Development of a Wireless Cassette Digital Radiography Detector: the AeroDR

Osamu TOKUHIRO* Tomonori GIDOU* Teruo KASHINO*

Abstract

Over the years, digitalization in X-ray photography has greatly progressed, with the number of annual shipments of CR (computed radiography) units today totaling over 20,000 units. In recent years, the DR (digital radiography) market has rapidly expanded due to the addition of portable DR cassettes to existing built-in DR detectors. Forecasting the trend toward portable DR cassettes and thoroughly investigating what these products would require, we developed the AeroDR, a cassette DR detector which can be used in both wired and wireless systems. The AeroDR is a highly complete system in which various technologies, which are appropriate to X-ray photography using a cassette, are combined and harmonized. These include the intimate contact between the columnar CsI (cesium iodide) scintillator and the sensor panel for fine sharpness, the world's lightest cassette case of all wireless X-ray detectors while providing exceptional mechanical strength, and a novel battery with power-saving technology.

* Konica Minolta Medical & Graphic, Inc., Development Center, Development Department

1. Introduction

The CR (computed radiography) system that has made rapid progress since the late 1990s has accelerated the digitalization in the field of X-ray photography. On the other hand, it had the problem of requiring considerable time for the examination of photographed images. Under that condition, Konica Minolta put on sale in 2008 the "PLAUDR"—a self-contained DR system that permits examining photographed images on a real-time basis [1]. This system is being well received by the market, especially by large hospitals. At present, however, cassette radiography is still implemented by CR. Cassette DR is also spreading gradually, but it still is not easy to use because it is heavy in weight and requires connection of power and signal cables. The presence of cables, in particular, has presented many problems, such as the difficulty involved in improving the work efficiency in frequent X-ray photography or the danger of aged patients who require assistance stumbling over the cables.

The AeroDR has been developed not only to solve the above problems but also to enhance the realtimeness of CR and significantly improve the quality of images obtainable with CR while maintaining the good operability and working performance of cassette CR that is playing an important role in the current market. With the AeroDR, Konica Minolta has solved many of the problems of the conventional cassette DR and materialized a real cassette DR system that is capable of offering high-quality images for diagnosis even in the low dose region. At the same time, the company has made various improvements, such as the wider dynamic range of DR comparable to that of CR, the safer and more durable battery employing a newly developed battery system, and the quick recharging. The technologies that the company has newly developed are described in detail below.

2. High Quality of Images

2.1 Required image quality

With diagnostic imaging equipment using X-rays, the greatest importance is attached to the relationship between image quality and dose. Generally speaking, the image quality improves as the dose is increased. When the dose is increased, however, the patient's radiation exposure increases too. Therefore, the X-ray image receptor is required to be able to provide a suitable image quality with a suitable dose. As an indicator of the image quality (performance) of an X-ray image receptor, DQE (Detective Quantum Efficiency) is often used. When DQE is high, it indicates that the dose is efficiently reproduced as input image information. In other words, it means that high-quality images can be obtained even with a small dose.

Another important indicator of the performance of an X-ray image receptor is the dynamic range. The dynamic range is a parameter that indicates the range of dose over which the X-ray image receptor can properly reproduce X-ray information as X-ray images. When the dynamic range is wide, it means that a wide dose range can be selected for X-ray photography. For example, the dynamic range that was somewhere around two digits for screen film was widened to four digits (about 10 μR to 100 mR) for CR. As a result, the risk of re-photography could be dramatically reduced.

2.2 DQE

Fig. 1 schematically shows a cross section of the interface between the scintillator and the TFT panel in an indirect conversion type DR system. In many of conventional indirect conversion type DR systems, the CsI scintillator and the TFT sensor panel are made to contact with each other via a protective film formed on the columnar CsI scintillator surface. Recently, we developed a new technology whereby the CsI scintillator is made to contact directly with the TFT sensor panel without any protective film between them. This technology has made it possible to guide the light emitted from the scintillator to the photodiode without causing the light to be dispersed at the interface with TFT.

