Development of "CALNEO", an Indirect-conversion Digital Radiography System with High-conversion Efficiency

Keiichiro SATO*, Fumito NARIYUKI*, Takeshi KUWABARA*, Shinichiro FUKUI*, Yoshihiro OKADA*, Toshiyuki NABETA*, Yuichi HOSOI*, Jun ENOMOTO*, Masanori SASAO*, and Yoshinori SEGUCHI*

Abstract

We have developed a new digital radiography system "CALNEO" which has realized dose reduction, a faster workflow, and space saving. Newly developed detection technology "Irradiation Side Sampling" and an optimized scintillator made it possible to utilize a signal from the scintillator without attenuation and spreading of the emission. DQE of the Irradiation Side Sampling system detector is 1.2 times higher than that of conventional Pentration Side Sampling system detectors, and 1.7 times that of our existing model of FCR VELOCITY. The combination of a thin and durable imaging unit and a newly developed console "Console Advance" enables a quick review of the image, making it highly suitable for any X-ray rooms or examination vehicles.

1. Introduction

We have developed radiographic modalities in diagnosis, which have evolved from screen/film (S/F) to FCR (Fuji computed radiography) and to DR (digital radiography). We are seeking to reduce radiation dose by raising image quality, enhance the diagnostic capabilities, and improve the workflow in the X-ray room. In the field of DR, we have succeeded in enhancing the image quality further by developing the ISS system, the first of its kind in the world. With the ISS system, the layers of the flat panel detector (FPD) are in reverse order of the conventional FPD. The FUJIFILM CALNEO (Fig. 1) which is equipped with this detector was launched in September 2009. This DR system provides 1.7 times higher quality images than the conventional FCR. It is space saving. It is high in throughput. In addition, the newly developed Console Advance helps create a comfortable workflow. The operator can operate the system on the console similar way to that of FCR. The features and capabilities of the FUJIFILM DR CALNEO (DR-ID 300) as well as the technology used in FPD for enhancing image quality will be described in this paper.

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* Medical System Equipment Research & Development Center
Research & Development Management Headquarters
FUJIFILM Corporation
Miyanodai, Kaisei-machi, Ashigarakami-gun, Kanagawa 258-8538, Japan

Fig. 1 External view of digital radiograph system FUJIFILM DR CALNEO.

2. Enhancing Image Quality

2.1 Features of FPD used for CALNEO

The FPD used for the CALNEO is an indirect-conversion FPD. It consists of a phosphor that converts X-rays to light and photodiode equipped with a TFT that converts light to electric charges. By driving TFT, charges produced in the photodiode are read out. And, the charges are converted to a digital image via the amplifier circuit and the analog-to-digital converter. An indirect-conversion FPD, as the phosphor layer and the photodiode are made into one panel, has several advantages. For example, loss of light, *i.e.*, loss of X-ray data is small, the display response is fast, and it helps build a thinner system. The conventional indirect-conversion FPD employs the PSS (Penetrated Side Sampling) system[1]. X-rays enter the phosphor layer and come out of the photodiode. It is the other way round with the FPD used for the CALNEO. It is called ISS (Irradiation Side Sampling) system (Fig. 2) which is the first of its kind in the world.

We use GOS (Gd_2O_2S:Tb) for the phosphor, considering efficiency in X-ray conversion and stability of performance. GOS is high in X-ray conversion efficiency and slow in deterioration with age or by X-rays. It will help provide stable image quality over a long period of time. GOS has been widely used for the intensifying screens of screen/film (S/F) systems. So even the users who are familiar with S/F systems will not feel strangeness resulting from difference in X-ray absorbance between materials used as phosphor.

As well as employing the ISS system, we have designed the phosphor suitable for the ISS system. That makes it possible to drastically enhance the image quality. The following sections provide detailed description of the technology.

2.2 ISS System and PSS System

The key point to raising the image quality of X-ray detectors is to increase the efficiency in use of X-ray energy and to reduce the spread of the X-ray input. For an indirect-conversion FPD, that means increasing X-ray absorption by the phosphor layer, enhancing the efficiency in detection of light emission (reducing the attenuation), and reducing the spread (blurring) of the emission.

