Determination of the modulation transfer function using the edge method: Influence of scattered radiation

Ulrich Neitzel
Philips Medical Systems, Röntgenstraße 24, D-22335 Hamburg, Germany

Egbert Buhr and Gerhard Hilgers
Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany

Paul R. Granfors
G.E. Medical Systems, c/o PerkinElmer Optoelectronics, 2175 Mission College Boulevard, Santa Clara, California 95054

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The edge method for measuring the modulation transfer function (MTF) has recently gained popularity due to its simplicity and appropriateness particularly for digital imaging systems. Often edge test devices made of rather thin metal sheets are used, which are semitransparent to x rays and may generate scattered radiation. The effect of this scattered radiation on the determined MTF was investigated both theoretically (assuming an ideal detector) and experimentally using a CsI-based digital detector. It was found that the MTF increases due to the scattered radiation for all spatial frequencies larger than 0 mm\(^{-1}\). The theoretical model developed in this study predicts that the maximum error compared to the true detector MTF is given by \(S/A\), where \(A\) is the attenuated fraction and \(S\) is the scattered fraction reaching the detector, relative to the incident radiation. Theoretical and experimental results are in good agreement for radiation qualities corresponding to general radiography (RQA3, RQA5, and RQA7), whereas for chest beam quality (RQA9) the experimentally observed MTF error is larger than predicted by the simple model, possibly because the energy response of the CsI-based detector differs from that of an ideal one. The theoretical MTF error reaches a value of 18% for a 0.25 mm thick lead edge of RQA9. Since the MTF enters squared into the determination of the detective quantum efficiency (DQE), an error of at least 36% in DQE may result when using this edge test device. In conclusion, the use of fully absorbing edge material is advised for MTF determination with the edge method. © 2004 American Association of Physicists in Medicine. [DOI: 10.1118/1.1813872]

Key words: modulation transfer function, edge method, scattered radiation

I. INTRODUCTION

The modulation transfer function (MTF) of an imaging system is defined as the absolute value of its optical transfer function, normalized to unity at spatial frequency zero.\(^1\text{–}^3\)

One established method to determine the MTF is based on the use of a sharp edge that is imaged to produce an edge spread function (ESF). The ESF is then differentiated to obtain the line spread function (LSF), from which the MTF is calculated by a Fourier transform.\(^4\text{–}^9\)

An edge test device with a well-defined edge is usually realized by carefully machining a thin piece of metal, e.g., lead, tungsten, or platinum. Material thicknesses of 0.1 to 0.25 mm are often used to allow easy manufacturing and handling as well as accurate alignment of the edge in the x-ray beam.\(^10\text{–}^12\)

Depending on the actual thickness of the material and on the beam quality used for imaging, the metal sheet may be either (almost) fully absorbing or semitransparent.

When x rays hit the edge test device, scattered radiation is inevitably generated. The scattered radiation may exit from the back side of the edge device toward the detector if the material is not thick enough to absorb all radiation. In this case the scattered radiation will superpose on the direct (transmitted or not attenuated) radiation forming the image of the edge transition; thus, the x-ray energy profile at the detector surface differs from the desired step-like profile (Fig. 1). The measured ESF will therefore be different from the true detector ESF and, consequently, the determined MTF will not be the true detector MTF.

In this paper we report on experimental and theoretical investigations of the magnitude of this error on MTF determination. Measurements were done with a semitransparent and an opaque edge test device in identical configurations using a CsI-based flat-panel detector. For the theoretical estimation a model was developed to describe the level and distribution of scatter in the image plane. Using this model the influence of the scatter contribution to the calculated MTF was determined for some typical edge device materials and thicknesses.

II. EXPERIMENTAL RESULTS

Measurements of the edge spread function were made using two different edge test devices, one with a 1 mm thick tungsten plate, which is substantially opaque to x rays and...
one with a 0.15 mm thick tungsten plate, which is semitransparent. The test devices were placed at the surface of a flat panel detector consisting of an amorphous silicon photodiode/thin film transistor array coupled to a CsI(Tl) scintillator, slightly tilted to the axis of the image matrix. The source to image distance was 155 cm, and the test device was positioned approximately 1.1 mm from the surface of the scintillator. Images of the test devices were obtained using four beam qualities defined in the standard IEC 61267: RQA3, RQA5, RQA7, and RQA9 (Table I). From each image, an edge spread function was determined. This was accomplished by first finding the position of the edge transition in the image using a least-squares fitting procedure. The distances from the transition were then calculated for pixels in a rectangular region of interest, 50 mm along the edge and within 10 mm perpendicular to the edge. The pixel values were binned based on distance from the edge transition (bin width ~0.01 mm), and the average of the values in each bin was calculated to determine the edge spread function. These ESFs were numerically differentiated and Fourier transformed to produce the presampled MTFs.