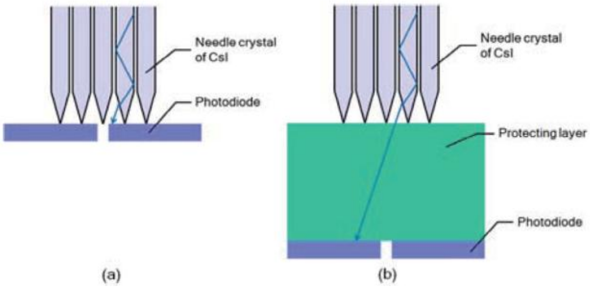


Fig.1 Schematic cross section of scinttilator and TFT-panel. (a) AeroDR, (b) Conventional DR.

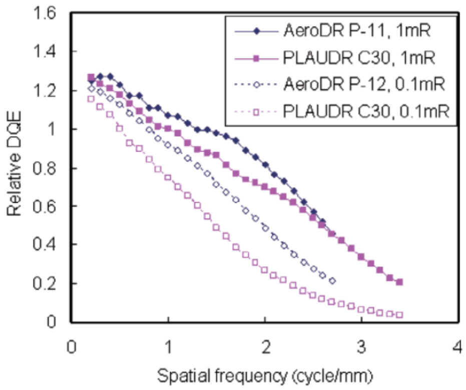


Fig.2 DQEs of the AeroDR and its predecessor, the PLAUDR.

In addition, by optimizing the technology for controlling the growth of scintillator crystals, we improved the efficiency of transmission of light emitted from the scintillator. As a result, the DQE (0.1 mR, 1 cycle/mm) could be improved by 20%, relative to the PLAUDR, as shown in Fig. 2. This technology permits the AeroDR to maintain a high DQE even at a low dose. It is considered therefore that the AeroDR is effective to reduce the amount of radiation exposure.

2.3 Dynamic range

Fig. 3 shows the input/output characteristics of the AeroDR and PLAUDR C30, respectively. At the radiation quality of RQA5, the AeroDR has a wide dynamic range comparable to that of CR, that is, about 4 digits (1.4 μR to 12 mR), whereas the dynamic range of PLAUDR C30 is about 3.5 digits (2 μR to 7 mR). In addition, with the AeroDR, the saturation dose on the high dose side is about 1.7 times higher than that of PLAUDR C30. This means that in radiography of shoulder joints, for example, the AeroDR permits describing the skin line accurately even when the radiographic conditions change along the way.

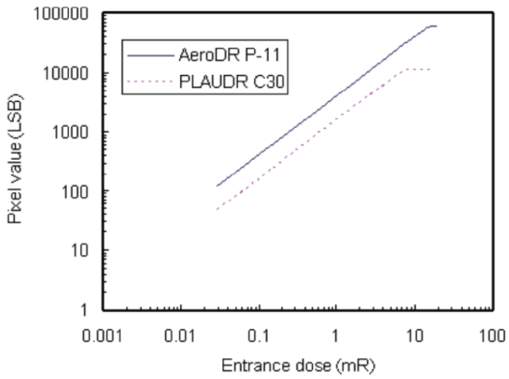


Fig.3 Digital characteristic curves of AeroDR and PLAUDR.

3. Lightweight and Durability

3.1 Requirements of cassette case

We considered that in order to implement stress-free cassette radiography safely and smoothly, it would be indispensable not only to get rid of power lines and communication cables that extend from the cassette but also to make the cassette lighter in weight and higher in durability so as to ensure trouble-free operation even under substantial shock or load. In designing a cassette which is lighter in weight and which has required resistance to shock and load, the structure and material of the cassette case are the most important considerations.

