X-ray Flat Panel Sensor

Application Manual

Mar., 2007
Revision 4.24c

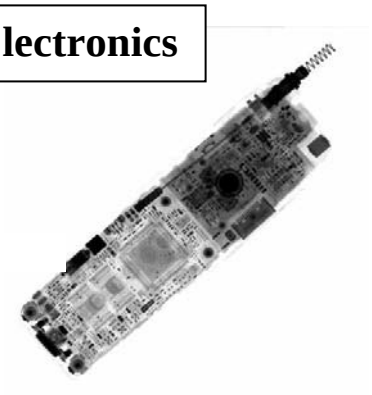
About This Application Manual

This Application Manual consists of mainly two parts.
The first part is 'How to use our Flat panel'. The outline of start up procedure and the concept of Flat Panel Sensors are mentioned in chapter1 to chapter6. For more detail information about the installation and startup, refer to the User's Guide for each Flat panel sensor.
The second part shows the application examples for X-ray imaging acquired by the HAMAMATSU Flat Panel Sensors. The Flat Panel Sensors are widely used in various fields. We categorized the images into six fields. These application examples are showed in chapter7.

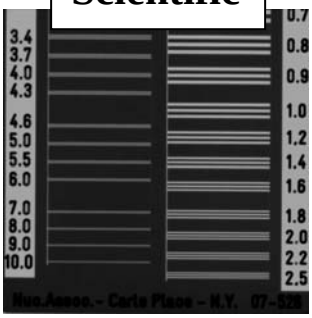
Table of Contents

Chapter 1 Application Field

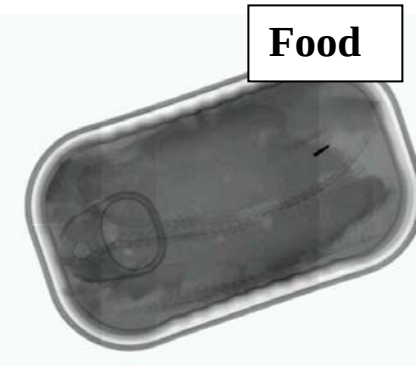
Electronics



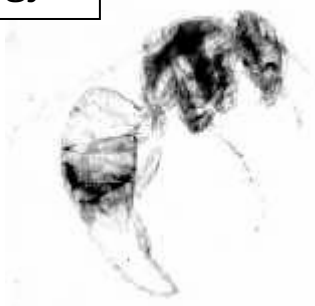
Scientific



Food



Biology



Component

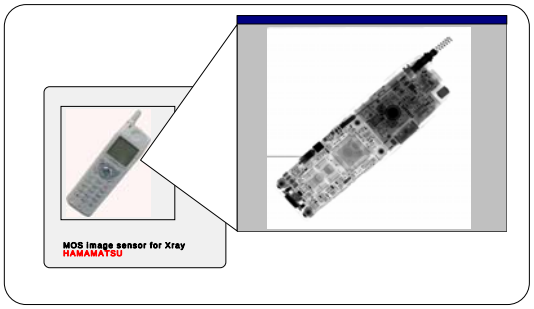
Others

- Soft X-ray Radiography
- Digital X-ray Photography

Chapter 2 Features

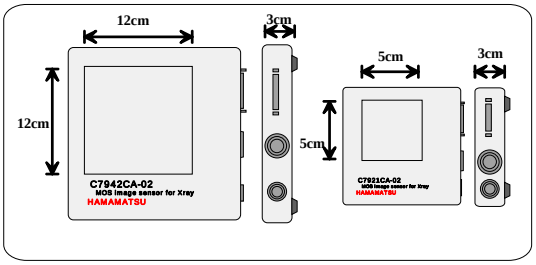
Dynamic Imaging

High Speed Amplifier and high Sensitivity has realized 30 frame / Second dynamic imaging. Users can get X-ray smooth and sharp moving image under X-ray exposure without developing time.



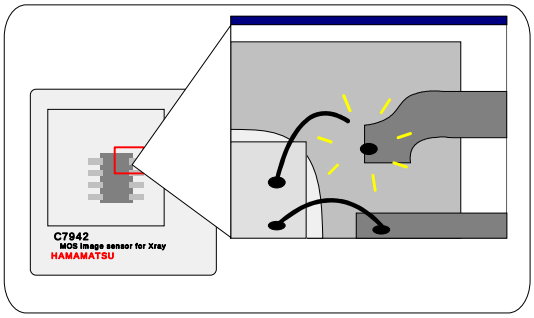
Compact & Large Active Area

Flat Panel has large active area. C7942CA-02&C7943CA-02 have 12cm x 12cm (diagonal size of 7 inches.) and C7921CA-02 has 5cm x 5cm (diagonal size of 3 inches). HAMAMATSU Flat Panel has no spatial distortion.



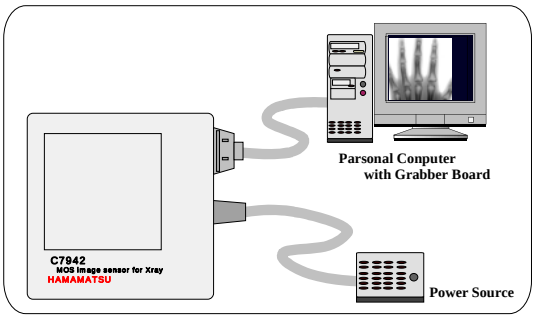
High Resolution

Flat panel incorporated 50um-pitch photo diode array with needle structured CsI scintillator. The C7942CA-02 & 7921CA-02 realized high spatial resolution as 8Line/mm CTF. This means user can recognize small unusual pattern or foreign object.



Off the shelf interface

Flat panel has control board that generates synchronized signals and trigger signals inside the case. User can acquire an X ray images easily after connecting two cables. One cable is for Power Source. The other one connects flat panel to PC with Grabber Board.



Chapter 3 Operating Manual

This chapter is described how to setup the Flat Panel and a procedure for X-ray image acquisition.

Setup

The flat panel module was developed for acquiring the digital X-ray images. The outline is very compact and easy to operate. After connecting the power cable and the data cable to frame grabber installed in a personal computer, User can easily acquire the X-ray digital image in real time by operating the software on PC.
Figure 1 shows the wiring diagram of the imaging system construction.
For more detail, refer to the User's Guide for each Flat Panel Sensor.

Caution : Do not expose the flat panel module to X-ray while the aging of X-ray source is proceeding. It gives unnecessary radiation damage on the flat panel module and shortens its lifetime. Please use a shutter or remove the flat panel module temporary to avoid it.

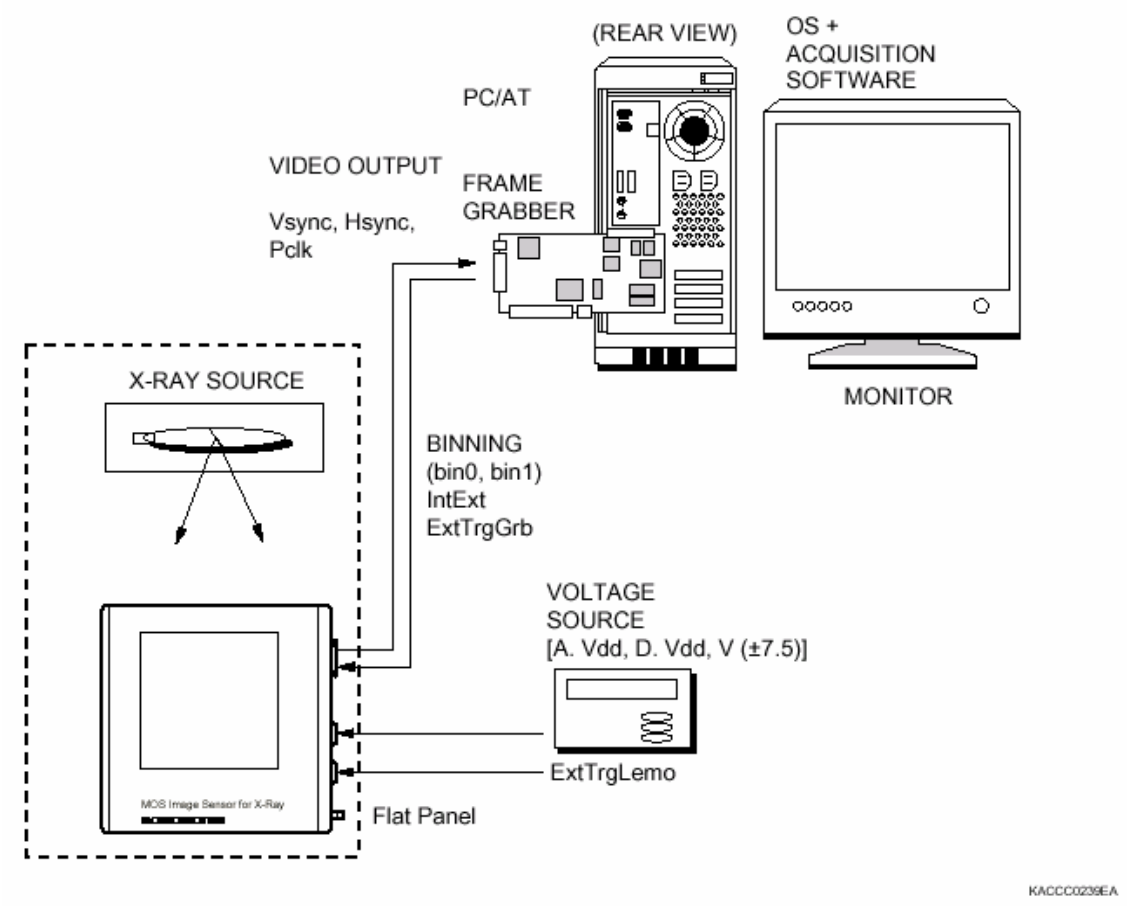


Figure 1

Image Acquiring

Depend on the application fields for X-ray imaging, various types of measurement settings can be considered. For example, User may need to acquire series of x-ray images with a continuous X-ray source, or to acquire a still image synchronized with pulsed X-ray source. Moreover, depending on the object is moving or standstill, the system will be different style.

If user has no need to change the accumulation period or no need to synchronize the trigger timing with the X-ray source, continuous image acquisition is suitable. The simple way for the continuous acquisition is the internal trigger mode as mentioned in the previous section. User can acquire the continuous image with the frame speed of Sf(int) without any external trigger timing signal. In case of continuous image with longer accumulation period, flat panel is set as the external trigger mode. In this case, user needs to send the external trigger signal repeatedly with the same period as the accumulation period.

On the other hand, to take a still image, user may need to know about the flat panel more detail. If user save one frame image during the continuous image acquisition, it will be a still image. However, under the pulsed X-ray source with which the acquisition timing of the flat panel sensor have to be synchronized, or when to synchronize it to the trigger timing with a moving object is always captured at the center of frame, external trigger mode has to be selected.

Under the external trigger mode, the external trigger signal must be supplied to the flat panel. For the flat panel sensor, this trigger timing is not only the end of accumulation period, but also the start of the readout sequence. It means that at least two trigger pulses are needed in order to synchronize the acquisition timing to the external event. (Refer to page-21) By adjusting the shot timing of the pulsed X-ray as it comes to between these two triggers, the still image will be captured perfectly.

Binning Mode

The C7921CA-02, C7942CA-02 and C7943CA-02 can deliver high-resolution images in the single pixel drive mode. On the other hand, they have a binning drive mode for high-speed and high-sensitivity operation. A user can select 2x2 and 4x4 binning mode. In the 2x2 binning mode, the neighboring 2x2 pixels are read out together. In the 4x4 binning mode, the neighboring 4x4 pixels are read out together. So the user can drive the module with higher frame rate, controlling the binning mode. Moreover when it is made to drive at the same frame rate, the amount of signals becomes 4 times larger by 2 x2 binning mode and 16 times by 4x4 binning mode.

Trigger Mode

The Flat Panel Sensor has two-trigger mode. One is internal trigger mode, the other one is external trigger mode. Under the internal trigger mode, video signal and synchronous signals always flow out from the flat panel at the highest frame speed of Sf(int), which is described in the electrical specification. On the other hand, the user can choose the external trigger mode to synchronize it 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 range of this period is restricted between Sf (int) and 0.1 frame/sec. 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 select internal trigger mode, the signal of 'IntExt' should be set to Low. If 'IntExt' is set to High, the flat panel 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 Personal Computer. The other is supplying the synchronous signal through 'ExtTrgLemo' from X-ray source. Please refer to following table about Pin number (Table 1) and Configuration chart (Table 2).

Table 1 Pin number

Type Number	receptacle	IntExt	ExtTrgGrb	ExtTrgLemo
C7921CA-02	36 pin	#33	#15	2 pins LEMO receptacle
C7942CA-02		#33	#15	
C7943CA-02		#33	#15	

Table 2 Configuration chart

Trigger Mode		IntExt	ExtTrgGrb	ExtTrgLemo
Internal		Low	ignored	ignored
External	Control by ExtTrgGrb	High or Open	TTL	High or Open
	Control by ExtTrgLemo	High or Open	High or Open	TTL

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.

Correction Procedure

Raw image taken by the Flat Panel Sensor inevitably contains unevenness of dark offset and X-ray sensitivity non uniformity, blemish of scintillating material, some defect lines, little bit higher sensitivity on the neighboring line to the defect line too. A spatial non-uniformity of X-ray source also causes un-flatness in light field image. Please make an image correction certainly in order to eliminate these components.

After the exposure of X-ray, the increase of dark offset and the decrease of sensitivity will be observed. Refer to 'Chapter6 FAQ' for the degree of their dose dependence. And they also depend on the operation temperature. So user should make a calibration periodically to keep a necessary image quality under your system.

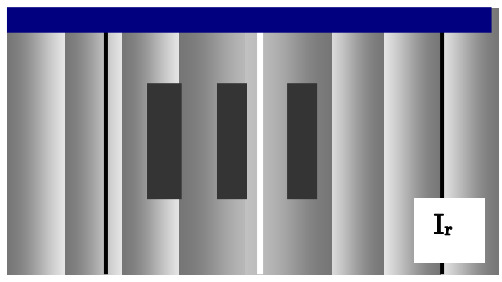
Followings are the basic example of image correction procedure.

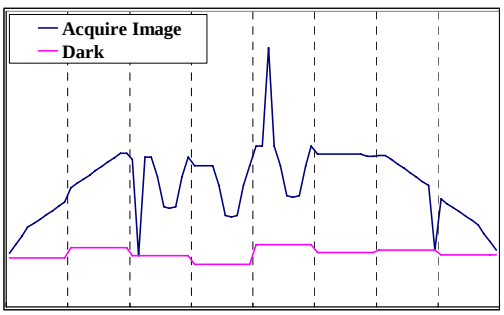
1.Substracrion of dark image

In order to subtract dark image, the Flat Panel was given a fixed offset specially. The dark image I_d contains the offset and dark current of pixels equivalent to the integration time. The dark image is included in an output raw image I_r (Graph 1). It must be removed from the raw image in order to get dark free image I_{c1} (Image2 & Graph 2).

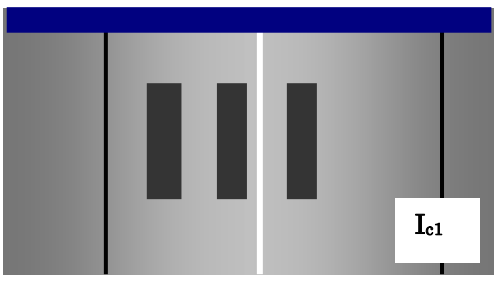
$$I_{c1}(x,y) = I_r(x,y) - I_d(x,y) \qquad (1)$$

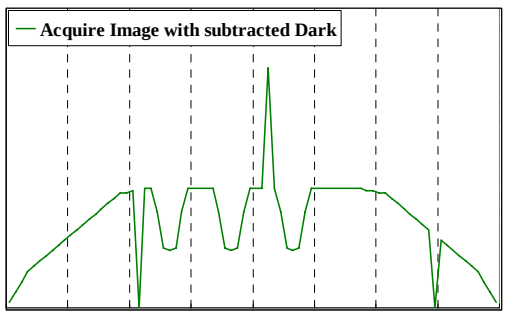
It is recommend taking the dark image after the flat panel would reach its temperature equilibrium, which depend on the installed surrounding in a system and to take it before image acquisition.