In order to increase the X-ray absorption, the thickness and density of the phosphor layer must be increased, and in order to enhance the efficiency in detection of light emission, attenuation of the emission must be reduced until the X-rays reach the photodiode. X-rays are absorbed in the phosphor layer and they move on while being attenuated. The emission in the direction of the thickness of the phosphor layer is large on the surface X-rays enter and small at the surface X-rays come out. GOS phosphor is made of phosphor particles packed densely. As the phosphor particles scatter light, attenuation in the phosphor layer is not negligible. Fig. 3 (simplified Lubberts effect[2)]) shows differences in intensity of received light and blurring depending on attenuation of X-rays in the direction of the phosphor thickness and scattering of light. The differences in detection efficiency and spread of light by system will be explained with reference to Fig. 3.

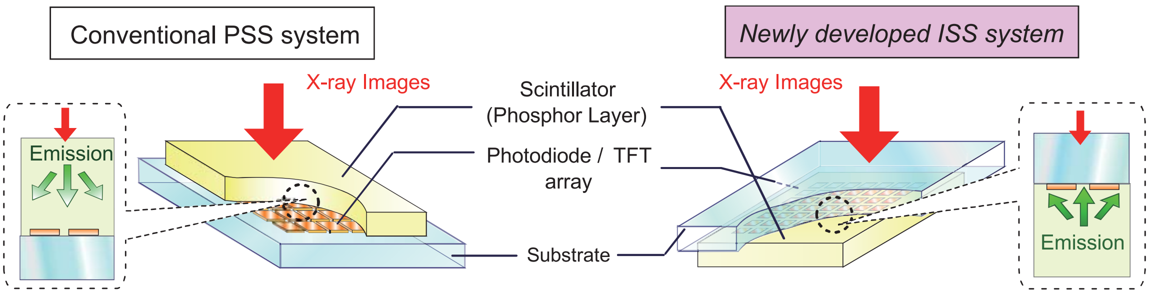

Fig. 2 Schematic view and cross section of conventional and newly developed flat panel detectors.

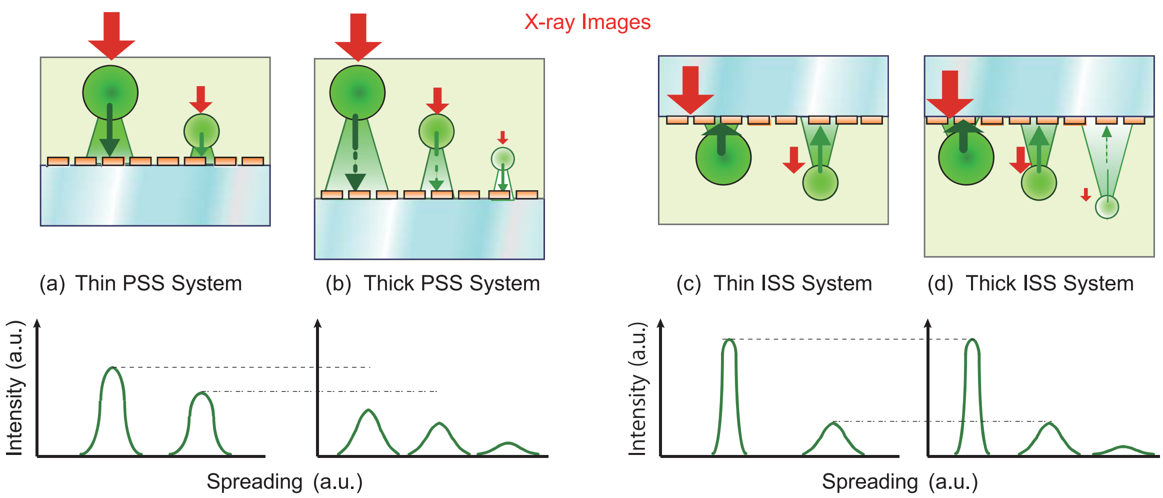

Fig. 3 Schematic diagram of intensity and blur of detected light signals.

