube voltage | 20 to 100 | | | kVp |
| Digital output (Interface) | 12 (RS-422 differential) | | | bits |
| Scintillator | CsI flipped scintillator plate | | | - |
| Top cover material (thickness) | Aluminum (1.0 mm) | | | - |
| Suitable frame grabber cable | A8406-5* series | | | - |

*1: Frame rate for internal mode
*2: Internal trigger mode, single operation
*3: At 80 kVp, without filter
*4: Spatial frequency at CTF=5 %
*5: Adjacent defect lines are not allowed. For the definition of defect line, see Chapter 3, “Description of Terms”.

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outlines (unit: mm, tolerance: ±1 mm)

### C7921CA-29

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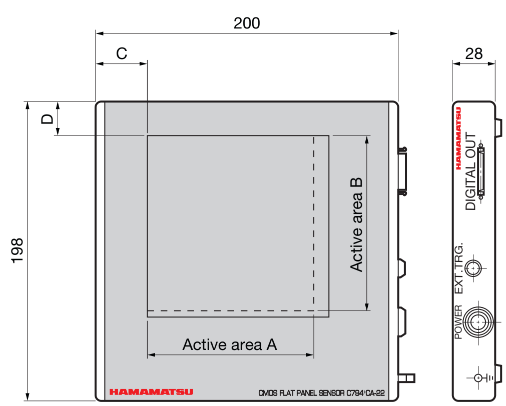
### C7942CA-22, C7943CA-22




| | C7942CA-22 | C7943CA-22 |
|---|---|---|
| A | 112 | 121.6 |
| B | 117.2 | 122 |
| C | 33.5 | 31.1 |
| D | 22.9 | 20.5 |

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# High tube voltage application

## 2-2. Non-destructive Inspection

These flat panel sensors install shielded FOP with GOS scintillator to protect CMOS chip against higher energy radiation. These sensors have 50 μm pixel pitch. C7942SK-25 has maximum radiation energy up to 150 kVp and C9312SK-06 has 110 kVp Max. Guaranteed dose is 6 · $10^6$ Roentogens.

### Features

- High quality image
- Wide dynamic range
- High-speed imaging
- Energy range:
  150 kVp Max. (C7942SK-25)
  110 kVp Max. (C9312SK-06)
- Scintillator: GOS-deposited FOP
- Top cover material: carbon fiber

### Applications

- Non-destructive inspection (offline)
- Radiography, etc.

The C9312SK-06 is warranted for a period of 12 months after the date of shipment. Even within the warranty period, if the total radiation dose exceeds 6 million Roentgen against 110 kVp X-ray irradiation, it is not warranted. In case of 8-hour operation in a day, it is equivalent to 92 days on the condition that the 110 kVp continuous X-ray is exposed to the detector as the intensity of 4096 LSB output can be taken at 8 frames per second (maximum frame rate for single operation). In a real operation, the dark and light field images may be taken frequently for offset and sensitivity calibration. The flat panel sensor may be exposed to X-ray before or after the valid image is taken. It is needed to count up all these shots for proper estimation. Please calculate the life time considering the operation condition in your system.

(Ta=25 ˚C, Typ, unless otherwise noted)

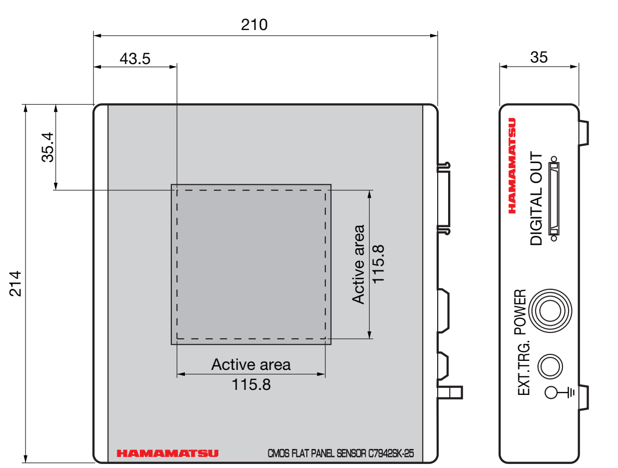
| Parameter | C7942SK-25 | C9312SK-06 | Unit |
|---|---|---|---|
| Pixel size | 50 | 50 | µm |
| Photodiode area | 120 (H) · 120 (V) | 124.8 (H) · 115.2 (V) | mm |
| Number of pixels | 2400 (H) · 2400 (V) | 2496 (H) · 2304 (V) | pixels |
| Number of active pixels | 2316 (H) · 2316 (V) | 2472 (H) · 2184 (V) | pixels |
| Frame rate (single operation) | 2 | 8 | frames/s |
| Frame rate (2 · 2 binning) | 4 | - | frames/s |
| Frame rate (4 · 4 binning) | 9 | - | frames/s |
| Frame rate external (single operation) | Sf (int)*1 to 0.2 | Sf (int) *1 to 1.0 | frames/s |
| Noise *2 | 1300 | 700 | electrons |
| Sensitivity *3 | 58 | 20 | LSB/mR |
| Saturation charge | 1.1 | 2.25 | M electrons |
| Resolution *4 | 8 | 9 | line pairs/mm |
| Dynamic range | 850 | 3200 | - |
| Defect line | 30 Max. *5 | 20 Max. *6 | lines |
| X-ray tube voltage | 20 to 150 | 20 to 110 | kVp |
| Digital output (Interface) | 12 (RS-422 differential) | 12 (LVDS differential) | bits |
| Scintillator | GOS-deposited FOP | | - |
| Top cover material (thickness) | Carbon fiber (1.0 mm) | | - |
| Suitable frame grabber cable | A8406-5* series | A8406-4* series | - |

*1: Frame rate for internal mode
*2: Internal trigger mode and single operation
*3: At 150 kVp, without filter (C7942SK-25)
At 110 kVp, without filter (C9312SK-06)
*4: Spatial frequency at CTF=5 %
*5: Only one pair of adjacent defect lines is allowed. For the definition of defect line, see Chapter 3 “Description of terms”
*6: Adjacent defect lines are not allowed. For the definition of defect line, see Chapter 3 “Description of terms”

Note: For detailed data on the products listed in this catalog, see their datasheets that are available from our website **www.hamamatsu.com** or contact our sales office.