Graph 1





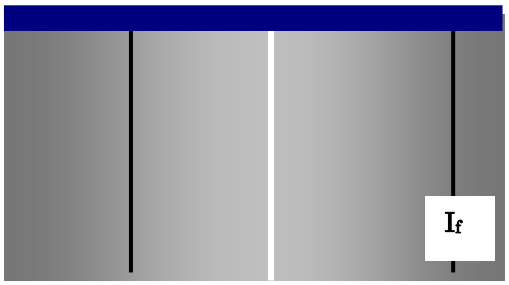
Graph 2

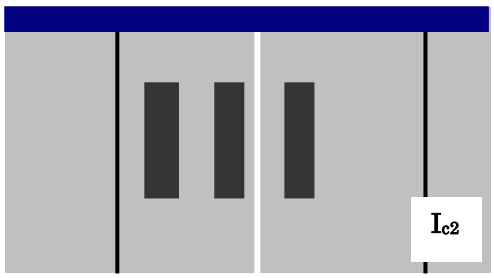
2.Correction of Light field

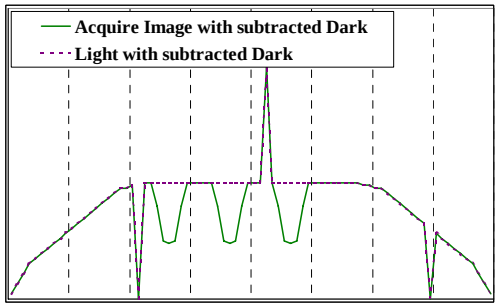
The light field correction will improve slightly varying sensitivity in a flat panel over the active region and spatial non-uniformity of x-ray source. A dark image is subtracted from a Light image I_f (Graph3) without the object. A signal level of a light field image was adjusted to be same gray level of the ROI with the object image in this example. User will get corrective image with dividing Object image by Light field image and multiplying by the average of Light image *c* (Graph4).

$$I_{c2}(x,y) = c \cdot \frac{I_{c1}(x,y)}{I_f(x,y) - I_d(x,y)} \qquad (2)$$

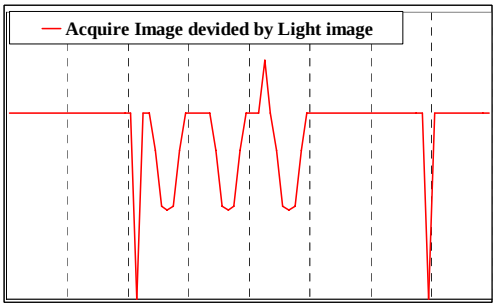
where c is constant which is the average of the $(I_f(x,y)-I_d(x,y))$.







Graph 3

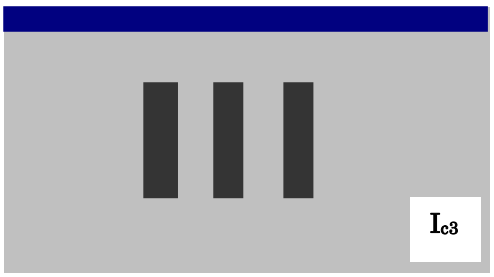


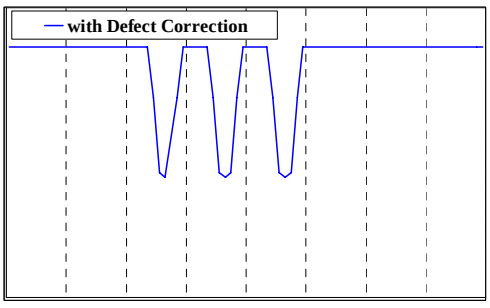
Graph 4

3. Correction of defect lines

A defect line V(p,y) will be interpolate from the neighbors of defect line (V(p-1,y), V(p+1,y)). After above procedure, users can acquire the high quality images I_{c3} (Graph5).

$$V(p,y) \leftarrow \frac{V(p+1,y) + V(p-1,y)}{2}$$





Graph 5

Range Adjustment

Thanks for the wide dynamic range of the flat panel module, the C9730DK and C9732DK can output 16384 gray scale video data (in case of C7921CA-02, C7942CA-02 and C7943CA-02, output gray scale video data is 4096.) On the other hand, Microsoft Windows can display only 256 gray scale. Therefore the image displayed by two methods described below.

1. Whole gray level is compressed into 256 gray level. (see Figure 2).
2. Partial gray level is compressed into 256 gray level. (see Figure 3).

By using the window adjustment function of the software, user can accentuate the image value range of interest in real time.

Figure 2

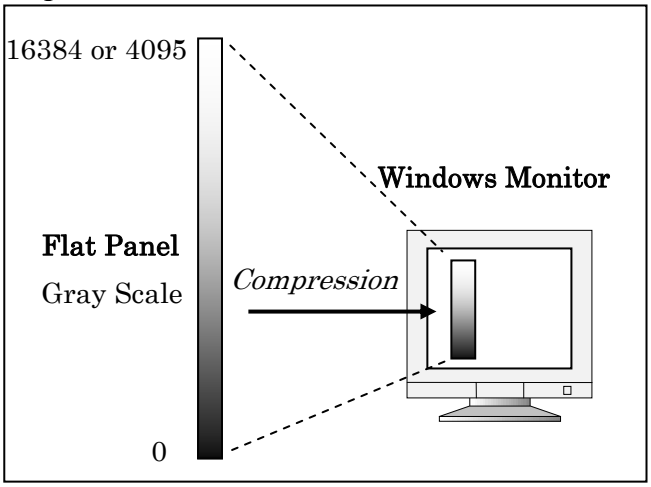
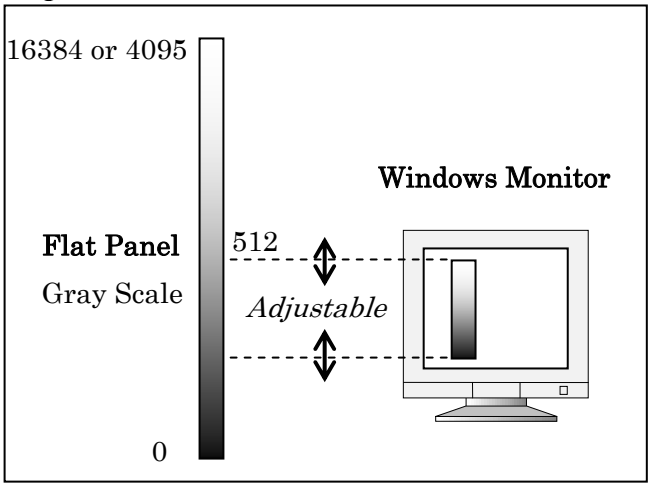


Figure 3



Chapter 4 Line up

Selection Guide

An unique and innovative CMOS Flat panel sensor (FP) product of Hamamatsu allow you to get wide range of x-ray imaging. Following tables assist you to make a best selection of the FP for your individual application.

Hamamatsu prepared two types of AD converter bit depth, three kinds of image area size and pixel piths, and a few types of Scintillator (coupling method to photo diode array) and Top cover materials.

Symbols follows a type number are shown below.

CxxxxV∆-yy

Cxxxx : Flat panel device type No.
(C7921 (C7920), C7942, C7943,C9250)

V : Scintillator
C: CsI:Tl (Conventional coupling method to Photo Diode Array)
D: CsI:Tl (Direct Deposited on Photo Diode Array)
S: GOS (GOS is deposited onto an X-ray shielded FOP)
G: GOS Kodak Lanex Regular screens --- depend on a request

∆ : Top cover material
A: Aluminum 1mmt
P: Poly-carbonate 1mmt
K: carbon fiber --- depend on a request

-yy : version No.
-(none) : Energy range is 20kVp to 80kVp
-02 : Exclusive external trigger receptacle is applied. Energy range is 20kVp to 100kVp

If the active area is 5 x5 cm, pixel size is 50um, CsI:Tl scintillator with conventional coupling method and Aluminum Top cover, the type Number is C7921CA-02.

The list of type number is shown below.

Type Number	A/D bit	pixel size	size	Scintilator	Top cover
C7921CA-02	12 bit	50um	5x5cm	CsI:Tl(conventinal)	Al
C7920DA-02				CsI:Tl(Direct Deposition)	
C7942CA-02			12x12cm	CsI:Tl(conventinal)	
C7943CA-02		100um			
C9250DP		200um		CsI:Tl(Direct Deposition)	Poly-Cabonate

The detail of each device, scintillator and top cover material is defined as below.

Device

C7921CA-02 and C7920DA-02 are compact and high cost performance CMOS imager of 50 um pixels. C7942CA-02 has 50 um pixels features high resolution of 8 Lp/mm and large active area (120x120mm). C7943CA-02 has 100 um pixels, can get images in a high speed of 30 frames/sec by means of 4×4 binning readout.
C9250DP has high sensitivity and fast frame rate.

For the selection, it is showed below five concern parameters on the Flat panels. Five Parameters are “Speed”, ”Sensitivity”, ”Resolution”, ”Active Area”, and “Cost performance”.

	C7921CA-02	C7920DA-02	C7942CA-02	C7943CA-02	C9250DP
Photo Diode Array	5 x 5		12 x 12		
Pixel size (um)	50			100	200
Scintillator	CsI Plate	CsI Direct Depo	CsI Plate		CsI Direct Deposition
Top cover material	Aluminum				Poly-carbonate
Energy Range (kVp)	20 to 100				20 to 80
Speed	B	B	B	A	A
Sensitivity	B	A	B	B	A
Resolution	B	A	B	B	B
Active Area	B	B	B	B	B
Cost performance	A	A	B	B	B

Functional Specifications

Items	C7921CA-02	C7942CA-02	C7943CA-02
Readout	Charge amplifier array		
Video output	RS422 (differential) 12 bit		
Output data rate	6.25 MHz	15.15 MHz	
Synchronous signal	RS422 (differential)		
bin0, 1, ExtTrg, IntExt	TTL		

Absolute Maximum Ratings (Ta=25deg.C)

Items	Symbols	Ratings	Units
Supply voltage for digital circuitry (+5V)	D.vdd	+ 6.0	V
Supply voltage for analog circuitry (+5V)	A.vdd	+ 6.0	V
Supply voltage for analog circuitry(+/-7.5V)	V(+/-7.5)	+/- 12	V
Operating Temperature (not condensed)	Topr	-0 to +35	deg.
Storage Temperature (not condensed)	Tstg	-0 to +50	deg.
Input Voltage (bin0 , bin1 , ExtTrgGrb , ExtTrgLemo , IntExt)	Vin	0 to +6.0	V

Electrical specifications

A.vdd=5.0V, D.vdd=5.0V, V(+/-7.5)=+/-7.5V, 25deg.C

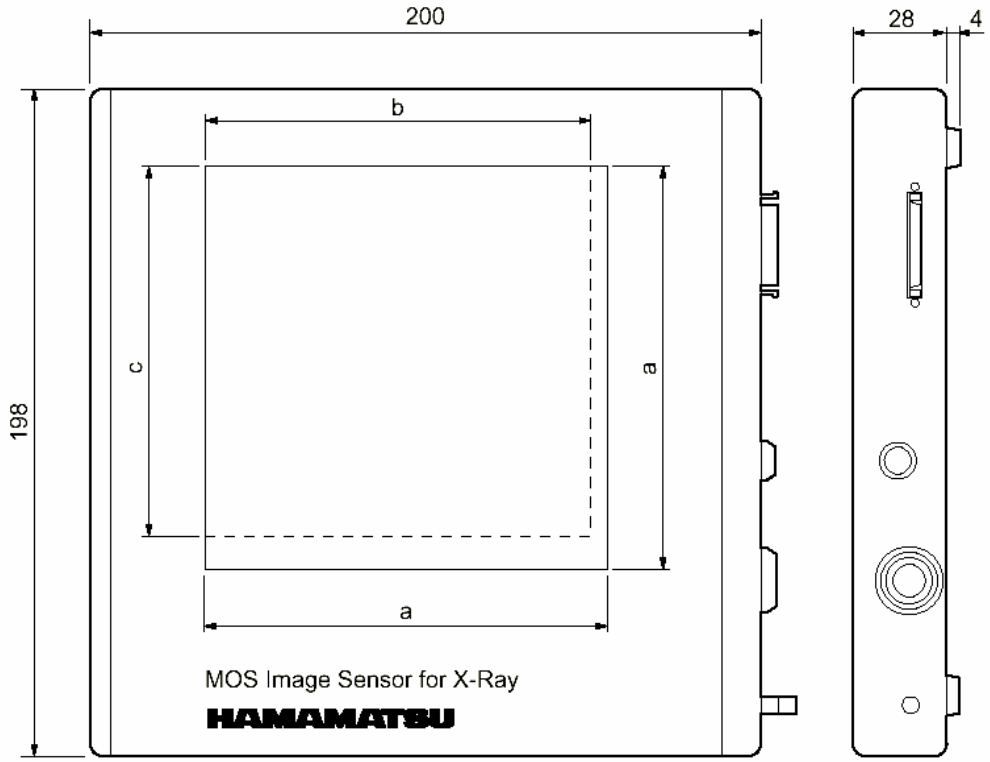
Items	Symbols	C7921CA-02 (Typ.)	C7942CA-02 (Typ.)	C7943CA-02 (Typ.)	Units
Pixel size		50	50	100	um
PD array area		52.8 x 52.8	120 x 120	124.8 x 124.8	mm
Array number		1.1	5.76	1.56	M pixels
Frame speed (single operation)	Sf(int)	4	2	7	Frame / s
Frame speed (2x2 binning)		8	4	15	Frame / s
Frame speed (4x4 binning)		16	9	30	Frame / s
Frame speed external (single operation)	Sf(ext)	Sf(int) to 0.1			Frame / s
Noise (rms.)	N(rms.)	1000	1100	2300	Electrons
Sensitivity @80kVp without filter	Sens.	18	25	25	LSB /mR
Sensitivity Mo target 30kV without filter	Sens.	-	-	-	LSB /mR
Resolution	Reso	8	8	5	Line pairs / mm
D range		2900	2000	4300	-

Number of elements	-	1056 x 1056	2400 x 2400	1248 x 1248	Pixels
Effective elements		1032 x 1012	2240 x 2344	1216 x 1220	Pixels

Physical Dimensions

C7942CA-02 & C7943CA-02 Physical Dimensions (unit:mm)

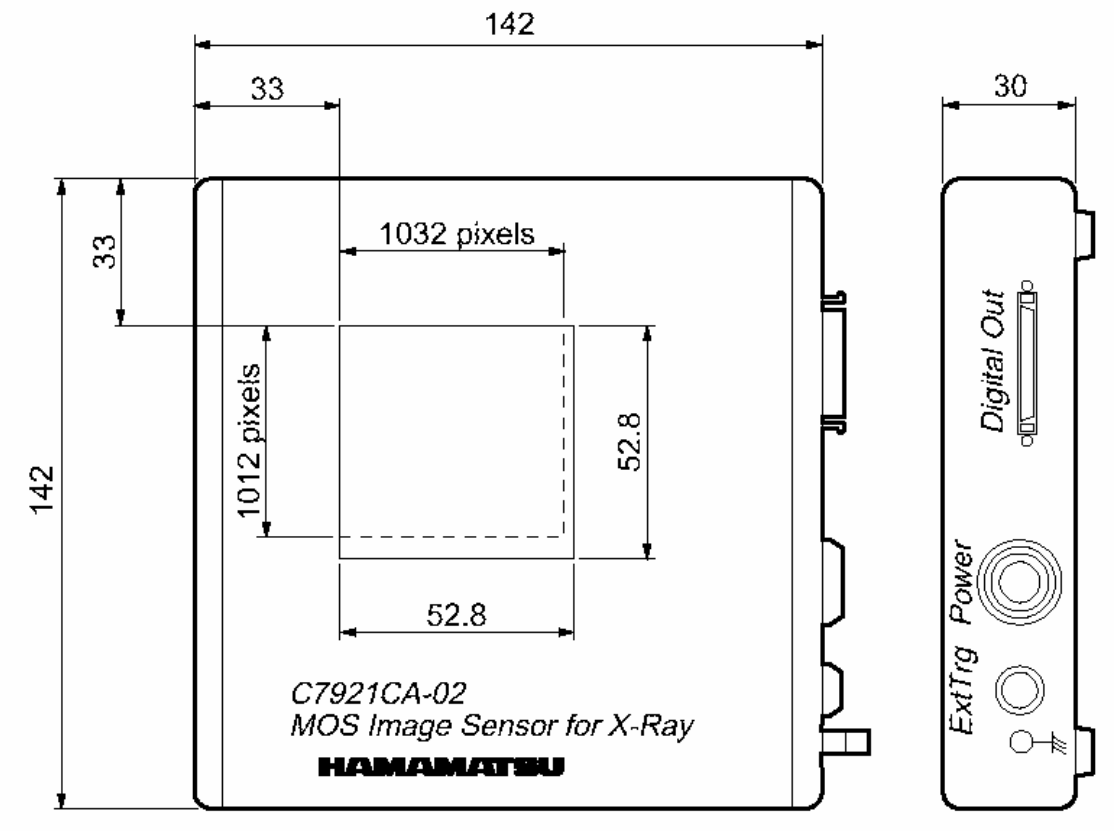
(In case of C7942CA-02, printing number changes to C7942CA-02)



The top cover is made of Aluminum 1.0-mm thickness.
Detective area is 8mm inside from top cover surface.