The changes in sensitivity according to the phosphor layer thickness are shown in Fig. 4. With the PSS, the sensitivity

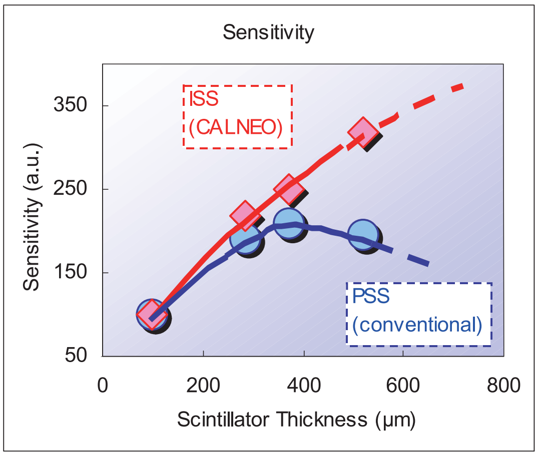

Fig. 4 Relation between scintillator thickness and sensitivity.

increases in proportion to the phosphor thickness while the thickness is small. The X-ray absorption can be increased. But, when the phosphor is too thick, the sensitivity falls. A thicker phosphor layer means that the emission is attenuated over a longer distance before reaching the photodiode. This adverse effect exceeds the effect of increasing the emission (Fig. 3 (a) and (b)). In the PSS system, there is a limit in the amount of effective X-ray absorption increased by thickening the phosphor layer. In the ISS system, the sensitivity does not fall even if the layer thickness is increased. Even if the layer thickness is increased, that does not change the intensity of the emission from the phosphors located on the X-ray entrance side or the attenuation distance to the photodiode. Only the phosphors located at the exit of X-rays and corresponding to the increase in thickness will be smaller in emission intensity and longer in attenuation distance. But, that does not affect the phosphors on the entrance side (Fig. 3 (c) and (d)). In the ISS system, although X-rays are slightly attenuated before entering the phosphor layer, the X-ray absorbance of the photodiode is relatively small and the sensitivity will not fall below that of the PSS system (Fig. 4). For this reason, in the ISS system, it is possible to increase the X-ray absorption exceeding the limit of the PSS system.

The ISS system is also advantageous compared with the PSS system in the point of the spread of emission. The emission of phosphor is scattered within the layer. In the PSS system, if the layer thickness is increased, the spread expands by the time the light is detected in the photodiode (Fig. 3 (b)). Especially, the phosphors at the X-ray entrance are high in emission intensity and scattered light is also detected with relatively high intensity, thereby resulting in blurring of the image. In the ISS system, the spread of the emission from the phosphors at the X-ray entrance will not change even if the layer is thickened (Fig. 3 (c) and (d)). Although the emission of the phosphors far from the photodiode and corresponding to the increase in thickness tends to spread, the contribution to image blurring will be relatively small on the reason that the emission intensity is small compared with the X-ray entrance side (Fig. 3 (d)).

The dependence of MTF on phophor layer thickness is shown in Fig. 5. In the whole thickness range, the ISS system is higher in MTF than the PSS system. That indicates the ISS system has an advantage about image blurring.

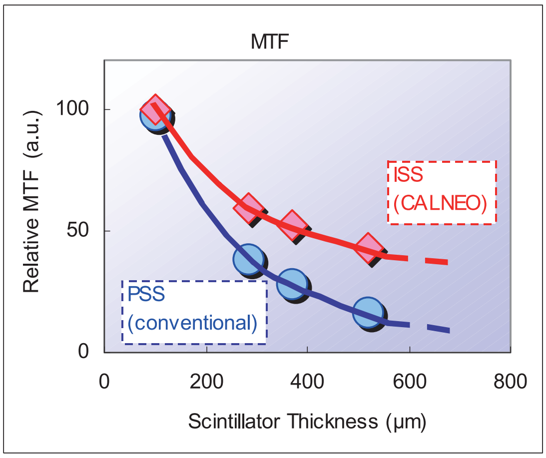

Fig. 5 Relation between scintillator thickness and spatial resolution.

2.3 Original Phosphor layer Design

Thanks to the ISS system, the phosphor of the CALNEO stands a drastic increase in thickness while maintaining the image quality. To use as much X-ray data as possible, it is effective to increase the phosphor layer thickness and density and enhance the emission efficiency of the phosphor particles. When increasing the density, the spaces between the phosphor particles must be minimized. When enhancing the emission efficiency, the optimum particle size must be selected. That is because of a trade-off. If the phosphor particle size decreases, the emission efficiency falls. If the particle size increases, the spread of emission increases. For the CALNEO, we applied our high-density particle filling technology we have developed for IP (imaging plate) to the GOS phosphor. We mixed large particles and small particles in an appropriate ratio (Fig. 6). Large particles are large in

