

# The Measurement and Evaluation of Standard DQE in Digital Radiography

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**Keywords:** Digital radiography; Flat panel detector; Detective quantum efficiency; Medical images measuring

**Abstract.** This study introduces the measurement and evaluation of the standard detective quantum efficiency in digital radiography. The detective quantum efficiency (DQE) is the most suitable parameter for describing the imaging performance of digital Radiography. DQE is defined as the squared ratio of the signal-to-noise ratio at the output to the signal-to- noise ratio at the input of digital radiography. In this study, the main work is to use some device to gain images, which used to obtain the modulation transfer function (MTF) and Noise Power Spectrum (NPS), according to the international standard IEC 62220-1. We also do some work about the algorithm of MTF and NPS. Finally we design a set of DQE assessment method which can be used in metrology and measurement of digital radiography. We define the test conditions as follows: RQA5 radiation quality, 21mmAl additional filtration. Experiment proved that DQE can show the basic properties of the flat panel detector in DR system. In the process of obtaining the DQE, the key performance parameters could be measured and normalized, which includes DQE, MTF, detector response curve and NPS. The digital radiography with poor DQE has the low imaging quality. The patients should have more body surface irradiation dose. Metrological verification and quality control personnel can determine the working station of DR system according to the indexes of DQE various performance indicators, which is good for decreasing collective effective dose equivalent.

## Introduction

Digital radiography (DR) is a famous breakthrough in the field of X-ray radiation. Since it has many advantages than conventional screen-film system and computed radiography, such as more functions, higher efficiency, lower exposure dose and higher image quality, its market penetration raised rapidly in recent years. One of the core components in DR is Flat panel detector (FPD), which absorbs the incoming x-rays and produces output electrical signals and then transforms the signals to digital image. The Characteristics of FPD highly influence the imaging properties of a DR system. Therefore, Metrological verification is needed. At present, there are two steps can do DR metrological verification. One step is judging the dose deviation between nominal dose of a system and a measured value, the other step is distinguishing line pair or different contrast in the image of a special phantom by eyes. The last type cannot reflecting the real characteristic of the system because the progress of converting X rays to image is not considered and human factors is not very certain. Furthermore, this method cannot monitor system running. In order to solve these problems, the connection between images obtained from FPD with the X-rays emitted from tube should be considered. Normally, DQE is used to describe the imaging performance of an X-ray imaging device[1,2,3,4].

## Method

The DQE is the most suitable parameter for describing the imaging performance of digital Radiography. DQE is defined as the squared ratio of the signal-to-noise ratio at the output to the

signal-to- noise ratio at the input of digital radiography. For digital radiography, the input is the X-ray photons, and the output is the digital image. It is well known that the X-ray photons depend on the X-ray exposure dose with the radiation quality. DQE reflects the relationship between the X-ray dose and the image form the flat-panel detector. This could be achieved by traditional metrology and measurement technique used in digital radiography. The equation for the frequency-dependent DQE is:

$$DQE(\mu, \nu) = \frac{SNR_{out}^2}{SNR_{in}^2} \quad (1)$$

In formula 1,  $\mu$  and  $\nu$  mean the spatial frequencies in the x and y direction;  $SNR_{in}$  and  $SNR_{out}$  are the input and output Signal-to-Noise ratios, respectively.

**SNR<sub>in</sub>.**  $SNR_{in}$  can be calculated by:

$$SNR_{in}^2 = w_{in}(\mu, \nu) \quad (2)$$

Where  $w_{in}(\mu, \nu)$  equals to the X-ray photo fluency  $Q$ , which can be calculated by

$$w_{in}(\mu, \nu) = Q = K_a \int \frac{\Phi(E)}{K_a} dE = K_a SNR^2 \quad (3)$$

Where  $E$  is the energy of X-ray energy;  $K_a$  is the measured air kerma, unit:  $\mu Gy$ ;  $\Phi(E)$  is the flux per air kerma;  $SNR^2$  is the squared signal-to-Noise ratio per air kerma. During a test, the radiation qualities should be RQA5 according to IEC 62220-1 standard [5] as shown in Table 1.