	C7942CA-02	C7943CA-02
a	120mm	124.8mm
b	2240 pixels	1216 pixels
c	2344 pixels	1220 pixels

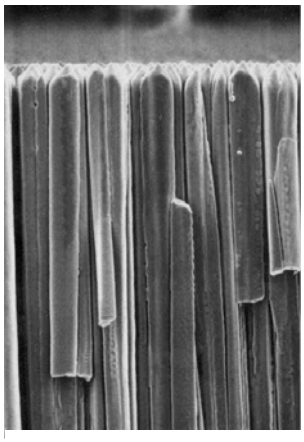
C7921CA-02 Physical Dimensions (unit:mm)



The top cover is made of Aluminum 1.0-mm thickness.
Detective area is 9mm inside from top cover surface.

Scintillator

HAMAMATSU adopted the indirect method for these flat panel devices utilizing a scintillator. By controlling the impurity profile and anti-reflection layer for CsI:Tl emission light wave length, we have developed an optimal, high-sensitivity X-ray device that is ideal for X-ray detection. And CsI:Tl scintillator plate has a needle structure like this picture. The needle acts as a light guide and the high resolution can be obtained. For CsI:Tl scintillator ,there are two coupling method between with CMOS. One is conventional type (Type C). Another one is improved direct deposition type (Type D). Improved type achieved higher sensitivity and higher resolution.



Needle like structured CsI

Each scintillator's characteristic is below.

Suffix	Scintilator	Coupling method	Sensitivity	Resolution	Note
C	CsI:Tl	Conventional	○	○	-
D		Direct deposition	◎	◎	relatively expensive

Note

As we describe above, If scintillator selection is Type D, the device Number also changes as below.

Scintilator Type is C		Scintilator Type is D
C7921	-->	**C7920**

Top cover material

Top cover protects the devise against a physical damage, shielding and acts as a filter for the soft X-ray. When X-ray source voltage is higher than 80kVp, absorption of X-ray by the 1mm thickness aluminum top cover is less than 50%, and its lifetime is expanded with the aluminum top cover. On the contrary, if the tube voltage is less than 80kVp, a polycarbonate top cover has good sensitivity.

Suffix	Material	Thickness	X-ray energy
A	Aluminum	1mm	20 to 100kVp
P	Poly-Carbonate	1mm	less than 80kVp

Chapter 5 Application Note

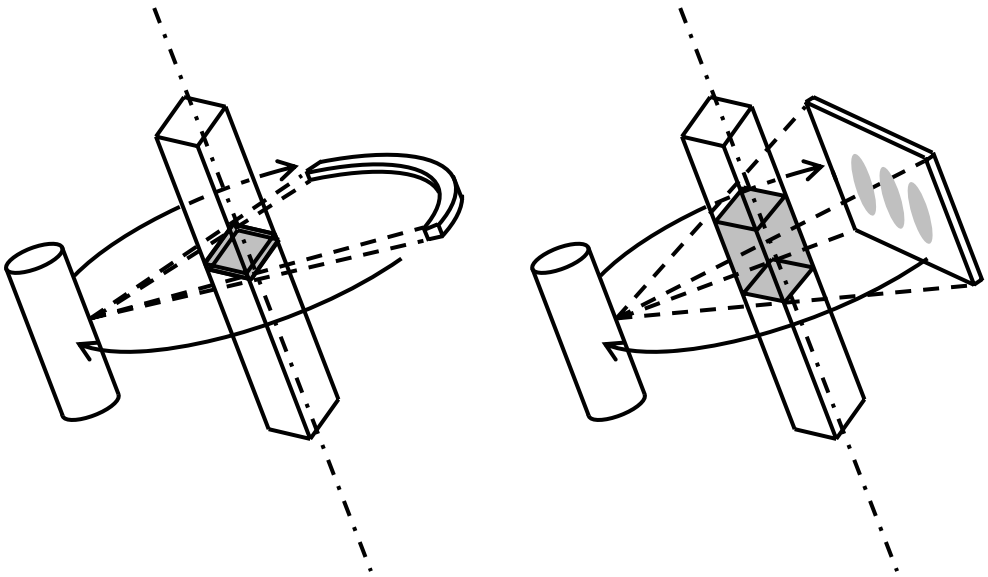
X-Ray CT

The X-ray CT is one method to analyze the internal structure of an object without destruction. The CT is a shortened form of the "Computed Tomography." Irradiating the X-ray from many directions and take the projection images of penetrated X-ray for each direction. By calculating the absorption coefficient of the inside of the object from these data, the slice image or 3D image of the object can be reconstructed.

In the traditional way of the CT scanning, two dimensional slice images is reconstructed from many one-dimensional acquired data. In order to reconstruct three-dimensional internal image of the object, it is needed to acquire the two dimensional projection data.

The flat panel sensor is very suitable for X-ray CT application especially for 3D-CT, because it can acquire two-dimensional image with high speed and high resolution.

The CT scanning system is mainly divided into two types for small object and large object. If the object is small, the easiest way for scanning is rotating the object between the X-ray source and the detector. But, in case of the inspection of large object, the X-ray source and the detector has to be rotated around the object. Then, the compactness and lightness of the flat panel sensor will become the advantages. Especially, because the thickness of the flat panel is only about 3 cm, the detector head of the scanner can be miniaturized.



External triggering for Pulse X-ray Source

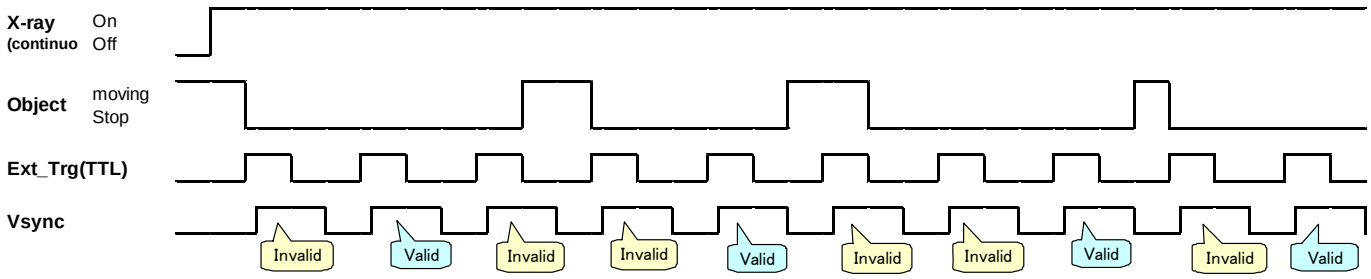
In most X-ray imaging applications, it is not needed to synchronize the X-ray timing with the image acquisition timing of the detector, because the continuous X-ray source is used. On the other hand there are some applications using pulse X-ray source.

The pulse X-ray source emits the X-ray in short period when the trigger is given externally. Furthermore, when the detector is acquiring the image continuously, if the pulse X-ray is triggered, the snapshot of the object can be taken.

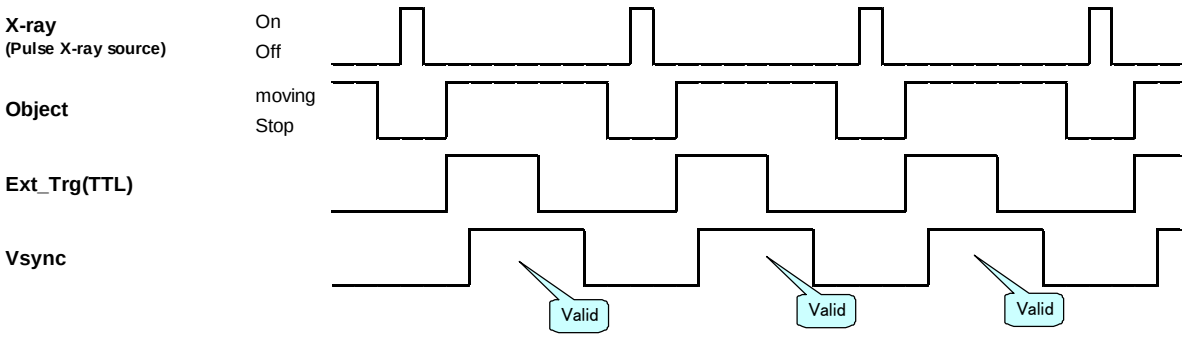
To use the pulse X-ray source with CMOS FP, the X-ray trigger timing and the acquisition timing of CMOS FP must be synchronized. For this application, it is convenient to use the external trigger mode of CMOS FP.

In external trigger mode, if the external trigger signal is applied to CMOS FP, the charges in photodiode that accumulated before the external trigger signal is applied are read out. In other words, Acquired image is accumulated before external trigger applied, is not image the time just external signal applied.

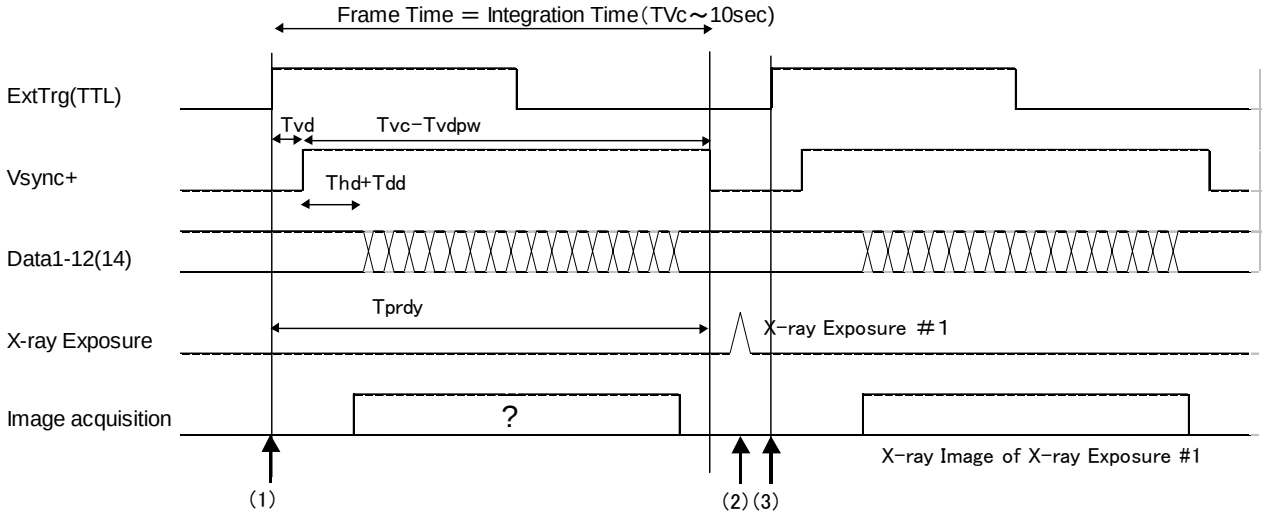
Therefore in case of acquiring the image of moving object using continuous X-ray source, it is need less than two trigger pulses to acquire valid image as shown below. In this Timing chart, because the invalid image contains moving object image, so user should be reset before taking valid image.



On the other hand, in case of using pulse X-ray source, because it can expose very short period, all acquired images is valid by adjusting the shot timing of the pulsed X-ray as shown below.



Timing diagram for external triggering with pulse X-ray source is shown below.



(1) Before the pulse X-ray exposure, the first external trigger signal has to be sent to the CMOS FP in order to clear the previous frame information and to begin the accumulation of new frame.

(2) Apply the exposure trigger signal to the pulse X-ray source. One important thing is that this X-ray exposure signal must be sent between Tprdy and the rising edge of the next ExtTrg as shown in above timing diagram. Tprdy is defines as follows, and refer to CMOS FP's user's Guides about the other parameter values.

$$Tprdy = Tvd + Tvc - Tvdpw$$

(3) After the irradiation of the pulse X-ray went out, by sending the second ExtTrg to the CMOS FP, the accumulation finishes and the acquired image is read out.

C7942 series 1x1 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	390	us
	Cycle Time	Tvc	470	ms
	Dummy Pulse Width	Tvdpw	770	us
Hsync	Delay Time	Thd	1.4	us
	Cycle Time	Thc	190	us
	Dummy Pulse Width	Thdpw	35	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	34	ns
	Cycle Time	Tdc	66	ns

C7942 series 2x2 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	390	us
	Cycle Time	Tvc	230	ms
	Dummy Pulse Width	Tvdpw	770	us
Hsync	Delay Time	Thd	1.4	us
	Cycle Time	Thc	190	us
	Dummy Pulse Width	Thdpw	110	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	34	ns
	Cycle Time	Tdc	66	ns

C7942 series 4x4 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	390	us
	Cycle Time	Tvc	117	ms
	Dummy Pulse Width	Tvdpw	770	us
Hsync	Delay Time	Thd	1.4	us
	Cycle Time	Thc	190	us
	Dummy Pulse Width	Thdpw	150	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	34	ns
	Cycle Time	Tdc	66	ns

* The number of significant figures is two.

C7943 series 1x1 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	210	us
	Cycle Time	Tvc	130	ms
	Dummy Pulse Width	Tvdpw	420	us
Hsync	Delay Time	Thd	1.8	us
	Cycle Time	Thc	110	us
	Dummy Pulse Width	Thdpw	22	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	33	ns
	Cycle Time	Tdc	66	ns

C7943 series 2x2 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	210	us
	Cycle Time	Tvc	66	ms
	Dummy Pulse Width	Tvdpw	420	us
Hsync	Delay Time	Thd	1.8	us
	Cycle Time	Thc	110	us
	Dummy Pulse Width	Thdpw	63	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	33	ns
	Cycle Time	Tdc	66	ns

C7943 series 4x4 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode	Tvd	210	us
	Cycle Time	Tvc	33	ms
	Dummy Pulse Width	Tvdpw	420	us
Hsync	Delay Time	Thd	1.8	us
	Cycle Time	Thc	110	us
	Dummy Pulse Width	Thdpw	84	us
Pclk	Delay Time	Tpd	65	ns
	Cycle Time	Tpc	66	ns
	Pulse Width	Tppw	33	ns
	Delay Time Between Each Block	Tpdb	200	ns
Data1-12	Delay Time	Tdd	33	ns
	Cycle Time	Tdc	66	ns

＊ The number of significant figures is two.