## Dimensional outlines (unit: mm, tolerance: ±1 mm)

### C7942SK-25

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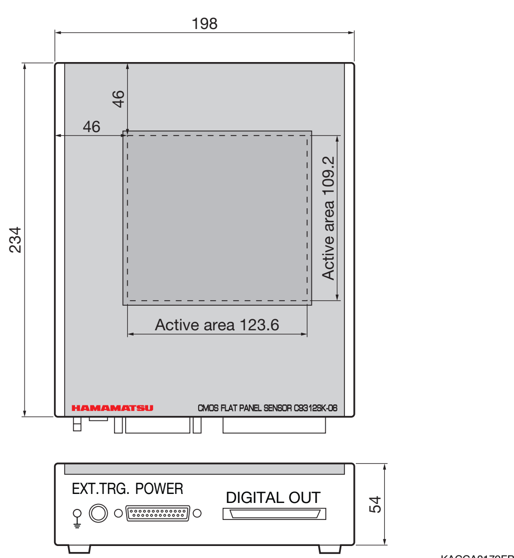
### C9312SK-06

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# 3. Description of Terms

## Active pixels
Pixels in the active area used for imaging excluding the shielded portion surrounding the photodiode area.

## Binning Mode
Binning mode is a method for taking images as superpixels that are the sum of several pixels, for example, 2 · 2 or 4 · 4 pixels. See 4-2 for details.

## Defect line
A defect line is a horizontal or vertical line containing 4 or more cosecutive pixels located at the opposite side of an amplifier array or a shift register, that produce 1/8 * of the sensitivity average of the surrounding pixels.

Note 1: Generally, the opposite side of an amplifier array and a shift register array corresponds to the 1st row and 1st column of the image data. On two-port devices, the image data format is different so refer to the individual datasheet.

Note 2: The port is the number of output digital data sets that are sent in parallel to a frame grabber board. The C9312SK-06 and C9252DK-14 are two-port flat panel sensors.

* The definition for some products differs from this value. Please consult the individual datasheets.

## Dynamic Range
The ratio of saturation charge to noise.

## Fill Factor
The ratio of active area (no-shielded area) to total pixel area. A larger fill factor can reduce light detection loss.

## Frame rate
The vertical sync (Vsync) frequency determines the frame rate. In internal trigger mode, video and sync signals always flow from the flat panel sensor at the highest frame rate. External trigger mode can drive the flat panel sensor at a lower frame rate. See 4-2 for details.

Note: The actual frame rate in individual software depends on the CPU processing performance as well as the display board or software load. The software might skip a few frames if the processing performance is lower than system requirements.

## Noise
The rms noise swing width in units of electrons, measured at 25 ˚C in internal trigger mode and single operation.

## Photodiode area
Area on the chip where a photodiode array is formed.

## Resolution
Spatial frequency at CTF=5 %, expressed in LP/mm (LP: line pairs). Resolution is measured using a 60 kV microfocus X-ray source.

## Saturation charge
The maximum output bit in units of electrons.

## Scintillator
A material that emits a small flash of light (or scintillation) when struck by nuclear particles or radiation. HAMAMATSU offers various scintillators to cover a wide energy range of incident X-rays.

## Sensitivity
Output bit per 1 mR irradiation, expressed in units of LSB/mR (LSB: least significant bit). The full scale of a 12-bit video output is 4095 LSB, 8191 LSB for 13-bit type and 16383 LSB for the 14-bit type. See tube voltages or filter conditions described in each data sheet.

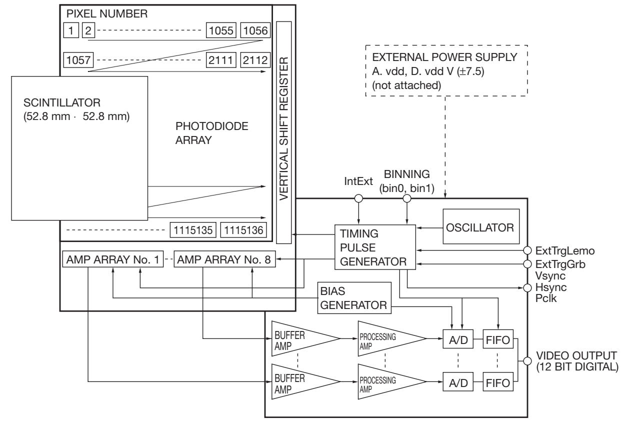
## X-ray Tube Voltage
The voltage applied across the anode and cathode of an X-ray tube to accelerate electrons emitted from the cathode filament in order to hit the X-ray tube target. When a voltage Vp is applied to the X-ray tube, X-rays are generated at an energy corresponding to Vp eV. The X-ray tube voltage range guaranteed for flat panel sensors will differ depending on the sensor type.

# 4. Operating Principle and Structure

## 4-1. Features

Flat panel sensor is a lightweight and compact X-ray imaging sensor module consisting of a sensor board and a control board. The sensor board has plural blocks of charge-sensitive amplifier arrays with CDS (Correlated Double Sampling) circuit and horizontal shift register. Amplified analog video signals sequentially flow from each block and transferred to the control board.  The analog signal is converted into a digital signal and outputs to an external frame grabber through the parallel port.

Figure 5: Example for block diagram

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## 4-2. Operating Principle

The CMOS flat panel sensor chip consists of large formatted photodiode matrix, low noise charge integration amplifier and vertical shift register.

A trans-impedance amplifier with a feedback capacitor converts photocurrent into an output voltage proportional to the input photon intensity. The output voltage of charge integration amplifier is proportional to the product of the photon intensity and integration time. The long integration time allows detecting extremely faint  radiation even with a tiny pixel size. The integration time in internal mode is specified in each data sheets. The integration time in external mode is determined by interval of the rising edges of a couple of successive external trigger pulses. The flat panel sensor cannot detect a change of radiation within the integration time. The vertical shift pulse is applied to every row of photodiode matrix sequentially. The start timing of the integration time of each row has a time lag that is equal to the cycle time of a horizontal synchronous pulse.

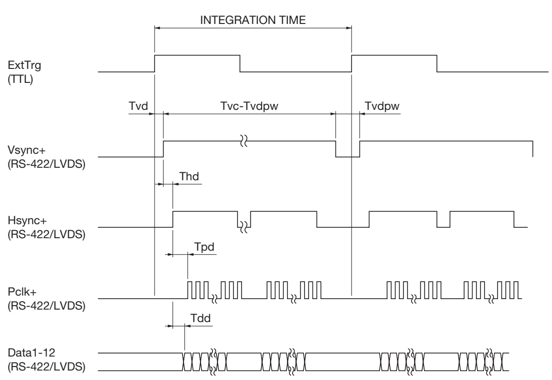
The capacitor of each photodiode element has limited value, so the integration charge is also limited. This is defined as the saturation charge in the data sheet. The linear output cannot be obtained if over radiation dose corresponds to the value is irradiated.