The measured edge spread functions are shown in Fig. 2. The edge enhancement effect for the semitransparent edge material is clearly visible, in particular for the harder radiation qualities. Figure 3 shows the corresponding MTFs: The

![Diagram](image)

**Fig. 1.** Distribution of primary and scattered radiation for a semitransparent edge test device (schematically).

![Diagram](image)

**Fig. 2.** Edge spread functions measured at different radiation qualities with tungsten edge test devices of 0.15 mm (curves A) and 1 mm (curves B) thickness. The insets show a magnified part of the edge transition.

MTFs obtained when using the semitransparent W edge are larger than those measured with the opaque W edge. Only for zero frequency the MTFs agree because of the normalization of the MTF at zero frequency [MTF(0)=1]. For spatial frequencies larger than about 0.5 mm⁻¹ the MTF ratio is almost constant. The relative difference between the MTFs depends on radiation quality and increases from about 1% for RQA 3 to more than 10% for RQA 9.

### III. THEORETICAL MODEL

In this section a theoretical model is developed to describe the influence of the scattered radiation originating from the edge test device on the determined MTF. First, in Sec. III A a qualitative description of the model is given, then in Sec. III B mathematical relations are derived that
allow quantitative modeling, and finally in Sec. III C characteristic parameters are calculated for typical edge device materials using Monte Carlo simulations.

A. Description of the model

An edge test device divides the irradiated field into an open and a covered area. In the open area all primary radiation reaches the detector unattenuated, whereas in the covered part it is attenuated by the material of the edge device. The degree of attenuation is dependent on the type and thickness of the edge material and the energy of the X radiation. Also, in the edge material secondary radiation is generated, e.g., coherently or Compton scattered photons, as well as characteristic (fluorescent) radiation if the energy of the incident x-ray photons exceeds the K edge of the material. In the open area no secondary radiation is generated if we neglect the small contribution of radiation scattered by air.

For modeling the scatter field behind the edge test device the following assumptions are made:

1. The edge device is assumed to consist of a homogeneous, thin layer of material, covering the negative half-space (negative x coordinates). I.e., it is considered to be semi-infinite; at least, it is much larger than the extension of the “scatter point-spread-function” (see below).

2. The thickness \(t\) of the edge device is considered to be small compared to the distance \(d\) of the device to the detector.

3. All secondary radiation generated in the edge device (e.g., coherent and incoherent scatter, fluorescent radiation) is considered to be “scattered radiation.”

4. For an incident pencil beam the scatter originating in the edge device can be described in the detector plane by a (rotationally symmetric) scatter point spread function \(\text{PSF}_{\text{scat}}(r)\).14

In the covered area far from the edge transition (distance from the edge greater than the range of \(\text{PSF}_{\text{scat}}\)) the scattered intensity attains a constant level \(I_S\), whereas in the open area far from the edge the scatter level is zero. In the edge region there is a transition between these levels (Fig. 4). The width of the transition is determined by the range of the scatter PSF and the distance \(d\) of the edge from the detector. Generally, the scatter intensity distribution forms also a step function, although smaller, more gradual and in the opposite direction to the primary radiation.

B. Model calculation

In this section a model calculation is presented which describes the effect of scattered radiation on the MTF measurement. For simplicity, it is assumed that the x-ray detector has equal sensitivity for the scattered and the primary incident radiation.

Consider a semitransparent edge device that is used to generate the edge spread function ESF. Sufficiently far away from the edge location, the radiation intensity behind the edge material is the sum of the transmitted primary \((I_t)\) and...
the transmitted scattered \( (I_s) \) radiation, see Fig. 4. The transmitted primary radiation is collinear to the incident radiation \( (I_0) \), whereas the scattered radiation has a certain angular distribution with respect to the direction of the incident and transmitted radiation.