C7921 series 1x1 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode)	Tvd	450	us
	Cycle Time	Tvc	243	ms
	Dummy Pulse Width	Tvdpw	920	us
Hsync	Delay Time	Thd	2.8	us
	Cycle Time	Thc	230	us
	Dummy Pulse Width	Thdpw	59	us
Pclk	Delay Time	Tpd	150	ns
	Cycle Time	Tpc	160	ns
	Pulse Width	Tppw	85	ns
	Delay Time Between Each Block	Tpdb	480	ns
Data1-12	Delay Time	Tdd	50	ns
	Cycle Time	Tdc	160	ns

C7921 series 2x2 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode)	Tvd	450	us
	Cycle Time	Tvc	122	ms
	Dummy Pulse Width	Tvdpw	920	us
Hsync	Delay Time	Thd	2.8	us
	Cycle Time	Thc	230	us
	Dummy Pulse Width	Thdpw	140	us
Pclk	Delay Time	Tpd	150	ns
	Cycle Time	Tpc	160	ns
	Pulse Width	Tppw	85	ns
	Delay Time Between Each Block	Tpdb	480	ns
Data1-12	Delay Time	Tdd	50	ns
	Cycle Time	Tdc	160	ns

C7921 series 4x4 Mode

Parameter		Symbol	Typ.	Unit
Vsync	Delay Time (only External Trigger Mode)	Tvd	450	us
	Cycle Time	Tvc	62	ms
	Dummy Pulse Width	Tvdpw	920	us
Hsync	Delay Time	Thd	2.8	us
	Cycle Time	Thc	230	us
	Dummy Pulse Width	Thdpw	190	us
Pclk	Delay Time	Tpd	150	ns
	Cycle Time	Tpc	160	ns
	Pulse Width	Tppw	85	ns
	Delay Time Between Each Block	Tpdb	480	ns
Data1-12	Delay Time	Tdd	50	ns
	Cycle Time	Tdc	160	ns

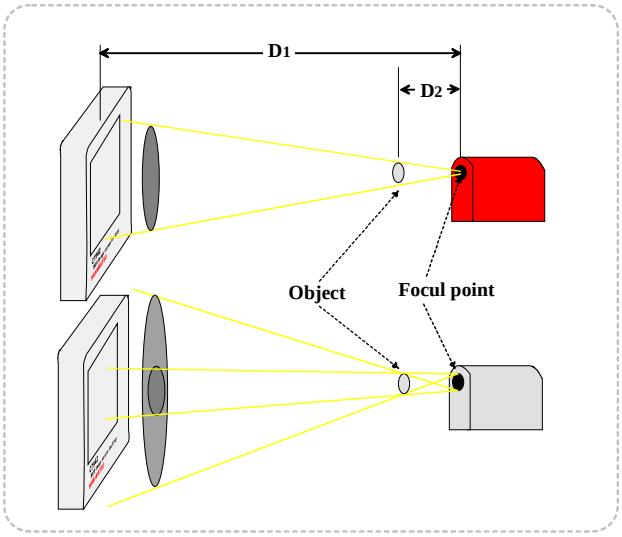
* The number of significant figures is two.

Magnification with Micro Focus X-ray Source (MFX)

Since CMOS FP has high resolution and no distortion, it is extremely available to acquire a very small object (foe example wire bonding of IC, Ball Grid Array type IC etc) image with high magnification.
The magnifying power at this time is define as follows. Therefore, When the distance of CMOS FP and the X-ray source is fixed, the more it brings an object to the X-ray source, the more it turns out that the magnifying power becomes large.

Magnifying power = D1 / D2
D1: (Distance from the focus of X-ray to Flat Panel)
D2: (Distance from the focus of X-ray to the object)

If the focal size of the X-ray source becomes large, dotage of the image at the time of expansion will become large as shown right illustration. Therefore more Clear expansion image can be acquired with micro focus X-ray source (MFX) where a focal size is small from several microns to several ten microns.



Chapter 6 FAQ

About Flat panel

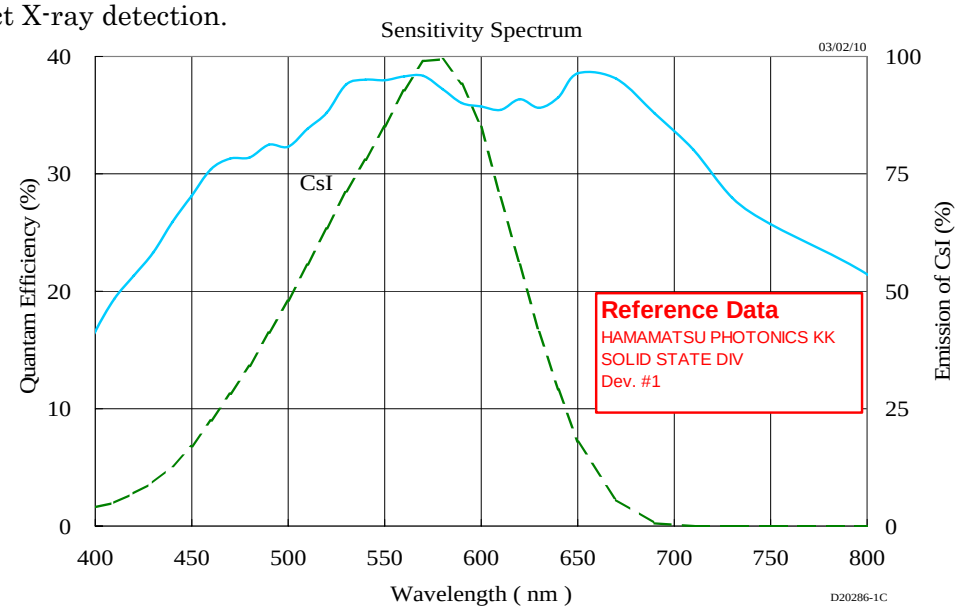
Q) For X-ray imaging system, X-ray Imaging Intensifier, CCD and a-Si are well known as the standard device. What are difference between CMOS flat panel and these devices?

A) CCD is difficult to make a large size device. It becomes disadvantage for the X-ray imaging, because the X-ray can not be condensed by lens system. On the contraries, the a-Si can be made a larger size, but the decay time is very long. Therefore, in case of the high-speed operation, after image becomes the problem. To solve these problems, we have developed the CMOS flat panel sensor. By using the CMOS, can make medium size device between the a-Si and the CCD without after image. Comparison of other characteristic is described below.

	Sensitivity	Resolution	Active Area Size	Dynamic Range	Cost Performance	Distotion	Note
X-ray II	◎	△	○	×	○	×	●Camera Volume is huge
CCD	○	◎	×	△	△	○	●Difficult to make a large size
a-Si	△	△	◎	○	△	○	●Decay Time is long ●Relative Expensive
CMOS Flat Panel	○	○	○	◎	◎	○	-

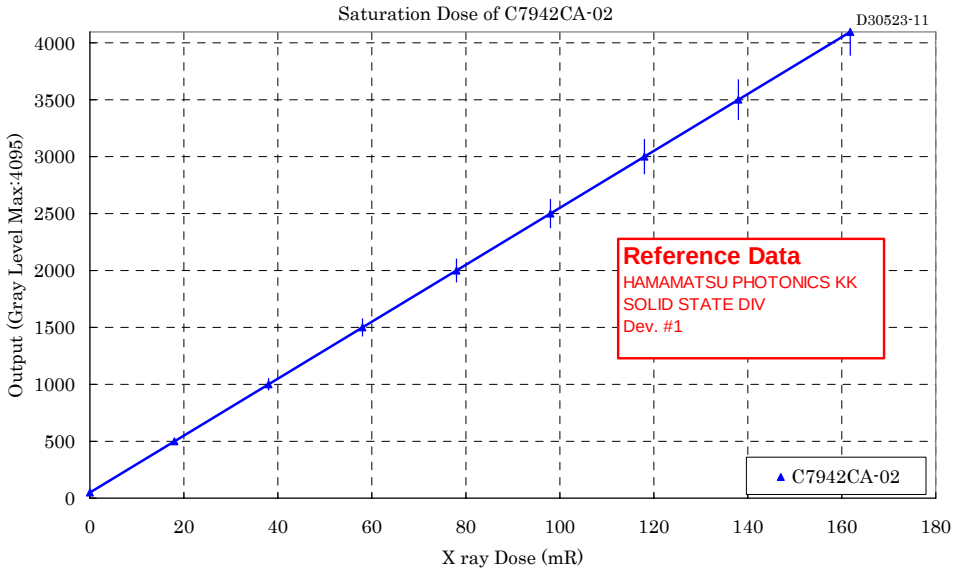
Q) How about CMOS Quantum Efficiency (QE) Curve is?

A) The QE curve of the CMOS flat panel and CsI Emission wavelength is shown below. A spectral response characteristic that matches the peak wavelength and spectral range of the scintillator emission is a critical factor for the photodiode and scintillator matrix design. By controlling the impurity profile and anti-reflection layer, we have developed an optimal, high-sensitivity X-ray device that is ideal for indirect X-ray detection.



Q) How about sensitivity these flat panels have?

A) Output (gray levels) to the X-ray Dose is shown below. You can see that flat panels have good sensitivity and linearity from this graph. (Incase of C7942CA-02, the sensitivity at 80kVp without filter is 25 LSB / mR)

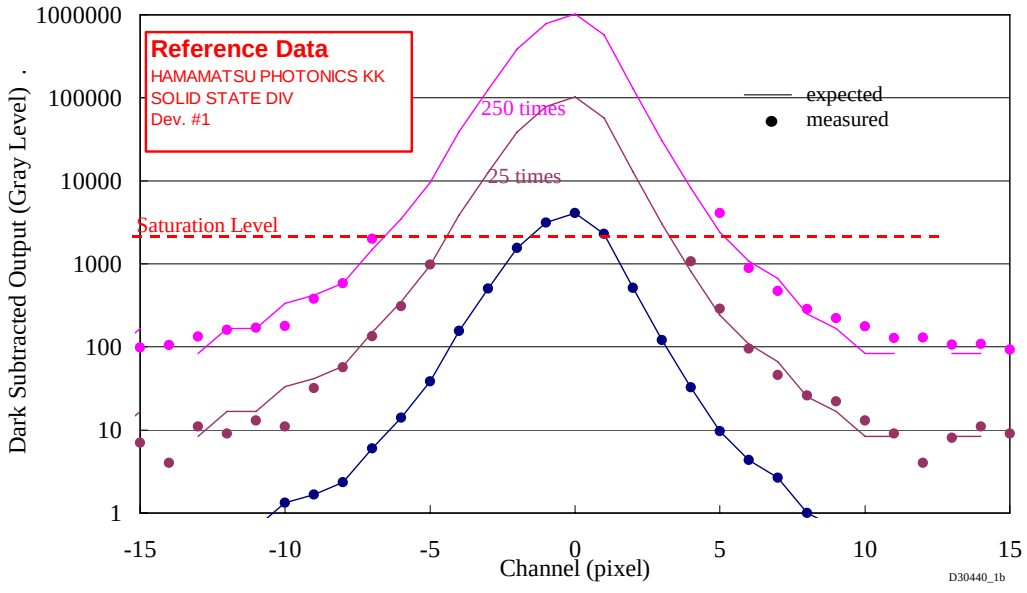


Q) What is the sensitivity at 5 - 15 MeV?

A) The Flat panels are designed to be sensitive less than 100 kVp.(In case of C9730DK and C7932DK is designed to be sensitive at 35kV.) Sensitivity is quite low at MeV level gamma ray. For example, in the case of 3 MeV Gamma ray, only 0.2 % is absorbed by Scintillator. The absorption is much lower at 5 to 15 MeV.

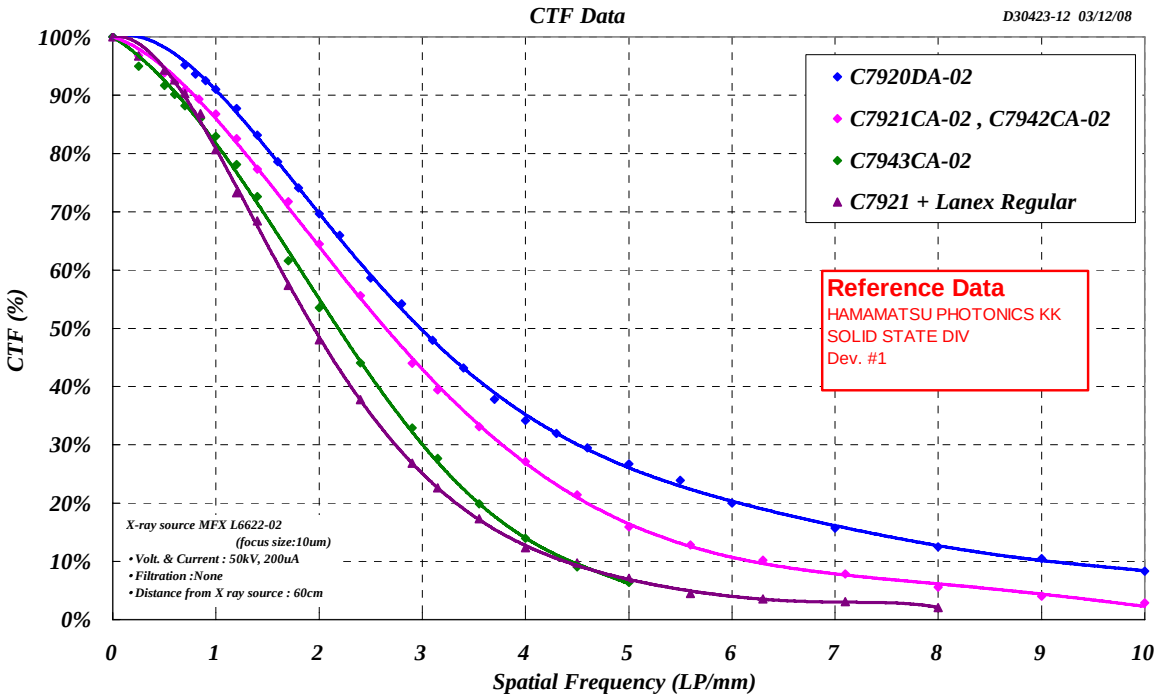
Q) Does a Flat panel show something like blooming?

A) An anti-blooming construction of the CMOS photodiode can suppress a cross talk to the neighbor pixels at 250 times of Saturation level as showed below.



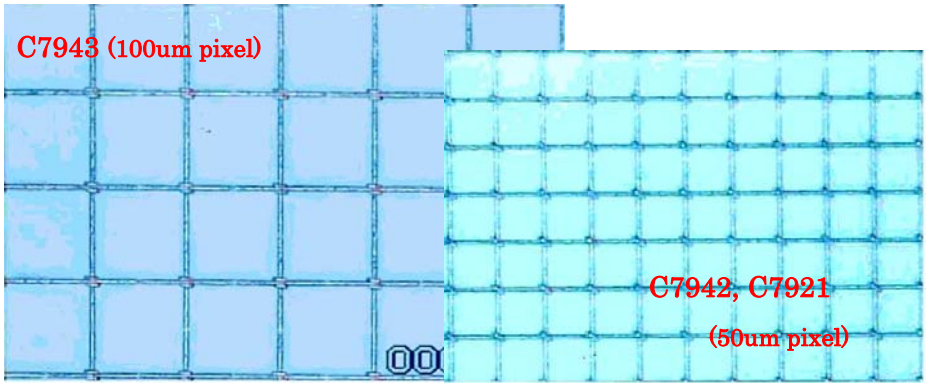
Q) What is the Resolution these flat panels have?

A) Contrast Transfer Function (CTF) curve is shown below. C7921CA-02 & C7942CA-02 have high resolution as 8Lp/mm with 50um-pixel size and needle like structured CsI. C7943CA-02 has 5Lp/mm resolution with 100um-pixel size. Because of adopted direct deposited CsI on the CMOS chip, C7920DA-02 has higher resolution as 10Lp/mm.



Q) Can you send the fill factor of these Flat panels has?

A) Our standard 0.6um ruled CMOS process achieves a high ratio of fill factor of 79 % for 50×50 um pixels (C7942 & C7921) and 87 % for 100 um pixels (C7943).



Q) Shipping conditions (shock, temperature, vibrations, etc) worst case values

A) The maximum storage temp is 50 deg C. The unit will be shipped in humidity resistant film with shock absorbing material to prevent some damages caused by the shock and the vibration.

Q) When an external frame rate is taken, the first image is very bright

A) The first frame should be ignored, for FP accumulates before software supplies an external trigger.