Table 1 RQA5 parameter

Radiation quality No.	Approximate X-Ray tube Voltage kV	HALF-VALUE layer(HVL) mm Al	Additional filtration mm Al	$SNR^2$ 1/(mm <sup>2</sup> · $\mu Gy$ )
RQA5	70	7.1	21	30174

**SNR<sub>out</sub>.**  $SNR_{out}$  can be calculated by:

$$SNR_{out}^2 = G^2 MTF^2(\mu, \nu) \frac{w_{in}^2(\mu, \nu)}{w_{out}(\mu, \nu)} \quad (4)$$

In formula 4,  $G$  is the gain of the detector at zero spatial frequency. When the pixel value is exposure quantum per unit area calculated by the liner correlation between quantum with raw data and does,  $G$  can be omitted.  $MTF(\mu, \nu)$  is the pre-sampling modulation transfer function of the FPD.  $MTF$  function reflects the sharpness of DR system, which is a measure of the ability of DR system reproducing image contrast from subject contrast. Mathematically, the  $MTF$  is a plot of the ratio of the output-to-input single -frequency sinusoidal function of their spatial frequency. The method of obtaining  $MTF$  function can be calculated as follows [6,7,8]:

Obtain an irradiation image of tungsten edge device according to IEC 62220-1

Analysis the image and get an edge profile

Construct an oversampled edge spread function (ESF)

The oversampled ESF is differentiated smoothed and its digital Fourier transform is calculated. The modulus of this Fourier transform yields the  $MTF$ .

$W_{out}(u, \nu)$  is the NPS of the output image. In radiographic imaging, noise interferes with the visualization of an abnormality of interest and with the interpretation of an image. Radiographic noise is best characterized by its NPS[9,10]. The NPS is the variance of noise within an image divided among various spatial frequency components of the image. Mathematically, the NPS is the normalized squares of Fourier amplitudes averaged over an ensemble of noisy but otherwise uniform images.

The NPS at the output of the digital X-ray imaging device ( $W_{out}(u, \nu)$ ) can be calculated according to this standard is:

$$W_{out}(u, \nu) = \lim_{M \rightarrow \infty} \frac{\Delta x \Delta y}{M \cdot 256 \cdot 256} \sum_{m=1}^M \left| \sum_{i=1}^{256} \sum_{j=1}^{256} (I(x_i, y_j) - S(x_i, y_j)) \exp(-2\pi i(\mu x_i + \nu y_j)) \right|^2 \quad (5)$$

In formula 5,  $I(x_i, y_j)$  is the region of interest (ROI) with a size of 256×256;  $M$  is the number of the ROIs;  $S(x_i, y_j)$  is reference image which can be calculated by averaging several images.

**DQE.** According to formula 2, formula 3, formula 4 and formula 5, DQE can be calculated by:

$$DQE(u,v) = G^2 MTF^2(u,v) W_m(u,v) / W_{oa}(u,v) \quad (6)$$

During the measurement of DQE, the dose of the input irradiation, the MTF of the detector of DR, the Noise of the image and the liner relation between raw data with input air kerma are all measured, thus it is a comprehensive verification. A system with higher DQE can obtain good image with lower irradiation, and the false positive or negative of identify lesions can be reduced.

## Results

**MTF.** In clinic, the spatial resolution is very important, because only lesions larger than special frequency can be recognized. People use line pair card to test spatial resolution for a long time, but it highly rely on eyes, thus it is not very certain. It test of DQE, the spatial resolution can be obtained by MTF. In this study, we choice one type of FPD to calcite the result of DQE, and the size of the FPD is 35cm×43cm, and the active matrix is 2560×3072.

Fig.1-3 shows the MTF results under irradiation of RQA5, 40ms and 100mA.