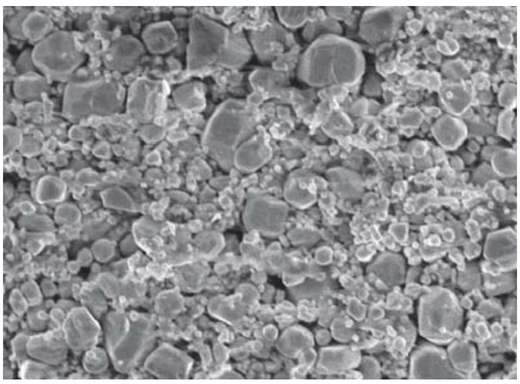

Fig. 6 A cross-sectional image of a GOS scintillator.

emission. The emission of small particles does not blur very much. As a result, we have achieved the volume filling density of 75%. It is a very high percentage for the density of phosphor particles. We have succeeded in increasing the X-ray absorption per unit thickness and balancing the emission intensity and image blurring.

3. Features of FUJIFILM DR CALNEO System

3.1 Image Quality

Fig. 7 and Fig. 8 show DQE and MTF of the ISS-system FPD (CALNEO), PSS-system FPD and our conventional model FCR VELOCITY. The beam quality is RQA5 as specified in the IEC standard[3] and the radiation dose is 1 mR. DQE of the CALNEO is about 1.2 times larger than that of the PSS-system FPD and 1.7 times the VELOCITY's. In principle, it is possible to reduce the radiation dose to lower than those of these systems. MTF of the CALNEO is higher than those of other systems in the frequency range higher than 1.5 cyc/mm. This indicates that the CALNEO will be good at showing fine parts of the anatomy, such as bone trabeculae and pulmonary blood vessels.

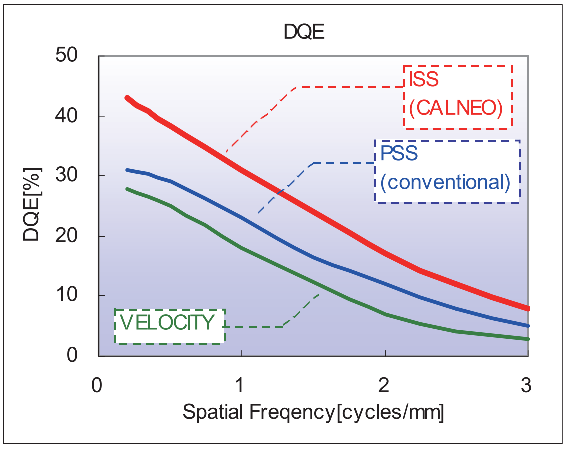

Fig. 7 DQE.

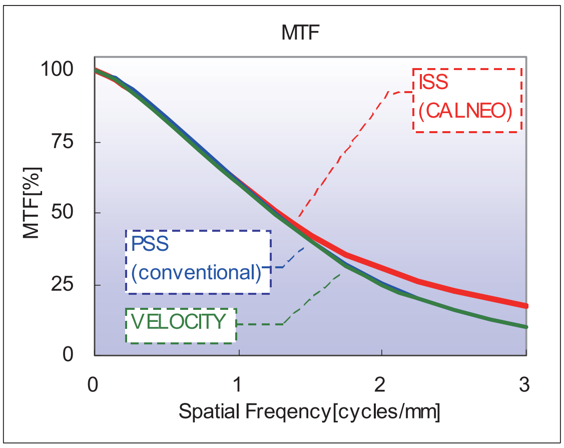

Fig. 8 MTF.

3.2 Compact Design

The CALNEO system is compact in size and simplified in configuration so that it will fit in various installation environments.

The imaging unit is more than 50% thinner than that of the FCR VELOCITY. As well as reducing the thickness of the FPD, we have increased the density using the mechanical design technology. The slim imaging unit will fit into a small space in an X-ray room. It is suitable for medical examination cars, which have limited space.

The console is the Console Advance, the same as the FDR AcSelerate. Several tasks can be done on one console. There is no need to install several PCs in one room. The space required for operation is also designed compact.

3.3 High Throughput

The CALNEO provides a high throughput similar to that of the FDR AcSelerate, thanks to the image lag reduction of the FPD and high-speed reading. It will create a stress-free workflow even in a very busy x-ray room.

4. Conclusion

This report has explained the technology for enhancing image quality used in the FUJIFILM DR CALNEO and its features and capabilities. This system and the developed technologies make it possible to reduce radiation dose and improve the workflow. We hope this system will be widely used.

We will continue to develop new technologies and provide high-performance products to advance the quality of medical care, and the quality of life.

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