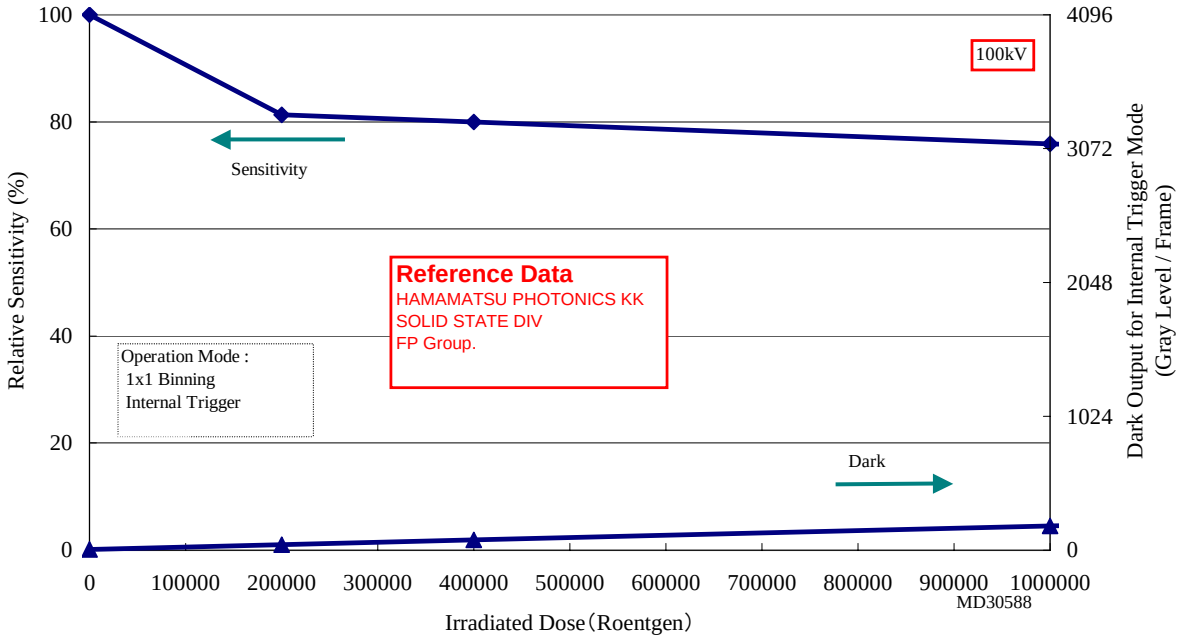
Q) What is max energy x-ray or total radiation dose causes damage or deterioration of unit?

A) C9730DK and C9732DK are designed for characteristic of 17keV x-ray with Mo target. Don't expose to other x-ray source.

On the other hand, C7942CA-02, C7943CA-02 and C7921CA-02 are designed for x-ray energy up to 100kVp and total dose is 1M roentgen. Refer to the X-ray dose dependence data for C7942CA-02 shown below (MD30588).

It will occur 25% decrease of the sensitivity, around 200 GL dark increase and radiation may cause partial increase of dark (see right side dark image example at 100kVp 1MR). An image correction of the dark will eliminate the partial increase. This partially dark increased region shows offset drift due to thermal increase of the FP around 1 hour after power on. Dark subtraction with proper period is recommended in order to calibrate the dark drift contribution. The calibration period depends on the system requirement for the measurement accuracy.

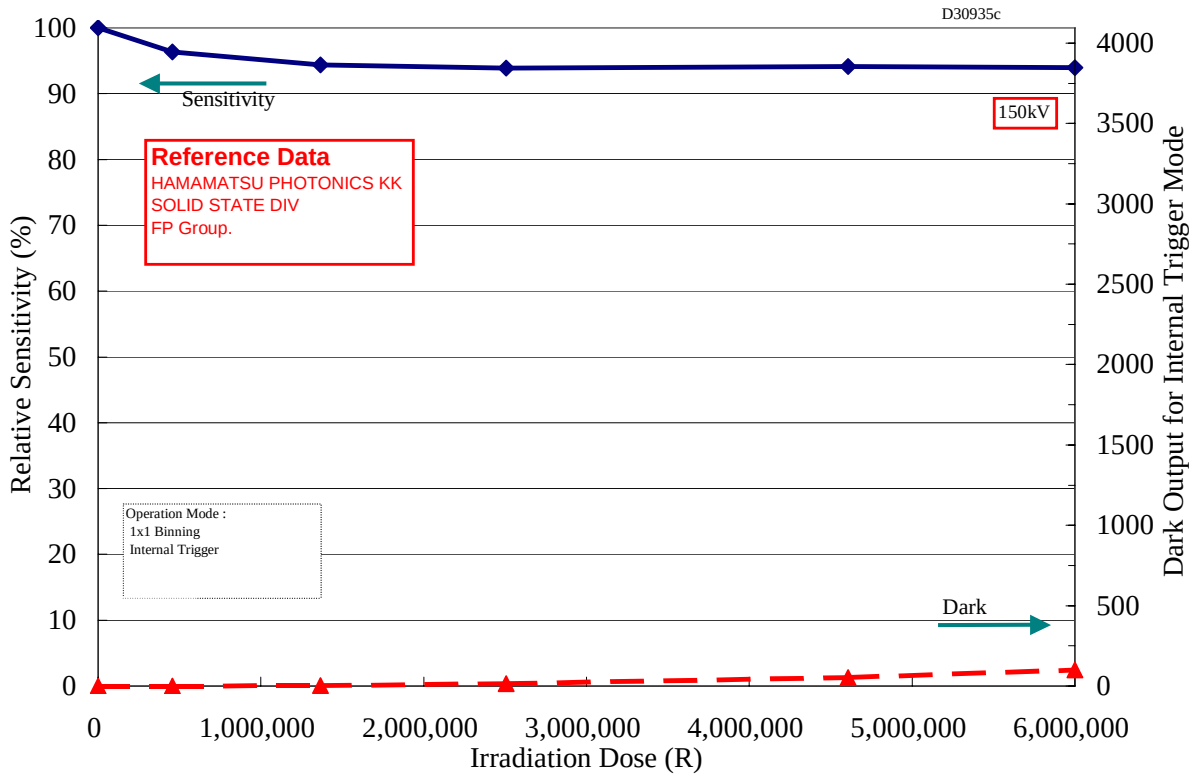
X-ray Dose Dependence of Sensitivity and Dark Output for C7942CA-02

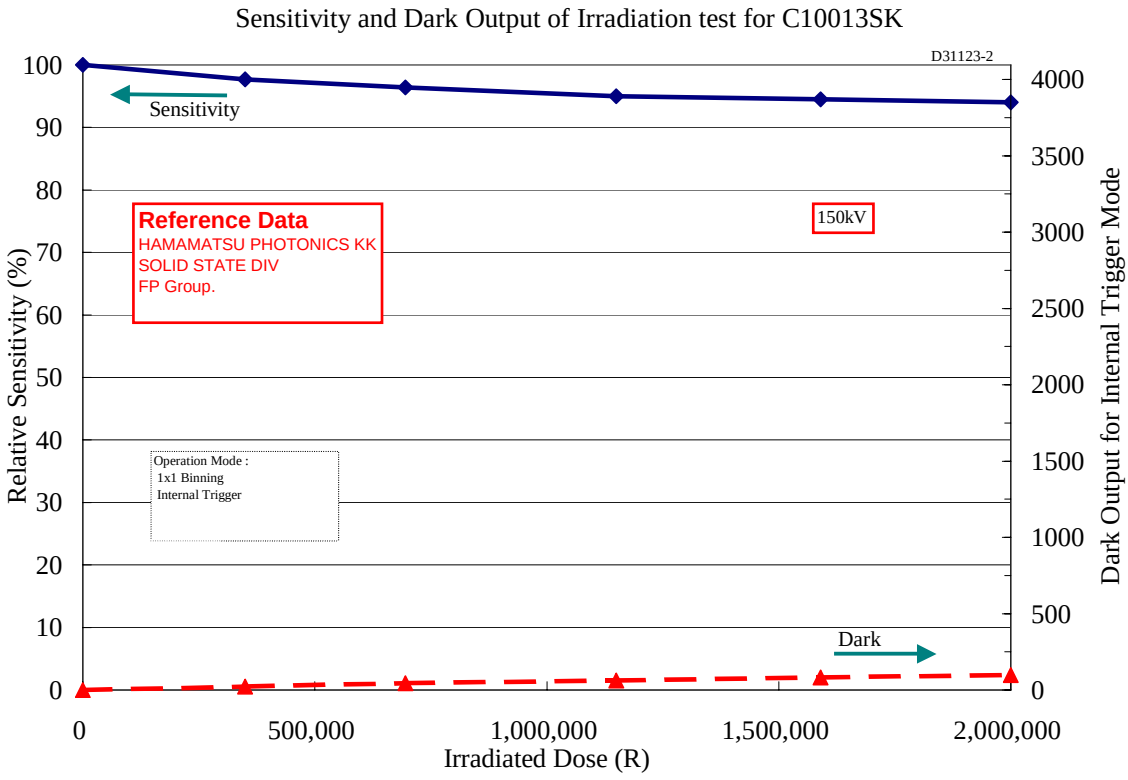


To decrease the permanent degradation for the FP and get longer life time of x-ray source, it is recommended to apply as lower dose as the range of interest of an image can be acquired. Adjusting the display range of interest following the procedure described in page-12, any 256 gray level can be displayed while the FP has a wide dynamic range of over 2000 gray level. The better condition can increase the number of images in a fixed total dose.

The other points are tube current of x-ray source, distance from the FP to the focus of the tube, magnification of view, etc to regulate the condition. For the heavy dose application, 'SK' type is recommended. The recommended replacement period for every type of FP will be around 1 year, however it depends on the total dose and tube voltage. Refer to the X-ray dose dependence data for C7921SK-05 and C10013SK shown below.

X-ray Dose Dependence of Sensitivity and Dark Output for C7921SK-05





Q) What's damage or deterioration of unit under 150kVp of X-ray radiation?

A) For over 100kV radiation 'SK' type is recommended. It is also recommended for long life application.

	Tube Voltage
'CA-02' type	< 100kV
'SK type	< 150kV

Q) What is the definition of the life time test?

A) The definition of the life time is as follows, the average of the dark increase(not the offset) in the internal mode is less than 500 GL, sensitivity is 50% of the initial, twice of defect line of the spec.

Peripherals (PC , Frame grabber card , Cable , Power source)

Q) What frame grabber card can interface the FP? Are there any peripherals to drive the FP?

A) Regarding the additional equipment that user has to prepare to operate the Flat panels, it is described in the datasheet.

- Frame Grabber Card: Monochrome, Digital, 12 bit, RS422 type is available in case of C7921CA-02, C7942CA-02 and C7943CA-02. Following grabber cards can be proved to interface to the flat panel.

  PCI-1424 (product of NATIONAL INSTRUMENTS (http://www.ni.com)).
  PCI-1422 (product of NATIONAL INSTRUMENTS (http://www.ni.com)).
  PC-DIG (product of Coreco Imaging (http://www.corecoimaging.com))
  Run-PCI-12 (product of BitFlow (http://www.bitflow.com))

  Caution

  Type number of Grabber card is generic number. Please note specified memory or interface rating.
- Signal cable: We recommend our optional cable, (please see page-33, Table of Cable line up) for the both grabber cards.
- Power Supply: Use Series Power Supply (Refer data sheet). Higher noise Switching Power Supply is not recommended for.

Q) What kind of personal computer and frame grabber card is recommended?

A) For PC, IBM compatible PC running on Windows2000 or later operation system is required. Flat panel has over million pixels, and they work at very high frame rate. To utilize the full performance of Flat Panel Sensor, high-grade personal computer is required.

Q) What kind of Power Supply is recommend?

A) Flat panel requires 3 types of power source, which are analog +5V, digital +5V and +/-7.5V. The voltage margin of A.vdd and D.vdd is from 4.90V to 5.10 V, also from +/-7.0 to +/-8.0V for V (+/-7.5). These three kinds of power source should be turned on/off at same time or +/-7.5V should be turned on earlier than others. Also +/-7.5V should be turned off later than others. The series power supply with small ripple (we recommend that ripple is less than 1mV) is utilized for every power. (Avoid using switching power supply.) In case of using a power source that has large ripple noise, horizontal line noise may appear in an image.

The separation of analog +5V source and digital +5V source is strongly recommended. Because all power source ground are connected to the frame ground at the flat panel sensor side, they should be disconnected from the frame ground at the power source

side.

The connection to the stable ground from ground terminal has to be made to decrease surrounding noise from motor or another peripherals and eliminate common mode voltage change of power supply.

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

Don't extend the power cable because it causes voltage drop.

Q) How long is Maximum cable length?

A) The video signal output is RS422 or LVDS. We recommend the length of 12m max for the video signal cable.

Cable line up is below. Refer to the datasheet for the flat panel sensor and choose a suitable cable for it.

Frame grabber	Cabel Type Number	Cable length	Cable end	Cable end
General-purpose	A8406-31	5m	TX-20A-36PH1-D2P1-D1(*2)	Open
	A8406-36	7m		
	A8406-37	10m		
	A8406-38	12m		
	A8406-41	5m	PCS-E80FA(*3)	
	A8406-46	7m		
	A8406-47	10m		
	A8406-48	12m		
	A8406-51	5m	10140-6000EL(*4)	
	A8406-56	7m		
	A8406-57	10m		
	A8406-58	12m		
IMAQ-PCI-1424(*1)	A8406-32	5m	TX-20A-36PH1-D2P1-D1(*2)	PCS-XE100MA(*3)
	A8406-33	7m		
	A8406-34	10m		
	A8406-35	12m		
	A8406-42	5m	PCS-E80FA(*3)	
	A8406-43	7m		
	A8406-44	10m		
	A8406-45	12m		
	A8406-52	5m	10140-6000EL(*4)	
	A8406-53	7m		
	A8406-54	10m		
	A8406-55	12m		

*1: Made by NI (National Instrument Corporation)

*2: Made by JAE (Japan Aviation Electronics Industry, Limited)

*3: Made by HONDA Tsushin Kogyou Co. Ltd.

*4: Made by 3M Co. Ltd.

Q) Please provide the information for the power cable attached to the Flat Panel and the A8406 series optional frame grabber cables.

A) The power cable and A8406-series optional cables are all robot type cable.
They do not have the UL and CE mark.
Their minimum bending radius can be calculated by the following equation,
(Minimum bending radius) = (Outside diameter of the cable) x 6.
For example, in the case of A8406-31 frame grabber cable which has the outside diameter of 7mm, the minimum bending radius becomes 42mm.

Q) Is there any software for driving flat panels?

A) The measurement & Automation Explorer (MAX) products of National Instrument and HiPic software from HAMAMATSU can operate every flat panel with basic function for NI IMAQ PCI-1424 grabber card. The XVS-FPD is intelligent software incorporate with image correction function for Bit Flow RoadRunner 12M.

Q) Is there any advice on designing X-ray imaging system with the Flat Panel Sensor considering its specification and life time?

A) There are three main interactions of X-ray photons in matter, Photoelectric Effect, Compton Scattering and Pair Production. X-ray imaging devices utilize these effects for the detection of X-ray photons. These interactions, however, cause the damages on the detector. In other words, X-ray image is the result of the radiation damage given on the detector. It means that the radiation damage cannot be avoided while the X-ray imaging.
The Flat Panel Sensor is designed as having a relatively high radiation tolerance against X-ray exposure. However, the degradation of some characteristics is unavoidable. The feasibility study for this radiation damage is very important when the imaging system is designed. As mentioned above, the degradation of X-ray sensitivity and the increase of dark output will occur after X-ray exposure. Furthermore, the partial increase of dark output will be also appeared. In order to eliminate these effects in appearance, image correction is necessary. The progress of the radiation damage depends on the X-ray energy and total dose. These are different from system by system, and please confirm the tendency of the damage by applying estimated radiation, temperature and another actual field conditions with your software. The appropriate calibration frequency should be taken considering the irradiation condition in your system.