1. Scatter-free case

If the scattered radiation fraction \( S = I_s/I_0 \) is small enough to be neglected, the normalized profile of the radiation behind the edge device is a step function with a height of \( A = 1 - (I_s/I_0) \), see Fig. 4. We call \( A \) the attenuated fraction. Such a steplike intensity profile is used as input for the MTF determination using the edge method. It allows us to determine the edge spread function of the detector \( ESF_{\text{det}} \), from which the transfer function \( T_{\text{det}}(u) \) can be calculated by a Fourier transform (FT) of the corresponding line spread function \( LSF_{\text{det}} \)

\[
T_{\text{det}}(u) = \text{FT}\{LSF_{\text{det}}(x)\} = \text{FT}\left\{ \frac{d}{dx} ESF_{\text{det}}(x) \right\} .
\]

Here, \( x \) is the coordinate transversal to the edge. Without loss of generality a positive step of \( ESF_{\text{det}} \) along the \( x \) direction can be assumed, and, in addition, the origin of the \( x \) axis can be chosen to be at the edge location. Further assuming an even symmetry of \( LSF_{\text{det}} \) (or, equivalently, an odd symmetry of \( ESF_{\text{det}} \) with respect to the edge location, the transfer function \( T_{\text{det}}(u) \) is real with \( T_{\text{det}}(u) = A > 0 \), according to the central ordinate theorem of the Fourier transform. In many practical situations, the transfer function is positive for all frequencies \( u \) under consideration, i.e., \( T_{\text{det}}(u) > 0 \). Under these assumptions, the MTF of the detector is given by

\[
MTF_{\text{det}}(u) = \left| \frac{T_{\text{det}}(u)}{T_{\text{det}}(0)} \right| = \frac{T_{\text{det}}(u)}{A} .
\]

2. Scattered radiation

In the edge device, scattered radiation is generated that—for an incident pencil beam—can be described in the detector plane by a rotationally symmetric scatter point spread function \( PSF_{\text{scat}} \). \( PSF_{\text{scat}} \) is normalized such that

\[
\int_0^\infty 2\pi r \times PSF_{\text{scat}}(r) dr = S,
\]

where \( S \) is the scatter fraction, \( S = I_s/I_0 \).

The extent of the scatter point spread function in the detector plane depends on the distance \( d \) between the edge and the detector. When the thickness \( t \) of the edge material is small compared to the distance \( d \), all scatter can be considered to originate from a point at a distance \( d \) above the detector. Changing the distance \( d \) will then lead to a radial expansion or contraction of \( PSF_{\text{scat}}(r) \) with simultaneous amplitude scaling to keep the integral [Eq. (3)] constant.

For homogeneous irradiation of the edge device the spatial distribution of the scattered radiation in the detector plane can be calculated by convolving \( PSF_{\text{scat}} \) with the Heaviside step function \( H(x) \) that has the value 1 in the area of the edge and 0 elsewhere. The result (in one dimension, transverse to the edge) is the scatter edge spread function \( ESF_{\text{scat}}(x) \)

\[
ESF_{\text{scat}}(x) = H(x) \ast PSF_{\text{scat}}(r).
\]

The step height of \( ESF_{\text{scat}} \) is \( S \), the step direction is opposite to \( ESF_{\text{det}} \), i.e., \( ESF_{\text{scat}} \) is high where \( ESF_{\text{det}} \) is low and vice versa, meaning that the scatter line spread function \( LSF_{\text{scat}} \) is negative (see Fig. 4). Since \( PSF_{\text{scat}} \) is rotational symmetric, the scatter line spread function \( LSF_{\text{scat}} \) has even symmetry with respect to the edge position. Therefore, the corresponding scatter transfer function \( T_{\text{scat}}(u) \) is real, and for \( u=0 \) has the value \( T_{\text{scat}}(0) = -S < 0 \). For most frequencies \( u \) under consideration, also \( T_{\text{scat}}(u) \) is smaller than 0. Under these assumptions, the MTF associated with the scatter transfer function \( T_{\text{scat}} \) is given by

\[
MTF_{\text{scat}}(u) = \frac{\left| T_{\text{scat}}(u) \right|}{\left| T_{\text{scat}}(0) \right|} = \frac{T_{\text{scat}}(u)}{S}.
\]

The scatter transfer function \( T_{\text{scat}}(u) \) can also be expressed by the Hankel transform of the \( PSF_{\text{scat}} \) [please note the negative sign in Eq. (6) considering the fact that \( LSF_{\text{scat}} \) is negative and \( PSF_{\text{scat}} \) is defined as a positive quantity]

\[
T_{\text{scat}}(u) = -\int_0^\infty 2\pi r \times PSF_{\text{scat}}(r) J_0(2\pi r u) dr.
\]