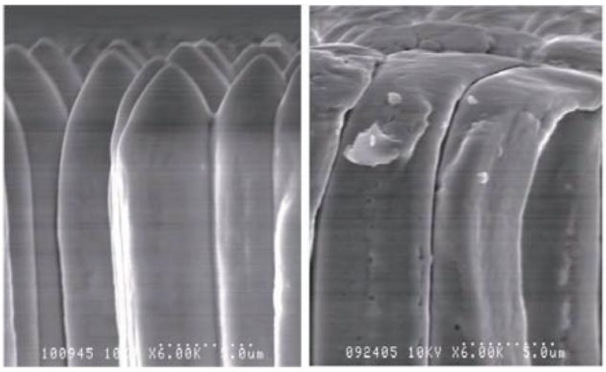
3.2 Structure of cassette case

Fig. 4 shows the cylindrical monocoque cassette case we adopted in the present development. It is made of laminated board of PAN-base carbon fiber formed in an autoclave. Since the battery is incorporated in the cassette (it need not be replaced), it is unnecessary to provide the case with a notch for battery replacement which reduces the rigidity of the case. Because of this, the cassette case that is appreciably light in weight has sufficient rigidity. Thanks in part to the buffer effect of the built-in battery, the load bearing performance of the cassette is the same as that of our CR cassette (80ø, 100 kg).

Fig.4 Monocoque-structured carbon chassis.

3.3 Structure of CsI scintillator protection

Concerning any load applied to the cassette from the outside, a special design is called for from the standpoint of protecting the CsI scintillator crystal too. Fig. 5 shows the initial condition of CsI crystal and the condition of a CsI crystal edge damaged by load, both observed under an electron microscope. In order to transform X-rays into light inside the CsI crystal and emit the light from the CsI crystal efficiently, it is important to secure the orderliness of columnar CsI crystal and the normal shape of CsI crystal edge. It has been empirically confirmed that the modulation transfer function (MTF) of the CsI crystal declines when the columnar crystal edge is crushed under a load.



(a) Normal edge (b) Damaged edge

Fig.5 SEM photograph of CsI crystal edge.

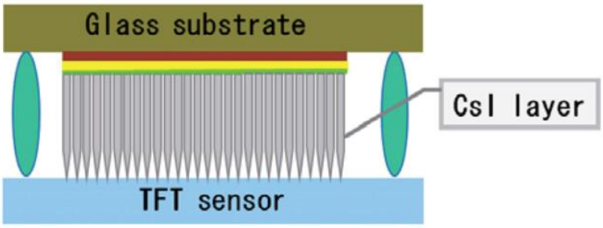
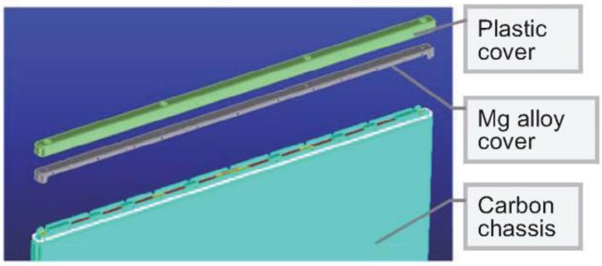


Fig.6 Glass seal structure for CsI scintillator.

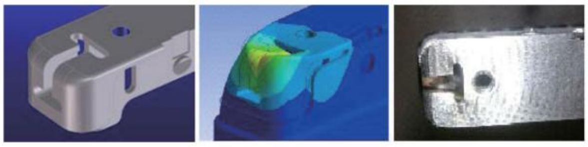
In order to prevent the CsI crystal from being deformed by local concentration of external force, a double-glass structure in which the CsI scintillator glass plate and the TFT panel glass plate are overlapped and sealed together is adopted for the AeroDR. This structure is schematically shown in Fig. 6. The double-glass structure not only enhances the load-bearing performance but also prevents the scintillator edge from being deformed by some mechanical shock (e.g., fall or striking of the cassette) and the TFT sensor panel glass plate from being broken.