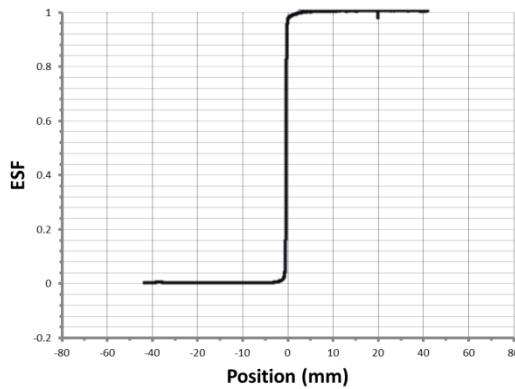


Fig.1 Edge-spread function

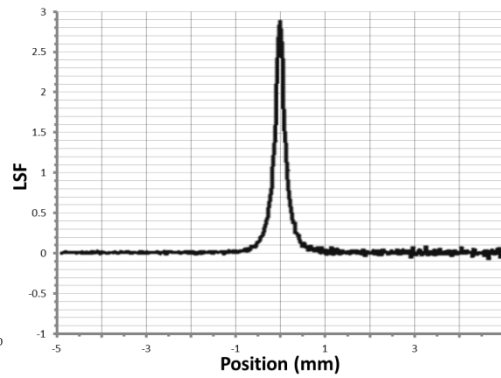


Fig.2 Line-Spread function

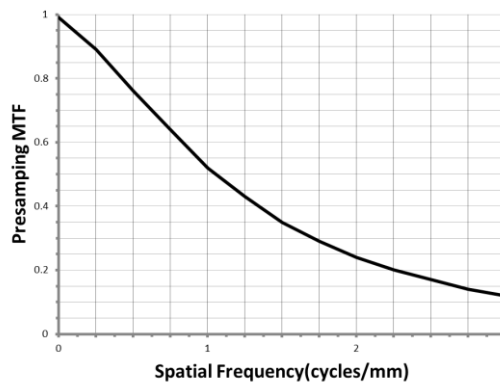


Fig.3 MTF value diagram

**DQE.** The DQE of the system in 3.3 was also tested, and the result is shown in Fig. 4. When a lesion is recognize in an image, it can be confirm by considering corresponding DQE value. Quality inspectors can judge a system by DQE. The result also shows that the efficiency of the X-ray conversion decrease with spatial resolution.

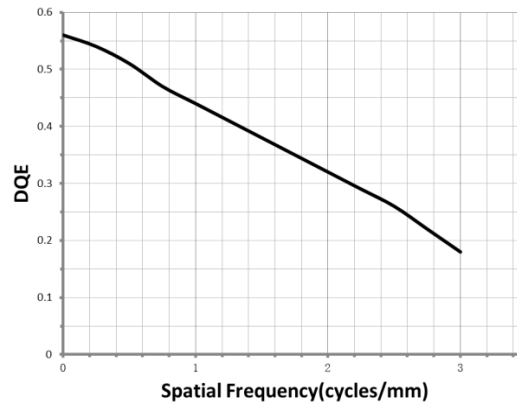


Fig. 4 DQE value diagram

Table 2 shows the MTF and DQE value corresponding to different spatial resolution.

Table 2 the MTF and DQE value based on spatial frequency

Spatial frequency (cycles/mm)	MTF value	DQE value
0.25	0.89	0.54
0.50	0.76	0.51
0.75	0.64	0.47
1.00	0.52	0.44
1.25	0.43	0.41
1.50	0.35	0.38
1.75	0.29	0.35
2.00	0.24	0.32
2.25	0.20	0.29
2.50	0.17	0.26
2.75	0.14	0.22
3.00	0.12	0.18

From table2, we can conclude MTF and DQE values have a trend of relationship with the spatial frequency. With the increase of spatial frequency, MTF and DQE gradually reduced.

MTF, which comprehensively reflects the image contrast and spatial resolution, can be used as a simple image contains information of evaluation index. For DR digital imaging, image quality in addition to the detector unit area, the factors such as sensitivity are affected by image processing method, the influence of the incident X-ray dose and energy. So, using the MTF has not fully expressed the quality of digital images. Now some adopt more perfect DQE index to evaluate the quality of digital image, because it combines various parameters affecting the quality of images, including the MTF. Therefore, performing DQE measurement is further perfection and development of image quality evaluation method.

## Summary

For medical image, we want to see the quality of the image and think about the conditions of the imaging. Only for images, the image quality should be evaluated by the spatial resolution and contrast resolution, dynamic range, the MTF, noise and other indicators. For digital imaging system, the indicators in addition to the detector unit area, the factors such as sensitivity, are affected by image processing method, the influence of the incident X-ray dose and energy, any distributed parameter cannot fully explain the characteristics of the DR system. The technology about more lower the incident X-ray dose for more higher SNR of images represent the level of detector performance. Currently the DR system manufacturers generally used DQE as evaluation index. The DQE index combination of the image contrast spatial resolution, noise and incident X-ray dose, and it can be a comprehensive ability expression of digital imaging system to detection of contrast. The DQE index

is considered to be the evaluation criteria of digital radiography for the imaging quality.

## Acknowledgement

This project is supported by Special Fund for AQSIQ-Scientific Research in the Public Interest (201410111).

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