3. Scatter influence on the measured MTF

Scattered and primary radiation superpose on the detector and cannot be separated with a single measurement. The measured edge spread function \( ESF_{\text{meas}} \) is thus the superposition of the edge spread function \( ESF_{\text{det}} \) originating from the steplike primary radiation profile and an edge spread function originating from the scattered radiation profile \( ESF_{\text{scat}} \) falling onto the detector. This “detected” scatter edge spread function is given by the convolution of \( ESF_{\text{scat}} \) [cf. Eq. (4)] with the (normalized) line spread function of the detector

\[
ESF_{\text{meas}} = ESF_{\text{det}} + ESF_{\text{scat}} \ast LSF_{\text{det}}/A.
\]

The transfer function \( T_{\text{meas}} \) is obtained from Eq. (7) by differentiation and subsequent Fourier transformation [cf. Eq. (1)]. Applying the Fourier differentiation rule and convolution theorem one obtains for \( T_{\text{meas}} \)

\[
T_{\text{meas}} = T_{\text{det}} + T_{\text{scat}} \times T_{\text{det}}/A.
\]

The measured modulation transfer function is thus given as

\[
MTF_{\text{meas}}(u) = \left| \frac{T_{\text{meas}}(u)}{T_{\text{meas}}(0)} \right| = \frac{|T_{\text{det}}(u) + T_{\text{scat}}(u)T_{\text{det}}(u)/A|}{|A - S|}.
\]

Deriving the MTF from the measured edge spread function \( ESF_{\text{meas}} \) will therefore not produce the true detector modulation transfer function \( MTF_{\text{det}} \) [cf. Eq. (2)], but will include the effects of scatter. Only when the scattered radiation is negligible, i.e., if \( S=0 \) and consequently \( T_{\text{scat}}=0 \), then Eq. (9) reduces to the expected result, i.e., Eq. (2).
Equation (9) can be further simplified by exploiting the fact that \( A \) is always larger than \( S \), as \( A \) is the sum of the scattered and the absorbed fraction. Furthermore, the expression within the magnitude brackets in the numerator of Eq. (9) is real due to the odd-symmetry of the edge spread function \( ESF_{\text{meas}} \) and is thus either positive or negative. In most cases the value of this expression is positive \( (T_{\text{det}} \text{scales with } A \text{ and } T_{\text{scat}} \text{ with } S \text{ where } A \text{ is larger than } S) \) and one obtains

\[
MTF_{\text{meas}}(u) = \frac{T_{\text{det}}(u) + T_{\text{scat}}(u)T_{\text{det}}(u)/A}{A - S}.
\]

Using Eqs. (2) and (5), we get for \( MTF_{\text{meas}} \)

\[
MTF_{\text{meas}}(u) = \frac{A \times MTF_{\text{det}}(u) - S \times MTF_{\text{scat}}(u)MTF_{\text{det}}(u)}{A - S} = MTF_{\text{det}}(u)\left(\frac{A - S \times MTF_{\text{scat}}(u)}{A - S}\right).
\]

For the ratio \( MTF_{\text{meas}}/MTF_{\text{det}} \) we obtain

\[
\frac{MTF_{\text{meas}}(u)}{MTF_{\text{det}}(u)} = \frac{A - S \times MTF_{\text{scat}}(u)}{A - S} = \frac{1}{1 - (S/A)}\left(1 - \frac{S}{A}MTF_{\text{scat}}(u)\right).
\]

Since \( MTF_{\text{scat}}(u) \ll 1 \) and \( S < A \), the measured MTF is larger than the true MTF of the detector for all spatial frequencies \( u > 0 \).

\( MTF_{\text{scat}}(u) \) falls off with spatial frequency much faster than \( MTF_{\text{det}}(u) \) since the scatter PSF has a much longer range than the unsharpness of the detector. For spatial frequencies not close to \( u = 0 \), i.e., where \( MTF_{\text{scat}} \approx 0 \), the ratio \( MTF_{\text{meas}}/MTF_{\text{det}} \) can thus be written as

\[
\frac{MTF_{\text{meas}}}{MTF_{\text{det}}} \approx \frac{1}{1 - (S/A)}
\]

from which follows that

\[
MTF_{\text{det}} = \left(1 - \frac{S}{A}\right)MTF_{\text{meas}}
\]

meaning that the true detector MTF is smaller than the measured MTF by a factor \( 1 - S/A \) for all spatial frequencies above the fall-off frequency of \( MTF_{\text{scat}} \).