Each vertical shift register pulse, charge amplifier drive pulse, horizontal shift register pulse, A/D converters and memory chip drive pulse are generated from associated electronic circuits within the sensor case. The user does not have to design and build an intricate timing generator but needs only connect it to a digital grabber card to acquire an X-ray image.

The integration time is the reciprocal of the frame rate. The frame rate specified in internal mode is the maximum speed. It corresponds to the shortest integration time. The longer integration time is attained in external trigger mode, which supplies a longer cycle of external trigger pulse to the flat panel sensor.

Figure 6: Timing chart

Common integration time

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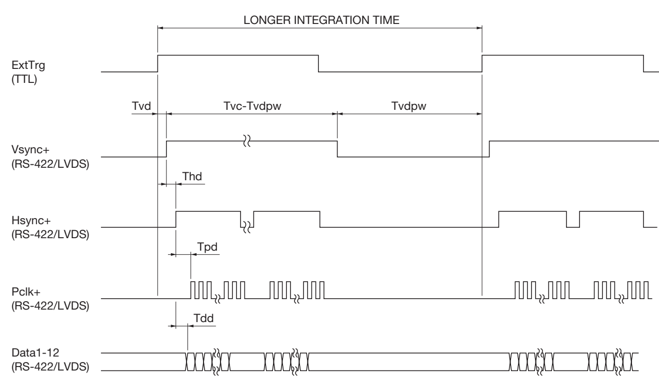
Long integration time

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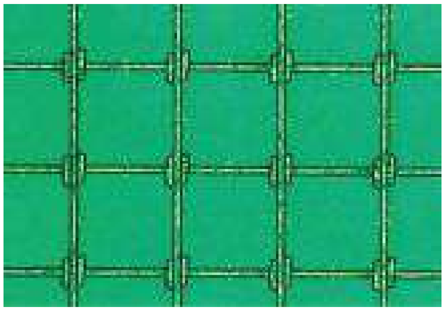
In the flat panel sensor drive sequence, the high-sensitivity photodiode matrix generates carriers and accumulates them in the junction capacitance of each pixel when they receive scintillation light from the scintillator material. All pixels have an overflow drain to protect against blooming in adjacent pixels even when a portion of the pixels is saturated. The standard CMOS process implemented with a photodiode matrix achieves a high fill factor ratio of 79 % for 50 · 50 µm pixels and 87 % for 100 µm pixels. (See Figure7.)

Figure 7: Photodiode array



Shift pulses are supplied by the vertical shift register for sequential scanning and a row of photodiodes flows the carrier into each data lines. The on-chip extremely-low noise charge amplifier array with CDS circuit is somewhat complicated in terms of structure and operation, however it can cancel out the offset components by finding the signal difference between the accumulated charge and zero level. This makes a huge improvement in image output uniformity. Usually, some kinds of corrections are made to an acquired image before it is displayed, but the flat panel sensor was designed to have a high level of image quality even before making those corrections. The output noise is mainly determined by the charge amplifier itself and the data line capacitance. The ENC (total Equivalent Noise Charge) is given by the following equation.

$ENC = 8KT/3\,gm \cdot (Ct)^2$ ·········· (1)

$Ct = Cd + Cp + Cf$ ······················ (2)

- K : Boltzman constant $1.3806 \cdot 10^{-23}$
- T : Absolute temperature [K]
- gm : Transconductance [S]
- Cd : Junction capacitance of photodiode [F]
- Cp : Data line capacitance [F]
- Cf : Feedback capacitance of the charge amplifier [F]

## ● Binning mode

The flat panel sensor can deliver high-resolution images in the single pixel drive mode. On the other hand, some types of the flat panel sensors have a binning drive mode for high-speed and high-sensitivity operation. A user can select 2 · 2 or 4 · 4 binning mode. In the 2 · 2 binning mode, the neighboring 2 · 2 pixels are read out together. In the 4 · 4 binning mode, the neighboring 4 · 4 pixels are read out together. So the user can drive the module with higher frame rate controlling the binning mode. Moreover when it is driven at the same frame rate, the amount of signals becomes 4 times larger by 2 · 2 binning mode and 16 times by 4 · 4 binning mode.

## ● Trigger Mode

The flat panel sensors have two trigger modes (internal/external trigger mode). Under the internal trigger mode, video signal and synchronous signals always flow out from the flat panel sensor at the highest frame speed of Sf (int), which is described in the electrical specification in its data sheets. On the other hand, the user can choose the external trigger mode to synchronize the flat panel sensor with the X-ray source or to expand the accumulation period to make the sensitivity higher. The period of this external trigger signal is equal to that of the integration time. The sensor starts to forward the video data to the frame grabber board at the rising edge of this signal. The duty of this trigger signal should be settled between 1 % and 99 % (50 % is recommended). The voltage of this signal should be compatible with TTL-level.

When the user selects internal trigger mode, the signal of “IntExt” or “IntExtTrg” should be set to Low. If “IntExt” or “IntExtTrg” is set to High, the flat panel sensor works as the external trigger mode.

In case of the external trigger mode, there are two methods to control integration period. One is supplying the synchronous signal through “ExtTrgGrb” from PC. The other is supplying the synchronous signal through “ExtTrgLemo” or “ExtTrgIO” from X-ray source. Please refer to the data sheet for the flat panel sensor.

Under the external trigger mode, the first image, which follows the first external trigger signal, is bright and useless because the integration time is not defined. It means that charge from dark current continuously accumulated until the trigger pulse is supplied. Therefore, the second image or later ones are valid.