3.4 Resistance to shock

Concerning resistance to impact from falling, the cylindrical carbon case needs to be protected from the shock at the corners. When the case is dropped with its corner facing down, the stress concentrates at the corner at the time when the case hits against the floor. Therefore, it is necessary that the corners should be made stronger than the sides. As the means of protecting the corners by rigid or elastic covering, a structure whereby the energy of collision is absorbed by plastic deformation was adopted for the AeroDR since the energy of collision is transmitted to the carbon case through the covering and ultimately causes the case to break down. Fig. 7(a) shows the construction of the sides of the carbon case. The opening in the carbon case is doubly protected by an Mg alloy cover and a plastic cover. The Mg alloy cover (Fig. 7(b)) is provided with a large H-shaped cut in the center to absorb the shock of fall by plastic deformation and thereby prevent the case from breaking down. Fig. 7(c) shows the results of an FEM analysis of the stress propagation and member deformation during fall of the case. The cut for absorbing the shock of fall has been optimized based on results of testing with various shapes and sizes of cuts. Fig. 7(d) shows a photo of a corner of the case damaged by fall. It can be seen that the cut part was deformed and the energy of impact was absorbed as designed. The falling impact test of the AeroDR was carried out under the same conditions as applied to our CR cassettes.



(a) Construction of chassis edge



(b) Corner part (c) FEM analysis (d) Damaged corner

Fig.7 Mg alloy cover.

The AeroDR was designed with consideration given to making the cassette size conform to the JIS (ISO) standard (356 mm × 432 mm) while securing not only the prescribed durability and weight but also the effective radiographic area, that is, within 20 mm from the external dimensions. Therefore, it is possible to implement X-ray photography by installing the AeroDR on an existing radiographic stand in any medical facility in the same manner as using a CR cassette. When an exclusive I/F cable is connected to the AeroDR, there is no fear that the built-in battery should be dead since the power is constantly supplied by the power cable. Therefore, it is possible to keep the AeroDR installed on an existing radiographic stand and use it as a self-contained DR system.

4. Wireless DR

4.1 Demand for wireless specification

In order to allow for wireless radiography, the AeroDR uses a wireless LAN for communications between the cassette DR unit and the console and has a built-in battery to supply power to the radiographic device. The transmission of control commands from the console to the cassette DR, the notification of status and the transfer of image data from the cassette DR to the console, etc. are all carried out on a real-time basis via a wireless LAN. With the aim of implementing the operation of a real wireless cassette, rather than confining the AeroDR within the category of cassette DR, we sought the users' demands and new technologies required to meet those demands paying our attention to various scenes of operation and work flows of radiographic applications. For wireless communications, we adopted IEEE 802.11a because IEEE 802.1b/g that is adopted for PCs and portable game machines was considered very susceptible to a drop of speed or a communication failure due to interference wave.

4.2 New type of battery

In selecting a battery, we attached the primary importance to the safety against fuming/combustion. Then, we sought a thin battery which could be built in the cassette. The other basic requirements of our battery were a charging capacity sufficient for long-hour operation, minimum time of recharging and long service life.
The lithium ion secondary battery is widely used for laptop PCs, cell phones, etc. because of a number of advantages, such as a high energy density and quick recharging. It is also employed for wireless cassette DR systems of other makers. However, fires from laptop PCs and portable music players caused by some defects in manufacturing of lithium ion secondary batteries still have occurred from time to time. Defective lithium ion secondary batteries which have occurred in the manufacturing process can hardly be detected by the receiving inspection. Besides, it is impossible to solve the problem by designing a special panel. Therefore, we judged inappropriate to use lithium ion secondary batteries for our cassette DR systems since we place the major emphasis on the safety of medical equipment that makes direct contact with the patient.
As a battery which meets the above requirements, including the safety of the patient, we adopted the lithium ion capacitor. Since the energy density of the lithium ion capacitor is about one-fifth that of the lithium ion secondary battery, it is absolutely necessary to design a capacitor which consumes less electric power. On the other hand, even if the electrodes are short-circuited, there is no fear that the capacitor should emit smoke or catch fire. In addition, the temperature at the part that makes contact with the patient does not rise above 41ºC. This conforms to the applicable international standard [2]. Table 1 compares the characteristics of the two types of batteries.

Table 1 Characteristics of lithium-ion battery and lithium-ion capacitor.