Chapter 7 Sample Images

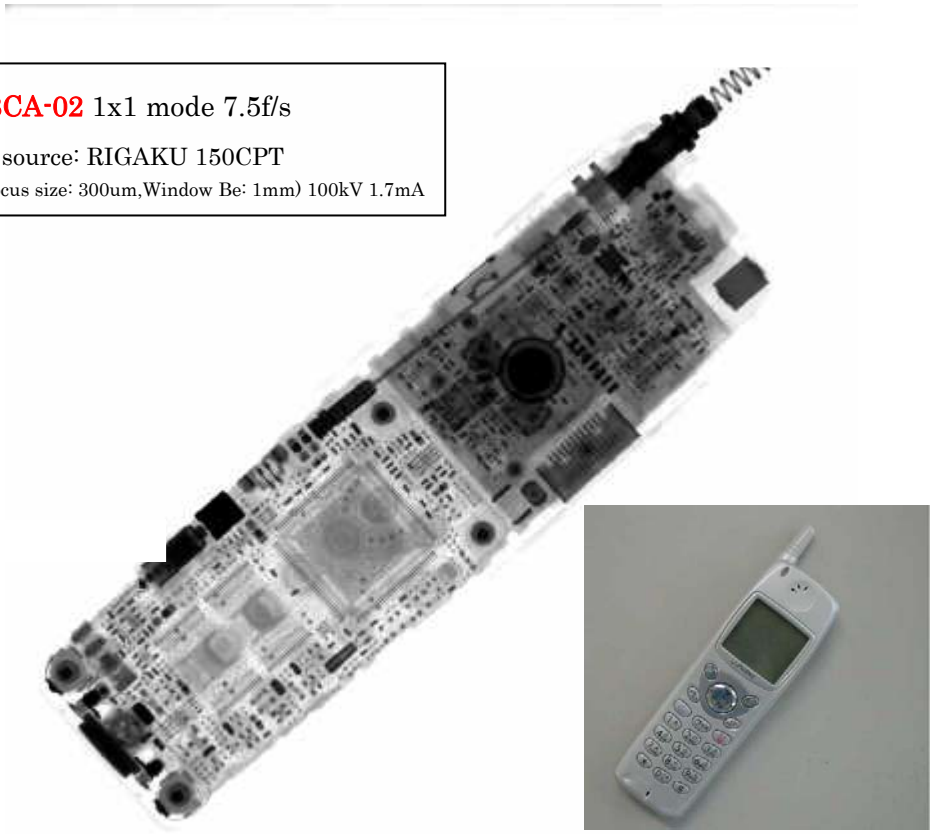
Electronics

< Cellular Phone >

C7943CA-02 1x1 mode 7.5f/s

X-ray source: RIGAKU 150CPT

(Focus size: 300um,Window Be: 1mm) 100kV 1.7mA

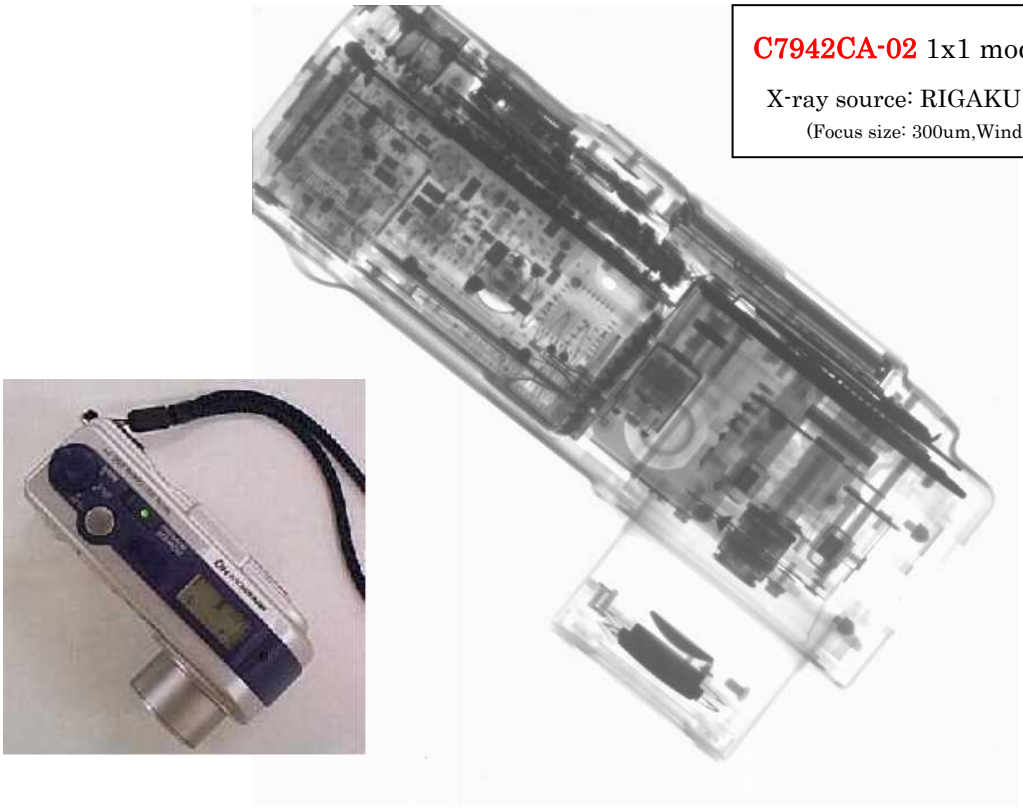


< Digital Camera >

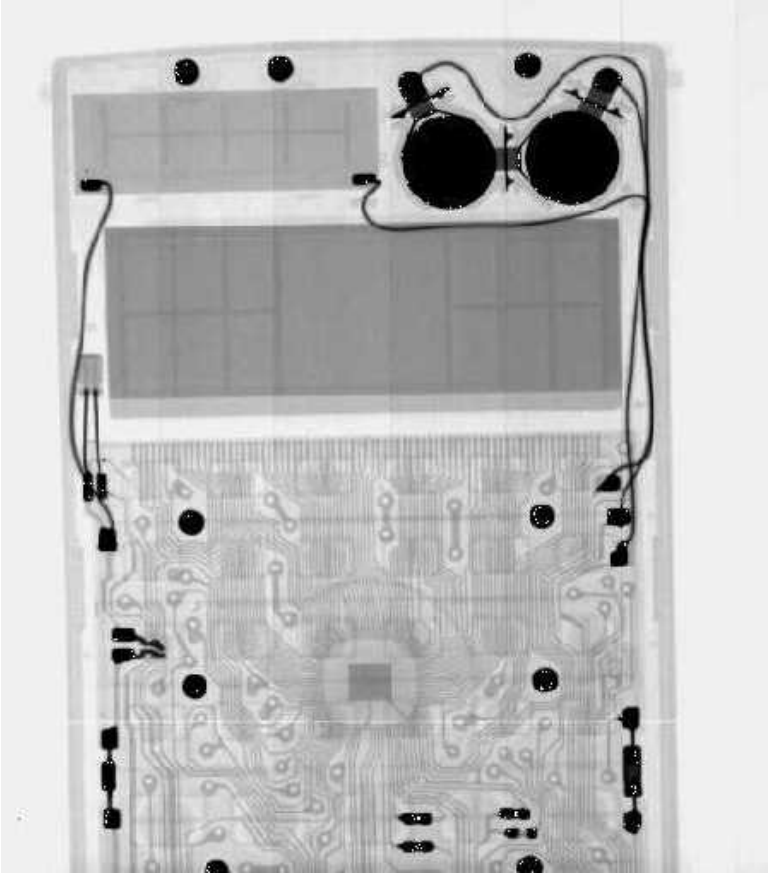
C7942CA-02 1x1 mode 2.2f/s

X-ray source: RIGAKU 150CPT

(Focus size: 300um,Window Be: 1mm) 100kV 1.0mA



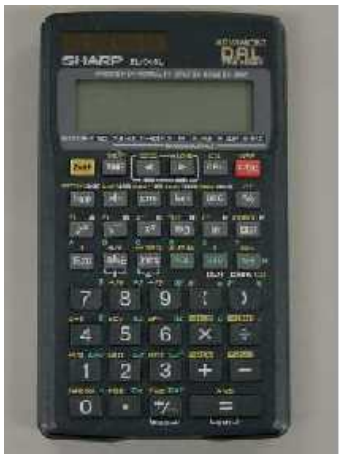
< Calculator>



C7942CA-02 1x1 mode 1.0f/s

X-ray source: HAMAMATSU L6622-02

(Focus size: 10um,Window Be: 200um) 80kV

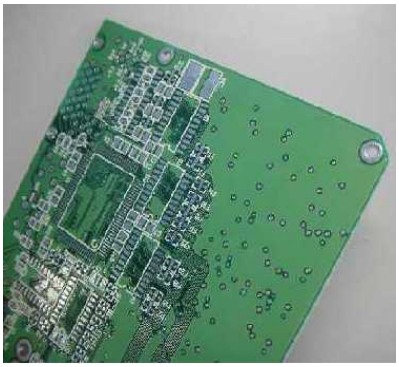


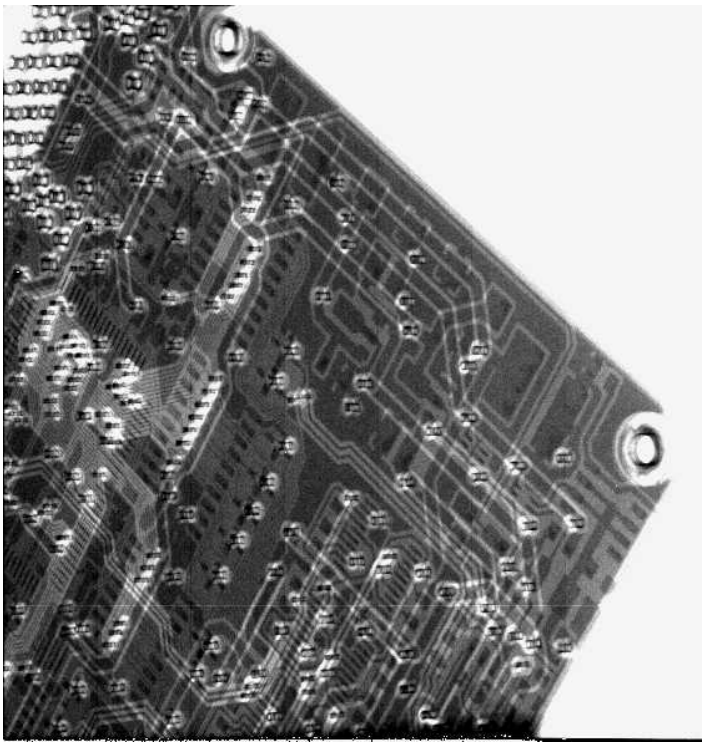
< 4-layer PCB>

C7942CA-02 1x1 mode 2.0f/s

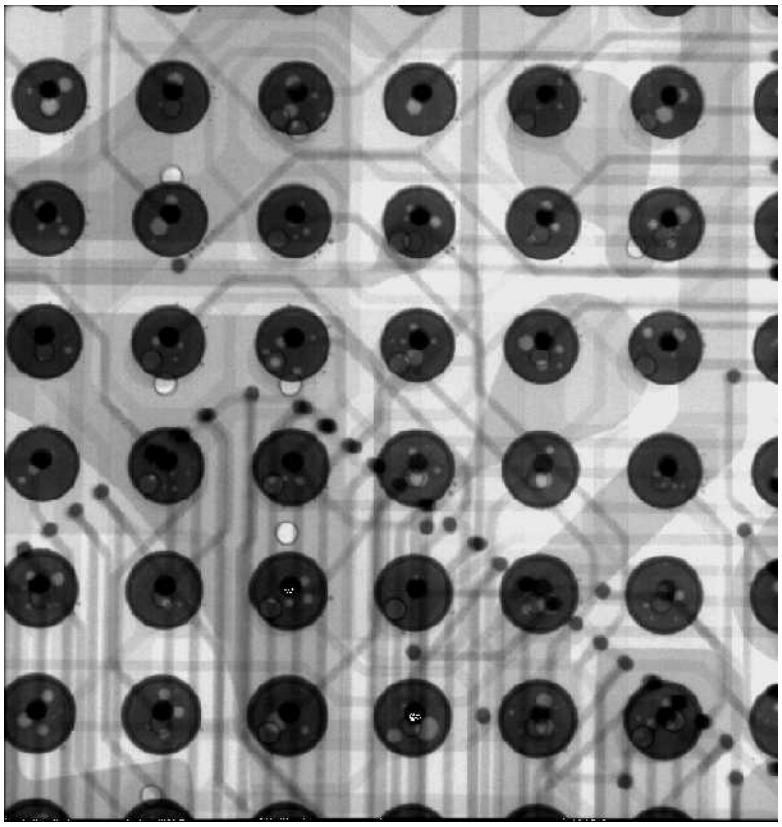
X-ray source: HAMAMATSU L6622-02

(Focus size: 10um,Window Be: 200um) 80kV





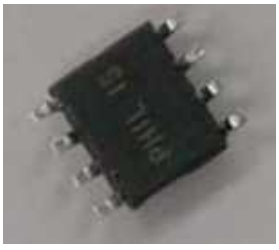
< Boll Grid Array (many bubble in the ball solders are observed)>

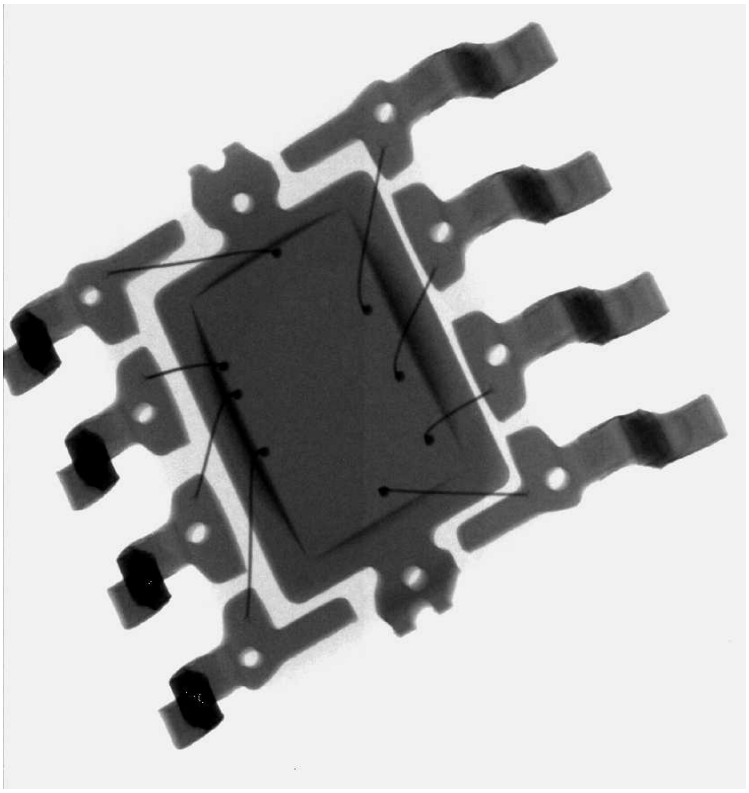


C7942CA-02 1x1 mode 1.0f/s
X-ray source: HAMAMATSU L6622-02
(Focus size: 10um,Window Be: 200um) 80kV

< Integrated Circuit (Bonding Wire & Conductive Paste is observed)>

C7942CA-02 1x1 mode 0.2f/s
X-ray source: HAMAMATSU L6622-02
(Focus size: 10um,Window Be: 200um) 80kV