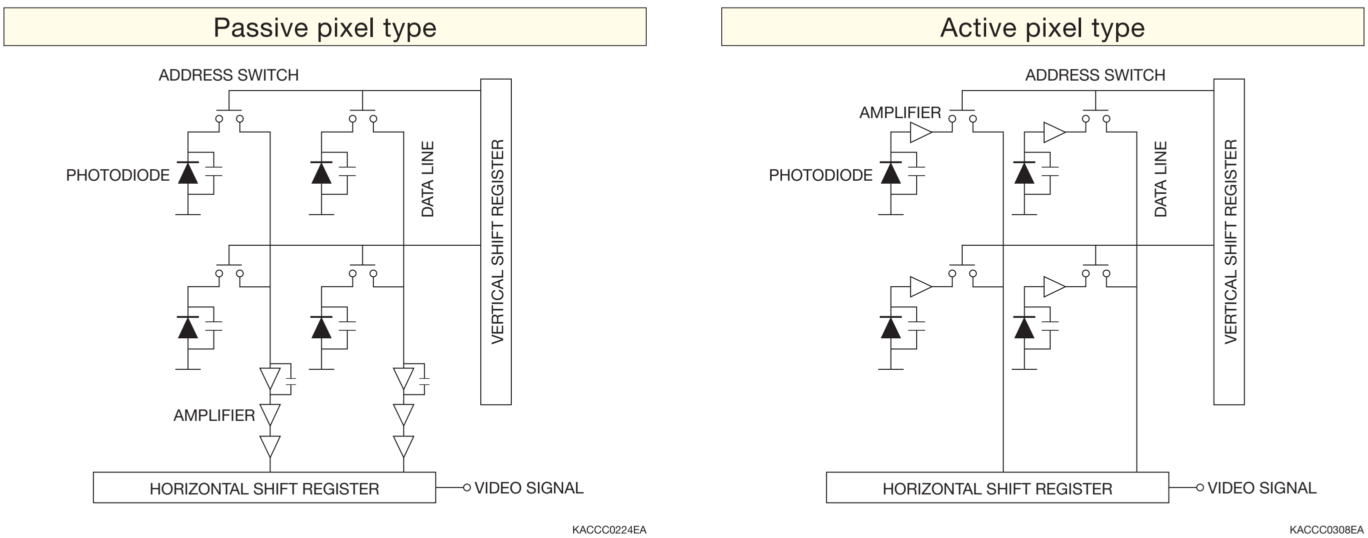
## 4-3. Active Pixel Construction

HAMAMATSU CMOS flat panel sensors adopt two kinds of amplifier circuit constructions ; one is passive pixel type for ordinary application, and the other is active pixel type for high-end use.

The passive pixel type incorporates amplifier arrays existing at one side of photodiode array and each amplifier is connected to one column of photodiode array via address switches. This simple structure allows high fill factor, high productivity and high radiation tolerance although there is limitation to reduce thermal noise of amplifier dramatically due to its large input capacitance caused by long data line.

The active pixel type solves the drawback of the passive pixel type. Its low noise or high S/N feature is appealing on low energy or low exposure application like an high quality imaging of low contrast objects or usage of an open-type microfocus X-ray source. This type has an amplifier built in each pixel, and accumulated charges are converted into voltage. The noise level is less than 180 electrons rms, which is less than 1/6 of the passive pixel type.

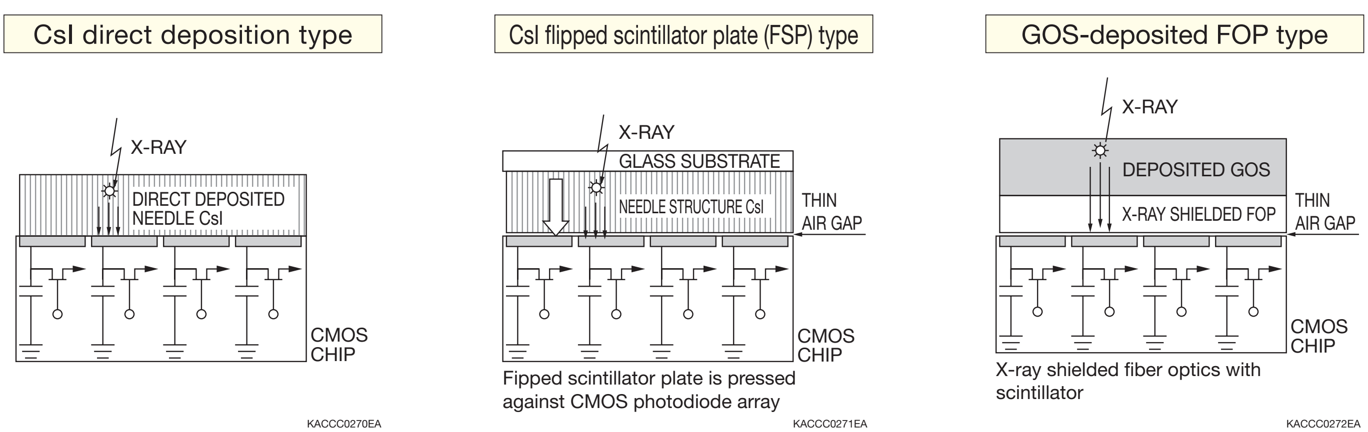
Figure 8: Internal circuit of CMOS chip




## 4-4. Coupling Method of Scintillator

HAMAMATSU flat panel sensor utilizes a needle structure CsI as an X-ray conversion layer. There are three methods for coupling a scintillator structure with a CMOS device. The first one is direct deposition of CsI onto the photodiode matrix, the second one is a CsI flipped scintillator plate (FSP). Both of these approaches utilize the needle structure CsI scintillator. A combination of CsI scintillator and CMOS large formatted photodiode array is essential for high-resolution devices, and the direct deposition CsI flat panel sensor in particular shows outstanding resolution. On the other hand, the FSP offers the advantage of relatively low cost. Another scintillator component is GOS-deposited FOP. It can be used higher tube voltages application.

Figure 9: Cross sectional figure of indirect and direct conversion devices



## 4-5. Scintillator

Achieving a spectral response characteristic that matches the peak wavelength and spectral range of the scintillator emission is a critical factor in photodiode matrix design. By controlling the impurity profile and passivation, HAMAMATSU has succeeded in developing an optimal high-sensitivity X-ray device ideal for indirect X-ray detection.

The second to the last letter of each product type number (e.g. C7942CA-22) indicates which type of scintillator is used.
Type C utilizes a cost effective and high resolution scintillator plate. Type D is an direct deposition type flat panel sensor which realizes high resolution and high sensitivity. Type S has GOS deposited X-ray shielded fiber optics plate against higher input irradiation.

| |
|---|
| C: CsI:Tl [CSI Flipped Scintillator Plate (FSP)], D: CsI:Tl (Directly deposited on photodiode array)<br>S: GOS (GOS is deposited onto an X-ray shielded FOP) |