Characteristics	Lithium-ion battery	Lithium-ion capacitor
Charge/discharge principle	Electrochemical reaction	Electro double layer on positive electrode Electrochemical reaction on negative electrode
Energy density by weight (Wh/kg)	100 - 140	15 - 27
Self discharge rate	5-10% per month	1-2% per month
Cycle life (40% decrease in power capacity)	300 - 500 times	Greater than 10,000 times
Safety risks		
Overheated/overcharged	Thermal runaway. Explosive	No thermal runaway
Max. temperature in overcurrent	greater than 180°C	Less than 78°C

The lithium ion capacitor has a charge & discharge cycle life more than 100 times longer than the lithium ion secondary battery and does not markedly decrease in capacity even after it continues to be used for 5 to 6 years. Therefore, it can be built in the cassette DR unit. By contrast, the lithium ion secondary battery needs to be replaced with a new one after about 300 to 500 charge-discharge cycles. Therefore, it can hardly be built in the cassette. When this type of battery is used, it is indispensable to provide the cassette DR unit with a mechanism for replacement of the battery pack. In this case, the structure of the cassette case becomes so complex that it is difficult to significantly reduce the weight of the cassette and increase the mechanical strength of the cassette.
Since the lithium ion capacitor has a small energy capacity, there might be concern about its unfavorable effect on the battery driving time and the number of radiographic images that can be obtained. Actually, however, the AeroDR secures sufficient battery driving time and a sufficient number of radiographic images thanks to the energy-saving technology described later. Incidentally, the small energy density of the lithium ion capacitor proves advantageous in terms of recharging time. Namely, when an exclusive cradle is used, the time required to fully recharge the capacitor is within 30 minutes, less than one-fourth of the time required by competitions. In addition, unlike the lithium ion secondary battery, the lithium ion capacitor deteriorates little even when the power is constantly supplied over a cable. Since the capacitor permits using a large current for recharging from the beginning, even if the capacitor has become almost exhausted, it can be used to take 5 to 6 pictures in emergency by recharging it for three minutes or so.

5. Savings of Electric Power

In order to allow for sufficient radiographic time/radiographic images by battery driving, it is indispensable to implement power-saving design. Needless to say, for the AeroDR, we selected parts which consume less electric power. We also strove to minimize the power consumption of the entire system taking into consideration the control of detector driving and the work flow during radiography. As a result, the power consumption of the new detector unit could be reduced to less than one-fifth that of conventional detector units. Several of the characteristic new power-saving technologies we have developed are described below.

5.1 Control system consuming less electric power

Fig. 8 compares the power consumption of detector unit in operation and asleep between the AeroDR and a conventional DR. The readout IC that reads out electrons accumulated by transformation of X-rays is an important part whose electrical noise determines the quality of final radiographic images. In order to reduce the electrical noise from that part, it is effective to increase the electric power of the first-stage amplifier circuit. However, the readout IC requires an amplifier circuit for each of the signal lines that ordinarily number 2,000 or more (twice that number for a two-side readout system). Therefore, increasing the electric power of the first-stage amplifier circuit would have an impact thousands of times larger than that on the power consumption. This makes it extremely difficult to implement a power-saving design of readout IC. Because of this, in the ordinary DR, the readout IC accounts for a large proportion of the power consumption, that is, about one-third of the power consumption of the entire detector unit. For the reason mentioned above, the power consumption dramatically increases when the number of transistors in the IC is increased. Therefore, in the newly-developed readout IC, we reduced the number of transistors to a minimum taking into consideration the electrical noise from the readout IC. In addition, we staggered the period of readout of electrons by the readout IC and the period of AD conversion of signals read out to decrease the peak power consumption.

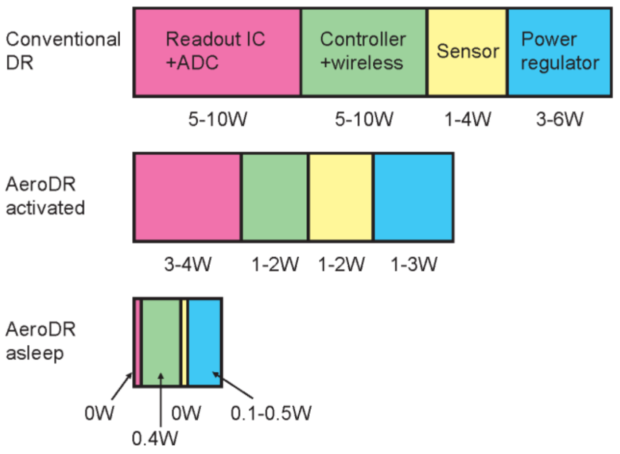


Fig.8 Power consumptions of conventional DR and AeroDR.