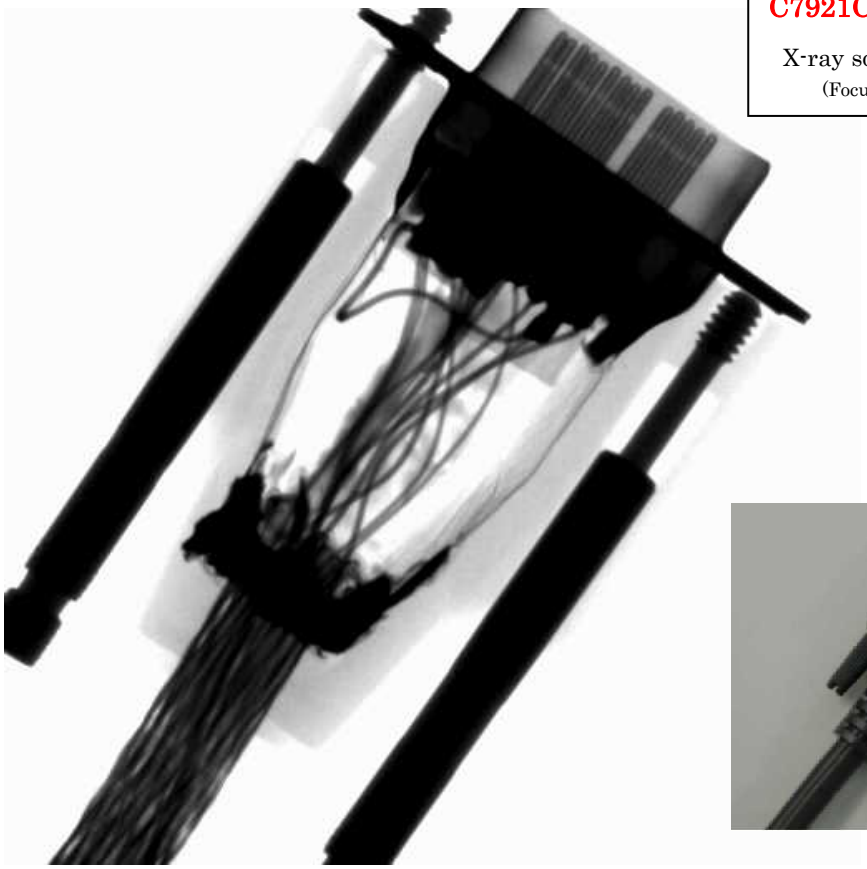
Components

< Connector >

C7921CA-02 1x1 mode 4.0f/s

X-ray source: RIGAKU 150CPT

(Focus size: 300um,Window Be: 1mm) 80kV



< Battery>

C7942CA-02 1x1 mode 1.0f/s

X-ray source: HAMAMATSU L6622-02

(Focus size: 10um,Window Be: 200um) 100kV

< Air Valve >

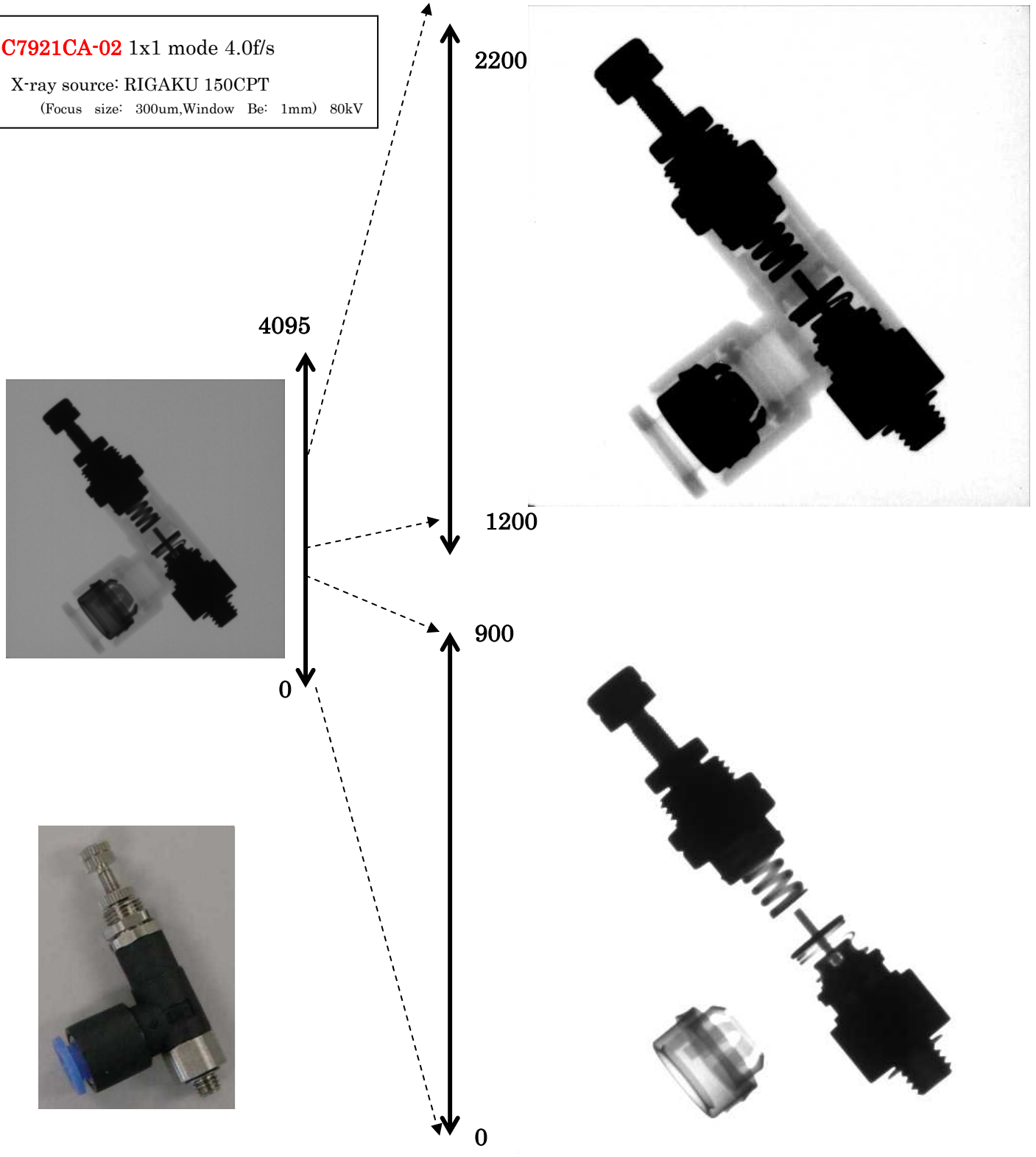
As mentioned above, HAMAMATSU Flat Panel Sensor has wide dynamic range, so we can get 4096 gray scale video data. On the other hand Windows can display only 256 gray scale. Therefor the displayed image is compressed into 256 gray scale .

So you can select the most interesting image value range in one image.

C7921CA-02 1x1 mode 4.0f/s

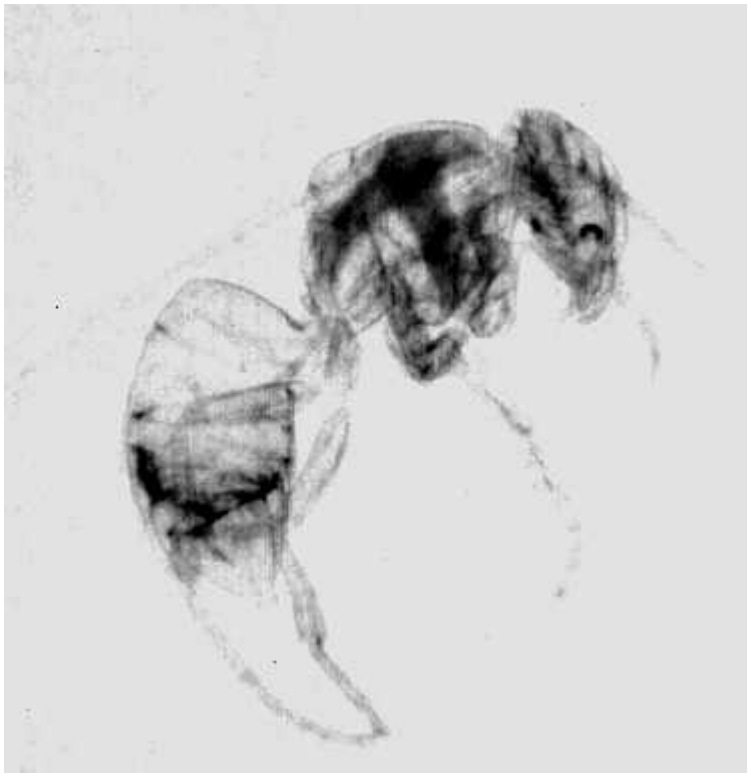
X-ray source: RIGAKU 150CPT

(Focus size: 300um,Window Be: 1mm) 80kV



Biology

< Hornet>



C7921CA-02 1x1 mode 0.35f/s

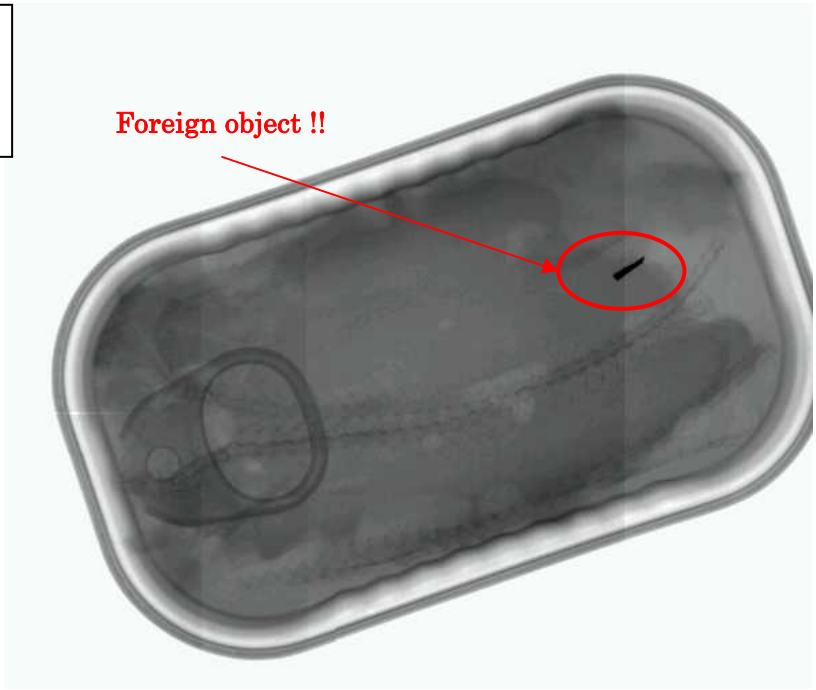
X-ray source: RIGAKU 150CPT

(Focus size: 300um,Window Be: 1mm) 35kV

Food

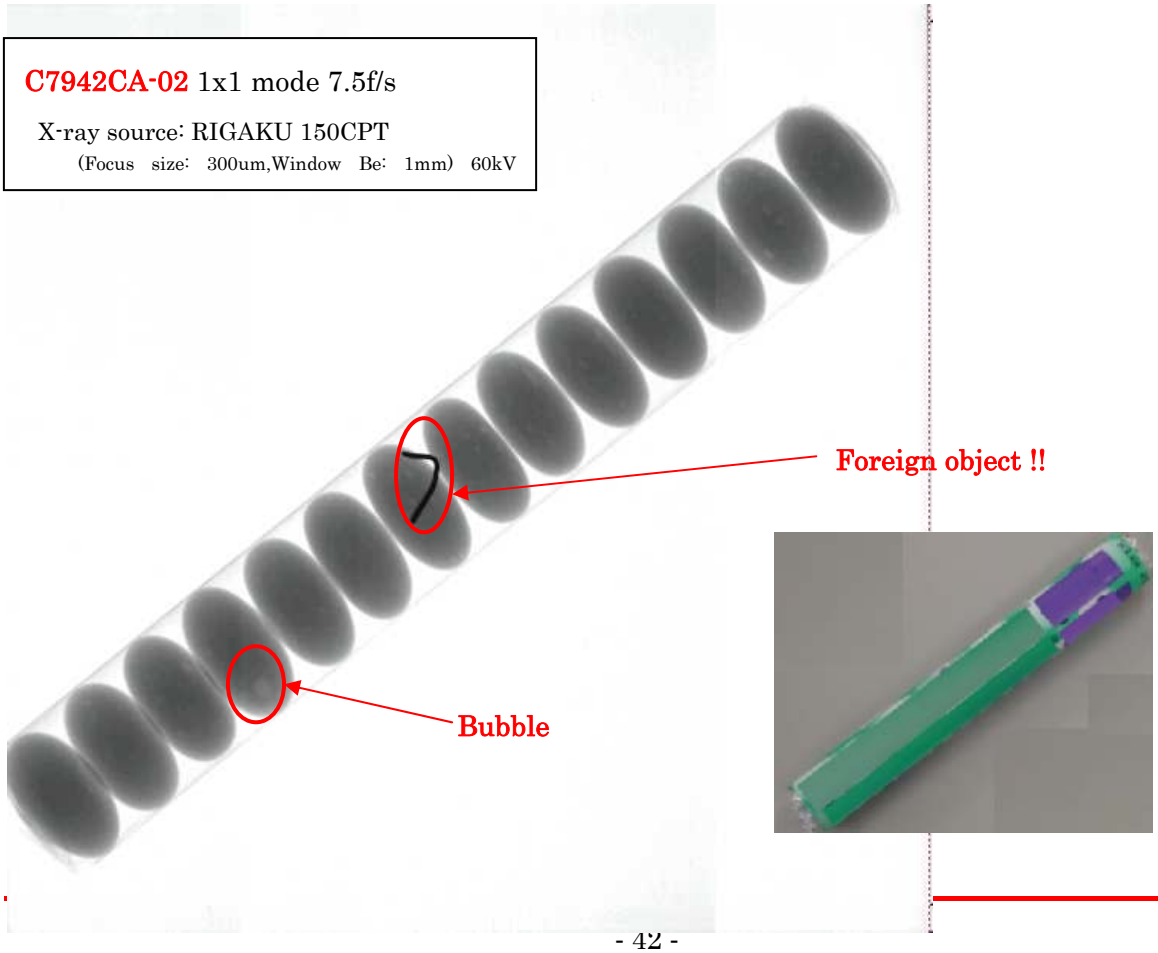
< Canned Fish>

C7942CA-02 1x1 mode 7.5f/s
X-ray source: RIGAKU 150CPT
(Focus size: 300um,Window Be: 1mm) 80kV



< Candy>

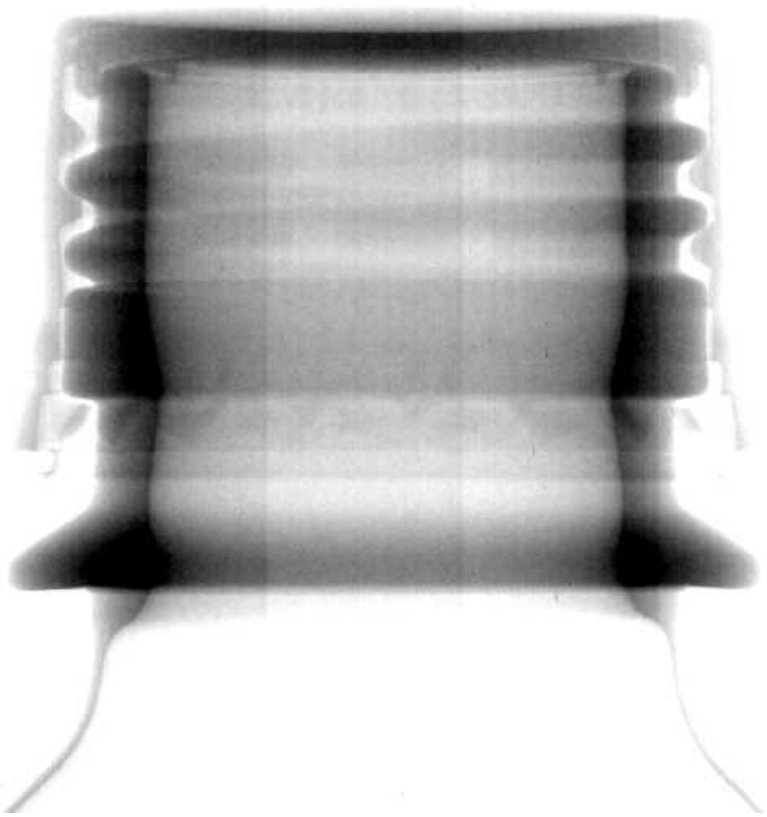
C7942CA-02 1x1 mode 7.5f/s
X-ray source: RIGAKU 150CPT
(Focus size: 300um,Window Be: 1mm) 60kV



< Cap of PET bottle>

C7942CA-02 1x1 mode 0.5f/s

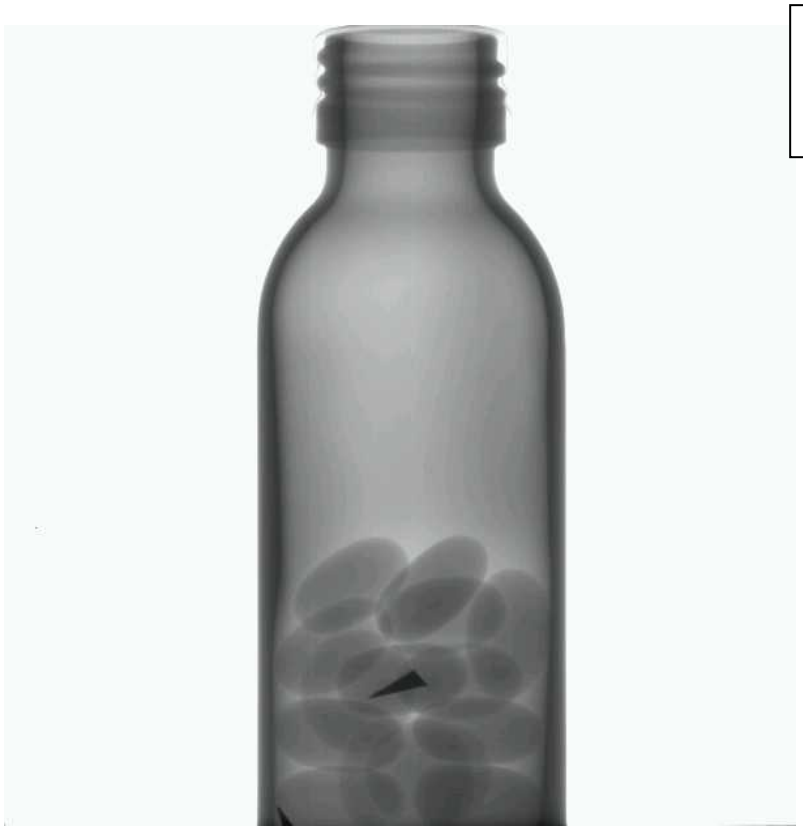
X-ray source: HAMAMATSU L6622-02
(Focus size: 10um,Window Be: 200um) 60kV