Figure 10: Scintillation spectrum of CsI and photo sensitivity of a pixel

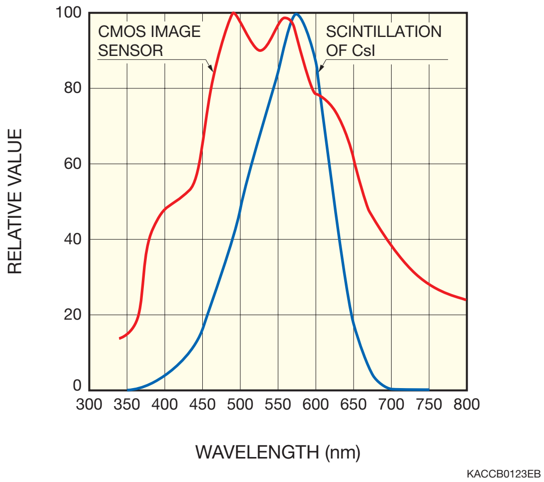
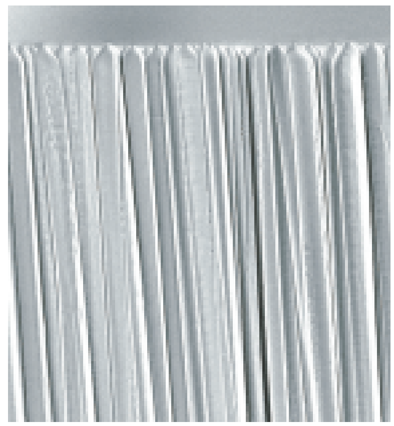



Figure 11: The needle-like crystal structure of CsI



## 4-6. Window Material of Top Cover

The last letter of each product number (e.g. C7942CA-22) indicates which type of window is used.

| |
|---|
| A: Aluminum (1 mmt), K: Carbon fiber (1 mmt) |

The top cover protects the device against physical damage, extends the service life of the CsI and photodiode array, and acts as a filter for the scattered soft X-rays.
The aluminum top cover is adequate for radiation of the X-ray tube voltage up to 100 kVp. The carbon fiber top cover, on the other hand, have high transmittance (more permeable to X-rays) and are the right option for detecting lower energy X-ray of less than 80 kVp.
The carbon fiber is also applied for the flat panel sensor on which X-ray shielded FOP is mounted.

## 4-7. X-ray Radiation Damage

The flat panel sensor shows the degradation of characteristics by X-ray irradiation. In general X-ray sensitivity decreases because of the browning of scintillator and the dark output increases by the radiation damage of the photodiode. In some cases, partial dark output increase is also observed. In the case of C7921CA-29, for example, sensitivity decrease around 25 % and the dark output increase of around 200 LSB/frame at internal frame rate are observed after the exposure of 1 million Roentgen at the tube voltage of 100 kVp. “SK” type is relativity tolerant against X-ray than the “CA” type because of the high absorption efficiency of X-ray shielded FOP. The X-ray life time of the “C9312SK-06”, for example, is 6 million Roentgen at 110 kVp. In case of 8-hour operation in a day, it is equivalent to 92 days on the condition that the 110 kVp continuous X-ray is exposed to the detector as the intensity of 4096 LSB output can be taken at 8 frames per second (maximum frame rate for single operation).

$$\frac{6\ [\text{million Roentgen}] \cdot 16^{*1}\ [\text{LSB/mR}] \cdot 0.9^{*2}}{4096\ [\text{LSB/frame}] \cdot 8\ [\text{frames/sec}] \cdot 3600\ [\text{sec/hour}] \cdot 8\ [\text{hour/day}]} = 92\ [\text{day}]$$

*1: Minimum X-ray sensitivity value. Refer to the individual datasheets for the values.
*2: Calculated assuming that the sensitivity decrease rate by X-ray irradiation is 0.9.

In a real operation, the dark and light field images may be taken frequently for offset and sensitivity calibration. The flat panel sensor may be exposed to X-ray before or after the valid image is taken. It is needed to count up all these shots for proper estimation. The upper limit of X-ray tube voltage and the life time of the sensor are determined by scintillator type, window material and the structure of sensor ship. Refer to the datasheet for each type of the flat panel sensor and application manual for more details.
Not recommended for use in inline applications where large radiation damage may occur.

# 5. Features

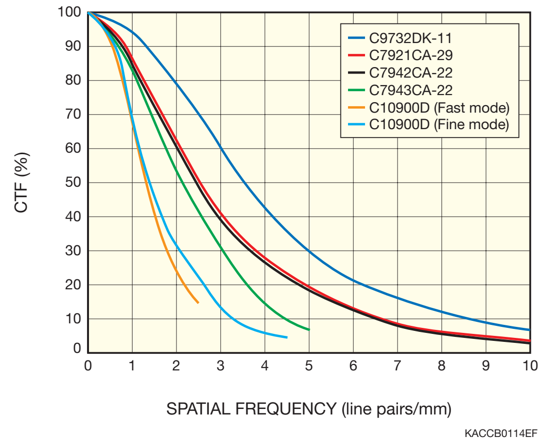
## 5-1. Spatial Resolution

The flat panel sensor spatial resolution is determined by the frequency function of photodiode array and the applied scintillator layer. The contrast transfer function (CTF) curve is an index of the total resolution of the flat panel sensor (See Figure 12). It appears from 0 line pair/mm to the Nyquist frequency (Fn). The frequency is defined by the pixel pitch.

$$Fn = \frac{1}{2 \cdot d} \quad \cdots\cdots\cdots\cdot (3)$$

d: Pixel pitch [mm]

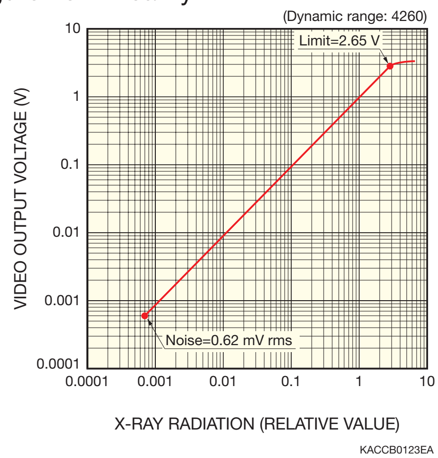
Figure 12: Resolution




## 5-2. Dynamic Range

An advanced design is essential for attaining a wide dynamic range with the 12-bit A/D converter which provides 4096 levels of gray or the 14-bit A/D converter which provides 16384 levels of gray. The value of dynamic range shown in each sensor type specification corresponds to the maximum bit depth of each type. Amplifier noise is minimized by lowering noise voltages in initial stage of the amplifiers. A wide dynamic range is obtained by keeping the swing width of the amplifier within the range of the 5 V supply used in the standard CMOS process and by optimizing the saturation voltage for the photodiode array. However, improving the gain in the initial stage of amplifier for the tiny pixels requires reducing the charge amplifier feedback capacitance (Cf). The capacitance of a column gate switch drain is also added on the data line capacitance, along a large active area making up large input capacitance (Ct).