### C. Determination of \( 1 - S/A \) for Typical Edge Devices

Equation (14) shows that the relative error in the determined MTF due to the presence of scatter is dependent only on the ratio of the scattered to the attenuated fraction, apart from the low spatial frequency influence of \( MTF_{\text{scat}} \). Whereas the attenuation fraction \( A \) in principle can be calculated analytically from the (spectrally weighted) attenuation coefficient and the thickness of the edge material, the determination of the scatter fraction \( S \) requires taking into account all contributions of secondary radiation, like single and multiple Rayleigh and Compton scatter as well as fluorescence radiation. This is most conveniently done using a Monte Carlo simulation approach.

The Monte Carlo calculations were carried out using the EGSnrc Code system. A special user code was developed to determine the contributions of the photons which have undergone different types of interactions. The geometrical model implemented is shown in Fig. 5. The detector array is assumed to consist of individual rectangular detector elements, each 0.2 mm wide. The edge device is located at a distance \( d \) above the detector plane and is aligned parallel to the individual detector elements. The radiation is incident from above and is uniformly distributed over the detector array. For this simulation, the detector is assumed to be ideal, i.e., totally absorbing and with no intrinsic unsharpness \( (MTF_{\text{det}} = 1) \). The energy deposited in the detector is partitioned according to the type of particle which deposits the energy. The energy deposited by photons is partitioned according to the type of interaction the photon has undergone (Compton scattering, Rayleigh scattering, Bremsstrahlung photon, fluorescence photon, primary photon). There is no discrimination with respect to the number of times a photon undergoes a specific interaction type, e.g., a photon which is Compton scattered twice is still counted as a Compton scattered photon. However, photons which undergo at least two different types of interaction are counted as “multiple type scattered” photons, e.g., a fluorescence photon which is Compton scattered in its following history is counted as “multiple type scattered” photon.

Figure 6(a) shows, as an example, the distribution of the \( x \) radiation at the detector surface for a 0.15 mm thick tungsten edge positioned 5 mm above the detector for the radiation quality RQA9. Figure 6(b) exhibits the contributions of the various scatter processes. The predicted edge enhancement due to the scattered radiation is clearly visible. From the transmitted primary \( (I_t) \) and the transmitted scattered \( (I_s) \) radiation components the scatter fraction \( S \) and the attenuation fraction \( A \) can be determined.

Table II shows the values for \( A, S, \) and \( 1 - S/A \) obtained for typical edge device materials and thicknesses at standard radiation qualities. Generally, the MTF error given by \( S/A \) increases with harder radiation qualities. This effect is predominantly caused by the increasing scatter fraction \( S \) reaching the detector at higher beam qualities and to a lesser extent by the reduced attenuation fraction \( A \).

### IV. COMPARISON OF EXPERIMENTAL AND THEORETICAL RESULTS

Figure 7 shows the comparison of the experimentally determined MTF ratios (Fig. 3) with the values of \( 1 - S/A \) ob-
tained from the Monte Carlo simulation for the 0.15 mm tungsten edge at the four radiation qualities (Table II). Note that the Monte Carlo results refer to the radiation at the detector entrance or, equivalently, to the signal generated in an ideal detector, whereas the experimental values include the absorption properties of the CsI-based detector. The theoretical estimate should only be compared to the experimental values at spatial frequencies above the initial falloff, caused by the scatter MTF [see Eq. (12)].

The general trend of increasing MTF error with increasing radiation quality is found both in the experiment and in the model calculation. Quantitatively, there is excellent agreement between experiment and theory for radiation quality

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**Table II.** Scattered and attenuated radiation fractions and the MTF factor $1 - S/A$ [see Eq. (14)] for typical edge device materials for four radiation qualities, as obtained from the Monte Carlo simulation.