The wireless LAN module and the CPU for communications are also capable of being driven with reduced power consumption and are compatible with WoWLAN (Wake on Wireless LAN). Therefore, they are kept in sleep state during the period of inactivity to control the electric power dynamically. The power consumption of the CPU for communications is further reduced by means of clock gating whereby the non-operating blocks in the circuit are partly put out of operation even during execution of some task.
As a power-saving measure at the system level, we adopted a "sensor on standby" mode in which, when the period of shutdown between radiographic operations is short, the power supply to the sensor unit is maintained, whereas the power supply to the other parts is stopped. When the period of shutdown is long, the above mode is shifted to a "sleep standby" mode in which all operations, excepting periodical wireless communications, are stopped. By automatically switching between the above two modes according to circumstances, it is possible to further reduce the power consumption.

5.2 Effects of saving electric power

The effect of reducing power consumption is not limited to prolonged battery driving time. When the electric power consumed increases, the quantity of heat generated increases proportionally. When the dynamic electric power control mentioned above is implemented, the temperature fluctuation and speed variation increase. The amorphous silicon sensor of a photoelectric conversion device used as a sensor is subject to a marked change in dark current according to temperature. Therefore, under a violent temperature change, the fluctuation in offset level of the sensor increases, causing unevenness to occur in the radiographic images. Fig. 9 shows the change in offset value relative to the time elapsed after the power supply is switched on. It can be seen that the offset value of the AeroDR stabilizes faster than that of the PLAUDR. The ability to get ready for operation in a short time after start-up of the power supply or return from the sleep mode is one of the salient features of the AeroDR.

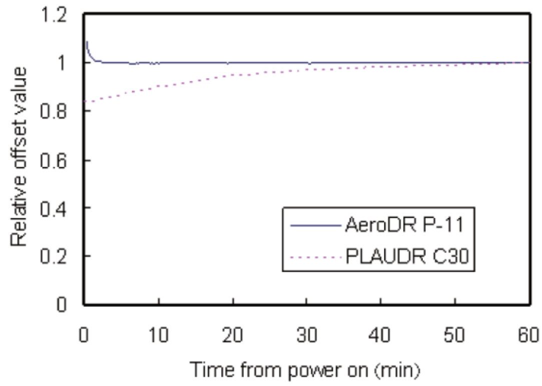


Fig.9 Change of relative offset value over elapsed time after power on.

6. Conclusion

We developed a new wireless cassette digital radiography detector with a built-in battery—the AeroDR. It is a lightweight cassette DR detector compatible with JIS (ISO) and has good load-bearing performance and resistance to shock.
In developing the new product, we did not decide on product specifications in view of technical limitations. Instead, we studied the way the cassette DR should be from the customer's standpoint and incorporated all the study results in the design of AeroDR. Concerning the safety of patients to which we attach the primary importance, we avoided using batteries which can emit smoke or catch fire and adopted a new-type battery having a high degree of safety. For that matter, we tackled, successfully, a comprehensive power-saving design. As a result, we could complete a real cassette DR system, rather than a simple wireless cassette DR detector, that is applicable in various operational scenes and work flows.
We will be happy if this new product will be utilized in clinical practices and every customer will feel the appeal of the new cassette DR proposed by Konica Minolta. Rather than being completely satisfied with the present success, we intend to continue developing innovative new products and thereby contribute to the improvement in quality of medicine in the world in the future.

• References

1) M. KABURAGI et al.: Development of DR System "PLAUDR," Konica Minolta Tech. Rep., 6, 77 (2009)
2) IEC 60601-1: 1988 Ed. 2