Figure 13: Linearity




X-ray image sensors usually require large active area. This causes the Ct value to increase significantly so that a large format active area and very fine pixels are drawbacks in terms of noise. However, by optimizing the transconductance (gm) of the initial amplifier stage, and using patterning that miniaturizes the data lines and reduces stray capacitance, a 100 μm type flat panel sensor was developed having a wide dynamic ranges of 4300 as shown above.

## 5-3. Detective Quantum Efficiency

Detective Quantum Efficiency (DQE) is one of the physical parameters used for the evaluation of image quality and it was derived from the idea of S/N. The DQE is defined as shown in equation (4).

$$DQE = (S / Nout)^2 / (S / Nin)^2 \quad \cdots\cdots\cdots\cdot (4)$$

Generally a detector is never ideal because the information fed into the detector is degraded due to the incomplete absorption efficiency, noise and contrast loss in the detection system. The DQE analysis is important to determine the effectiveness of the imaging system. The DQE essentially involves the conversion gain of the system, resolution characteristics (MTF: Modulation Transfer Function) and noise characteristics (NPS: Noise Power Spectrum). Since the MTF and NPS are the function of the spatial frequency, DQE is also represented as a function of the spatial frequency. The DQE(f) is calculated by the equation below,

$$DQE(f) = G^2 \cdot q \cdot MTF(f)^2 / NPS(f) \quad \cdots\cdots\cdots (5)$$

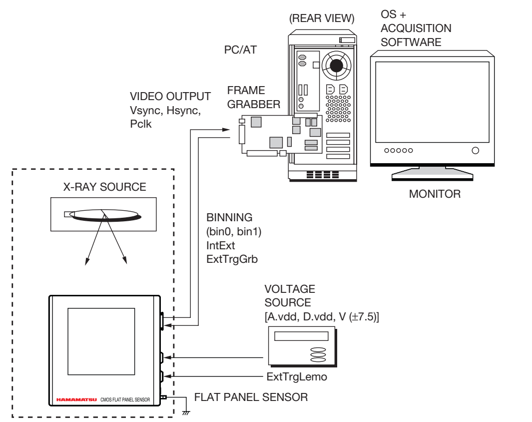
where G is a constant which is defined as the average conversion gain [mV/quantum] of the system, q is the number of X-ray quanta incident per pixel upon the detector during one acquisition period, MTF(f) is the Modulation Transfer Function which is another representation of the spatial resolution obtained from the Line Spread Function (LSF) by applying the Fourier transform method, and NPS(f) is the noise power spectrum obtained from the image data by applying the Fourier transform method.

## 6-1. Set-up Example

Connect the flat panel sensor to the grabber board that was installed in a PC according to the manufacturer's instructions. A highly flexible grabber board can control binning bit, IntExt, ExtTrg as binning or triggers operation though its digital I/O lines. A power cable* which is terminated with the applicable plug at one end and open at another end is shipped as an accessory with the flat panel sensor.

* Power cable is not supplied with some products. Please refer to the individual datasheets.

Figure 14: Connection example




## 6-2. Precaution for Power Source Configuration

In case of using a power source that has large ripple noise, horizontal line noise may appear in an image. A power source whose ripple noise is less than 1 mVp-p should be used.

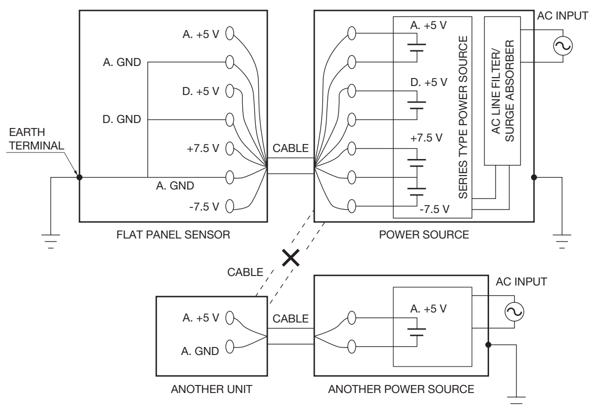
For the high quality image acquisition, analog +5 V and digital +5 V sources should be separated, because all power source ground are connected to the frame grounds at the flat panel sensor side, they should be disconnected from the frame ground or another power source ground at the power source side (refer to Figure 15).

The voltages described above are specified at the flat panel sensor side. The impedance of the power cable attached with the flat panel sensor is low enough, but it causes 0.1 V drop. Therefore the voltage at the power source side should be set 0.1 V higher than the voltage specified above.

Avoid to extend the power cable because it causes voltage drop.

An AC line filter should be placed at the AC input line in the power source to prevent the surge from the AC line. A power source with CE mark is recommended.

Figure 15: Example for power cable connection




## 6-3. Frame grabber cables

HAMAMATSU provides the A8406 series as frame grabber board cables. The A8406 series is available in several types with different cable lengths and terminations. Check the cable specifications that meet your needs. For detailed information, refer to the A8406 series datasheet.

### Power Supply Unit

Please consult with our sales office.

## Dog paw

Taken with radiology type flat panel sensor
Photodiode area: 124.8 · 124.8 mm
Pixel size: 200 μm
Scintillator: direct deposition CsI
Flame rate: 0.5 frames/s
X-ray source: HAMAMATSU L6622-02
(Focus size: 40 μm, window Be: 200 μm) 50 kV, 300 μA