<table>
<thead>
<tr>
<th></th>
<th>$S$</th>
<th>$A$</th>
<th>$1 - S/A$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0.25 mm Pb</strong></td>
<td></td>
<td></td>
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<tr>
<td>RQA3</td>
<td>0.016</td>
<td>0.330</td>
<td>0.952</td>
</tr>
<tr>
<td>RQA5</td>
<td>0.013</td>
<td>0.176</td>
<td>0.926</td>
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<td>RQA7</td>
<td>0.011</td>
<td>0.124</td>
<td>0.908</td>
</tr>
<tr>
<td>RQA9</td>
<td>0.021</td>
<td>0.115</td>
<td>0.820</td>
</tr>
<tr>
<td><strong>0.1 mm Pt$<em>{0.9}$Ir$</em>{0.1}$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQA3</td>
<td>0.012</td>
<td>0.898</td>
<td>0.987</td>
</tr>
<tr>
<td>RQA5</td>
<td>0.029</td>
<td>0.682</td>
<td>0.958</td>
</tr>
<tr>
<td>RQA7</td>
<td>0.046</td>
<td>0.613</td>
<td>0.925</td>
</tr>
<tr>
<td>RQA9</td>
<td>0.071</td>
<td>0.630</td>
<td>0.888</td>
</tr>
<tr>
<td><strong>0.1 mm Pt$<em>{0.9}$Ir$</em>{0.1}$+2 mm PMMA</strong></td>
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<tr>
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<td>0.985</td>
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<td>RQA9</td>
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<tr>
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<td>0.011</td>
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<td>0.988</td>
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<tr>
<td>RQA5</td>
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<tr>
<td>RQA9</td>
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<td><strong>0.2 mm W</strong></td>
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<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>RQA5</td>
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<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>RQA7</td>
<td>0.001</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>RQA9</td>
<td>0.001</td>
<td>0.999</td>
<td>0.999</td>
</tr>
</tbody>
</table>

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FIG. 6. Result of the Monte Carlo simulation for a 0.15 mm thick tungsten edge lying 5 mm above the detector, radiation quality RQA9. (a) Relative energy intensities of primary, scattered, and total radiation, (b) contribution of the different scatter components as function of the distance from the edge transition.

FIG. 7. Ratio of the modulation transfer functions measured with the opaque edge (MTF$_A$, 1 mm tungsten) and with the semitransparent edge (MTF$_B$, 0.15 mm tungsten) at four radiation qualities, compared to the theoretical high-frequency estimate $1 - S/A$ (dashed lines), see Table II.
RQA7. For RQA5 and RQA3 the measured effect is slightly smaller than expected from the model, but is considerably larger at RQA9.

One reason for the differences between theory and experiment at high kilovoltage may be that the Monte Carlo simulation does not include the spectral and directional absorption properties of the detector. Scattered radiation is of lower energy and hits the detector at an angle of less than 90 deg; both effects lead to a higher absorption efficiency for scattered radiation compared to the primary transmitted radiation and, consequently, to a larger value for \( S/A \). The difference between the MTF error experimentally observed and that predicted from the simple model assuming an ideal detector may vary somewhat for other types of detectors due to the possibly different energy dependence of x-ray absorption and scattering for other materials. A more detailed comparison of theory and experiment would require the inclusion of the detector properties into the Monte Carlo simulation.\(^{16,17}\)

V. DISCUSSIONS AND CONCLUSIONS

The determination of the modulation transfer function of an imaging detector with the edge method may be influenced by several factors which can lead to systematic errors in MTF\(_{\text{det}}\), e.g., the extrafocal radiation, the radiation field size and inhomogeneity, or the radiation scattered from the edge test device. It this study we investigated the latter effect.

Both the experimental results and the model calculation show that scattered radiation, originating from a semitransparent edge device, modifies the edge spread function in a way that leads to the determined MTF being larger than the true detector MTF.

The theoretical model described in this paper explains the general features experimentally observed for the edge device made of 0.15 mm thick tungsten. For the radiation qualities RQA3, RQA5, and RQA7 also the quantitative agreement with the experimental results is quite reasonable; for RQA9 the measured effect is larger than expected from the simple model, probably because the energy and angle dependence of x-ray absorption in the detector has not been included.

For other edge devices the MTF error due to scatter may be larger or smaller than for 0.15 mm tungsten, depending on the thickness and the material composition. In general, thinner (more transparent) layers generate a larger effect, because a higher scatter fraction reaches the detector and simultaneously the absorbed fraction is smaller. The edge material influences the radiation quality dependence of the MTF error through the relative proportion of the scatter components, in particular the fluorescence fraction near the \( K \) edge of the material.

Deviations on the order of 5% for RQA5 or 10% to 20% for RQA9 may seem—at a first glance—not very significant. However, as the MTF enters squared into the determination of the DQE, the corresponding errors in DQE determination will be twice as large and thus exceed the maximum uncertainty of 10% (95% confidence interval) that is required for DQE determination according to the standard IEC 62220-1.\(^{18}\) With semitransparent edge test devices the accuracy require-