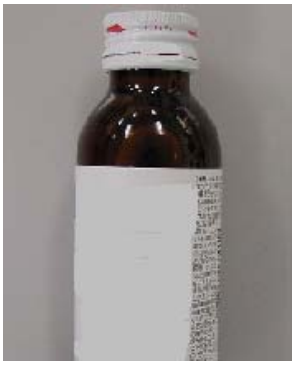


< Medicine Bottle>

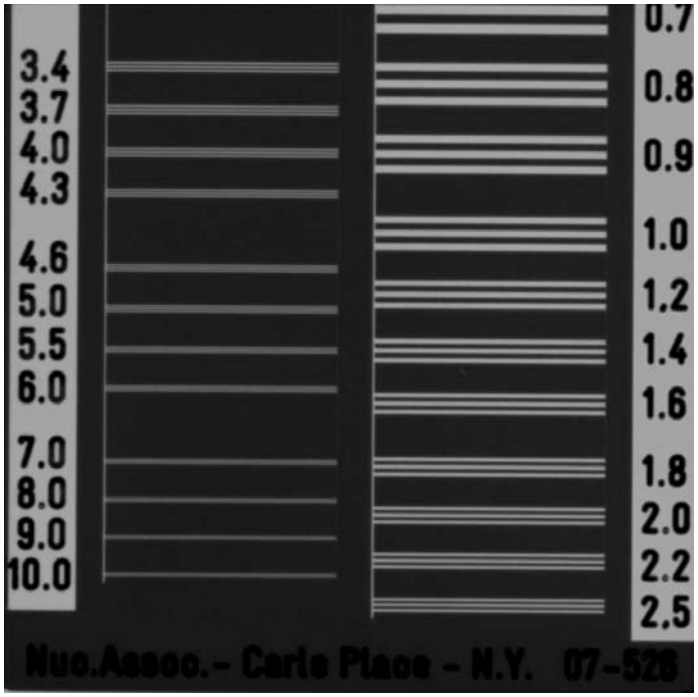
C7942CA-02 1x1 mode 1.0f/s

X-ray source: HAMAMATSU L6622-02
(Focus size: 40um,Window Be: 200um) 80kV





< X ray test patterns>



C7921CA-02 1x1 mode 0.3f/s

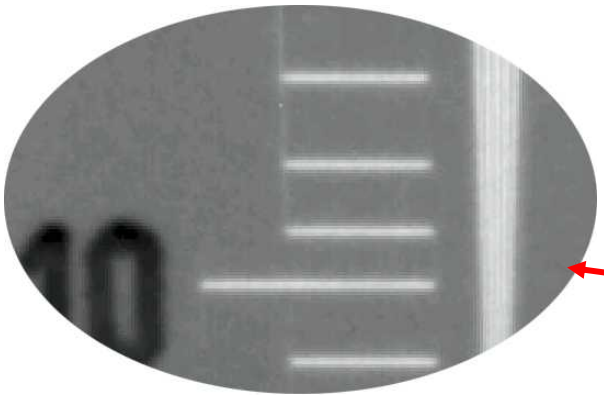
X-ray source: HAMAMATSU L6622-02

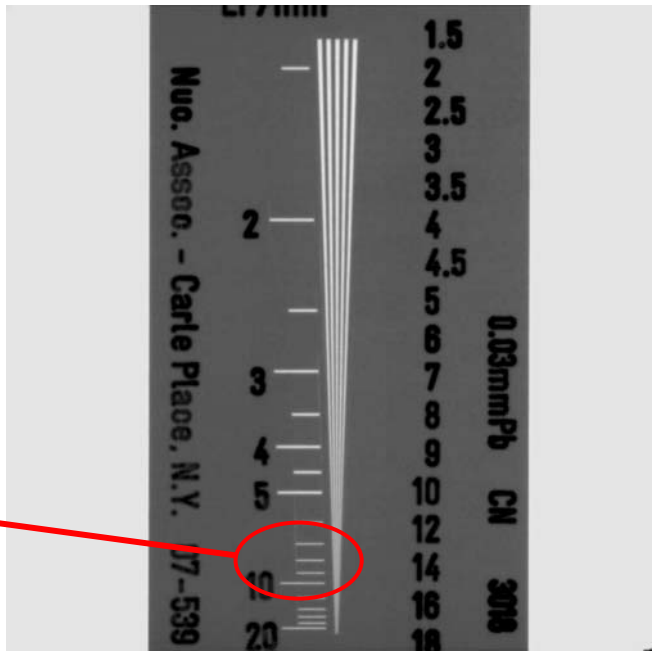
(Focus size: 10um,Window Be: 200um) 60kV

C7921CA-02 1x1 mode 0.3f/s

X-ray source: HAMAMATSU L6622-02

(Focus size: 10um,Window Be: 200um) 60kV





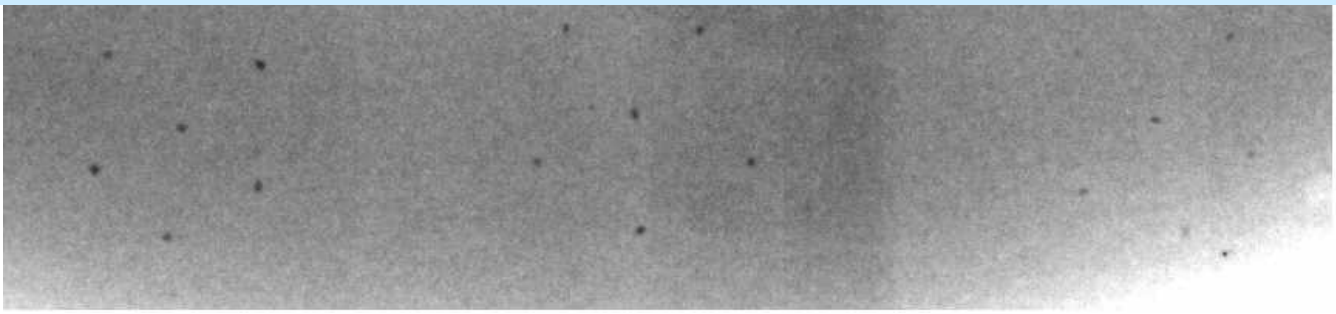
Others

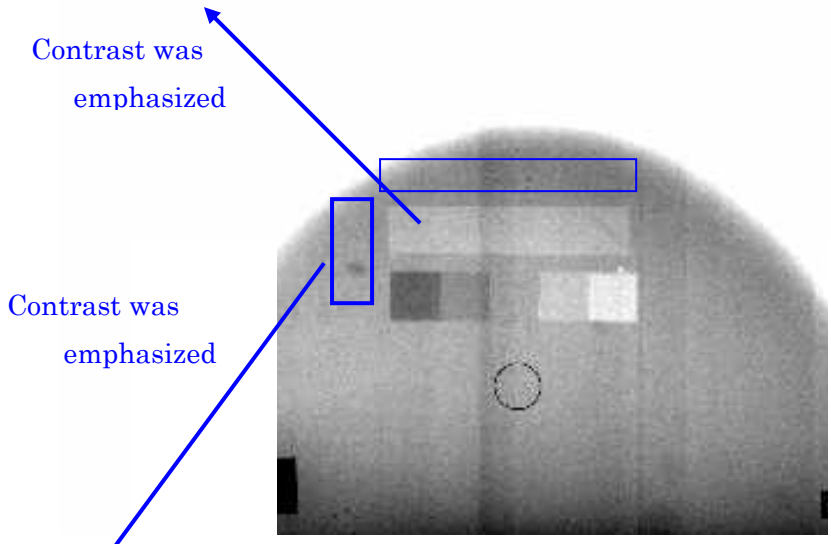
< Tissue-Equivalent Phantom(Nuclear Associates#18-222)>

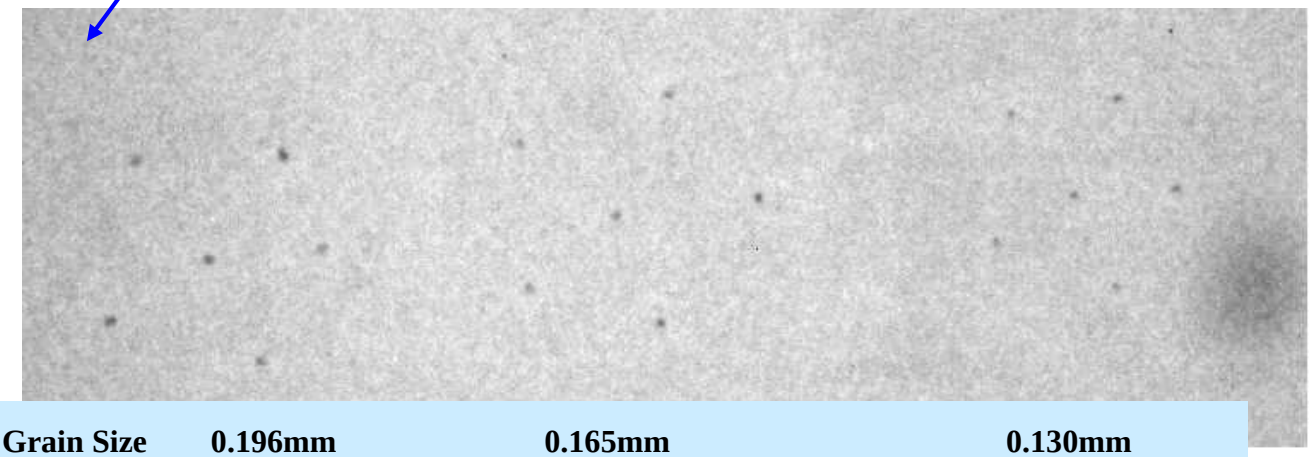
C9732DK

Sample : Tissue-Equivalent Phantom
(Nuclear Associates#18-222)
X-ray Source : Mo Target (Tube Voltage 30kV)
Target Size : 0.15mm
Filter : 1mm Be and 0.03mm Mo
Absorbed Dose : 1 mGy

Grain Size **0.23mm** **0.196mm** **0.165mm**





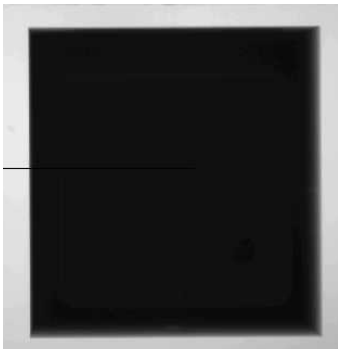


Grain Size **0.196mm** **0.165mm** **0.130mm**

< ACR Phantom(Nuclear Associates#18-220)>

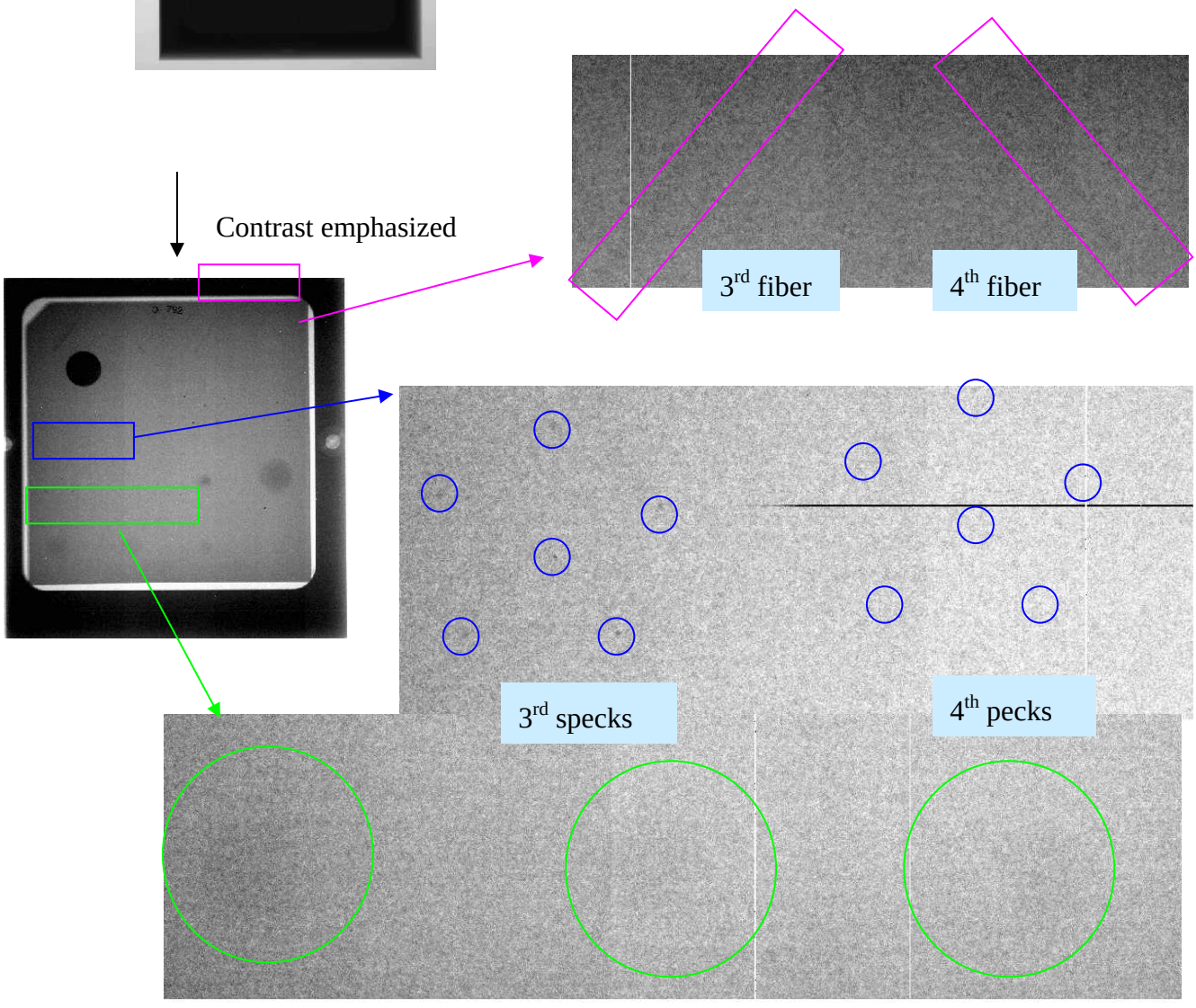
C9732DK

Sample : ACR Phantom
(Nuclear Associates#18-220)
X-ray Source : Mo Target (Tube Voltage 30kV)
Target Size : 0.15mm
Filter : 1mm Be and 0.03mm Mo
Absorbed Dose : 1 mGy



According to Instruction Manual, A good imaging system should be able to see the 3rd speck group(0.32mm Al2O3 speck), 4h fiber(0.75mm nylon fiber), and the 3rd mass(0.75 mm(thickness) mass).

Contrast emphasized



Chapter 8 Warranty

X-ray flat panel sensor, C7921, C7942 and C7943 series are warranted to the original purchaser for a period of 12 months following the date of shipment. The warranty is limited to replacement or repair of any defective material due to defects in workmanship or materials used in manufacture. It does not cover loss or damage of the product due to natural calamity, misuse or total radiation dose described in individual data sheet even within the warranty period.

HAMAMATSU

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