## Hornet

Taken with non-destructive inspection type flat panel sensor

Photodiode area: 52.8 · 52.8 mm

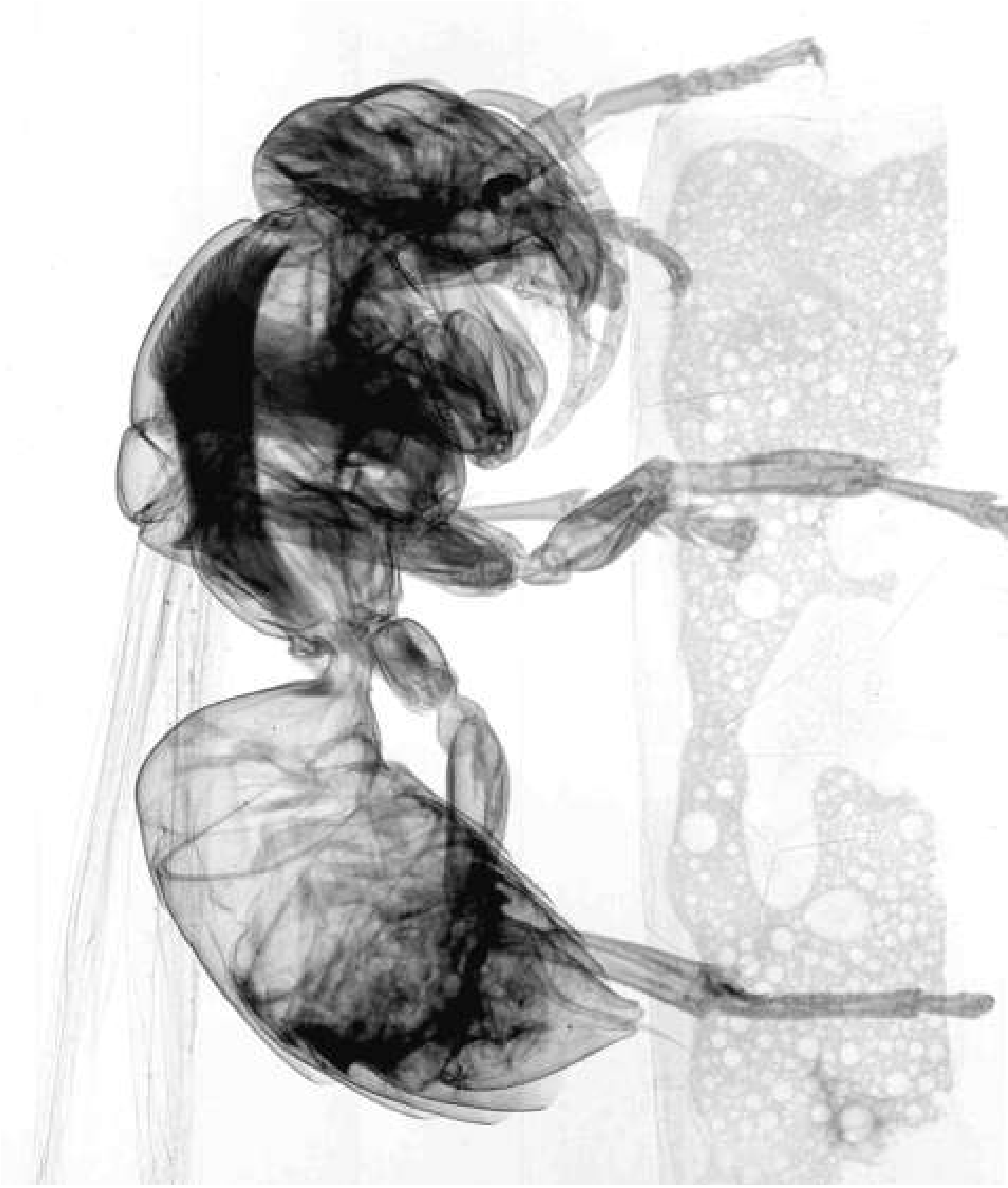
Pixel size: 50 μm

Scintillator: CsI flipped scintillator plate

Flame rate: 0.35 frames/s

X-ray source: RIGAKU 150CPT

(Focus size: 300 μm, window Be: 1 mm) 35 kV, 1.7 mA



## Fish

Taken with radiology type flat panel sensor
   Photodiode area: 120 ·  120 mm
   Pixel size: 50 μm
   Scintillator: direct deposition CsI
   Flame rate: 0.1 frames/s
X-ray source: HAMAMATSU L6622-02
(Focus size: 10 μm, window Be: 200 μm) 35 kV, 200 μA

## Chicken wing

Taken with radiology type flat panel sensor

Photodiode area: 124.8 · 124.8 mm

Pixel size: 200 μm

Scintillator: direct deposition CsI

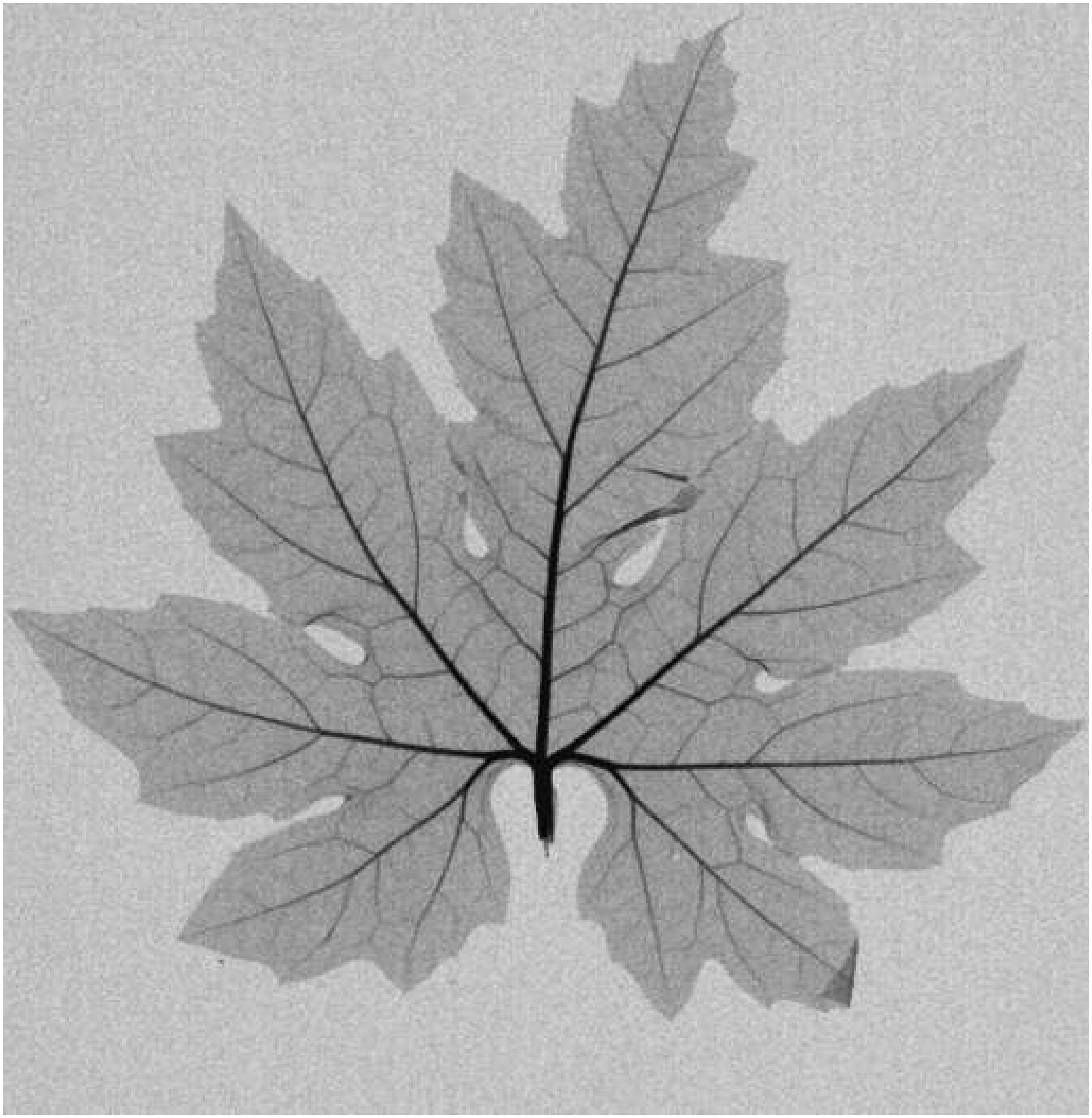
Flame rate: 0.1 frames/s

X-ray source: HAMAMATSU L6622-02

(Focus size: 10 μm, window Be: 200 μm) 30 kV, 150 μA

## Leaf

Taken with radiology type flat panel sensor
Photodiode area: 120 ·  120 mm
Pixel size: 50 μm
Scintillator: direct deposition CsI
Flame rate: 0.1 frames/s
X-ray source: HAMAMATSU L6622-02
(Focus size: 10 μm, window Be: 200 μm) 30 kV, 150 μA



## Cell phone

Taken with non-destructive inspection type flat panel sensor

Photodiode area: 120 · 120 mm

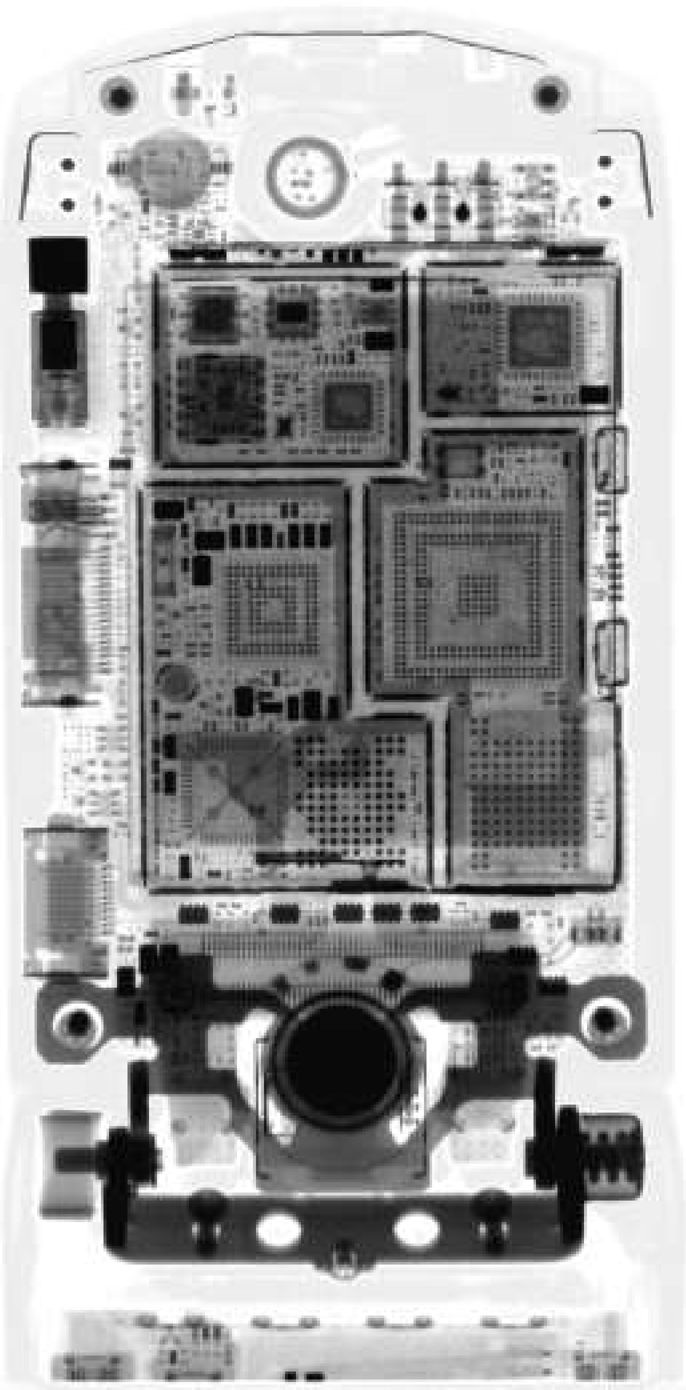
Pixel size: 50 µm

Scintillator: CsI flipped scintillator plate

Flame rate: 0.5 frames/s

X-ray source: HAMAMATSU L7901

(Focus size: 7 µm, window Be: 150 µm) 90 kV, 100 µA



HAMAMATSU has a full line of X-ray sources and cameras for X-ray inspection of electronic components, industrial products as well as for a wide range of fields to meet needs in food processing and security, etc. For detailed information and PDF catalogs on these products, please access our homepage at **www.hamamatsu.com**

Microfocus X-ray source
(sealed type, 100 kV)

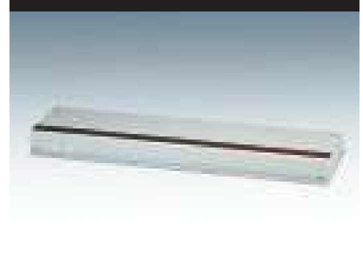
Microfocus X-ray source
(sealed type, 150 kV)

X-ray I. I. digital camera unit

Berillium window
X-ray I. I. camera unit

Compact X-ray CCD camera
“X-CUBE™”

X-ray line scan camera

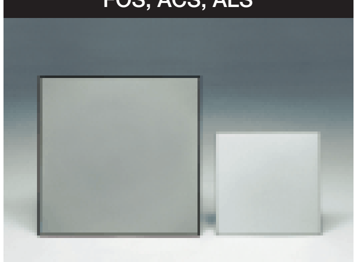


Dual-energy
X-ray line scan camera

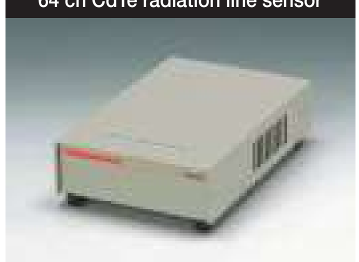
X-ray TDI camera

High resolution
X-ray imaging system

Scintillator plate
“FOS, ACS, ALS”



Energy differentiating
64 ch CdTe radiation line sensor



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