# An Evaluation of MTF Determination Methods for 35mm Film Scanners

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## Abstract

Three different techniques were used to determine the Modulation Transfer Function (MTF) of a 35mm film scanner. The first involved scanning sine wave charts comprising a number of patches with different frequencies of known modulation. The second method involved the scanning and Fourier transform of a photographic grain noise pattern to simulate low modulation white noise. Finally, the ISO 12233 Slanted-edge Spatial Frequency Response (SFR) plug-in was used to determine the average MTF of the device. This creates a super-sampled edge profile from sequential scan-lines of the sampled image of an edge.

Procedures for creating test targets, where appropriate, are described. Advantages and limitations encountered in applying each methodology are discussed, as well as the precision of each method for deriving the MTF. Conclusions are drawn concerning the comparability of MTFs determined by the three methods.

## Introduction

In analogue imaging systems the determination of the MTF depends critically on the method of measurement due to non-linearities. Digital imaging devices suffer from additional non-linearities, because they are non-stationary, anisotropic systems and often incorporate non-linear image enhancement [1]. These result in additional problems for evaluating the system MTF and different techniques often yield large discrepancies.

The Spatial Frequency Response plug-in [2] has been proposed as a standard method for the determination of averaged digital MTFs. However, other measurement methods are being used and a need for comparison was considered essential.

## Experimental Methods and Results

A 35 mm film scanner was used for which the overall system MTF is a combination of the MTF of the CCD array, the lens and the electronic components. It acquires images at 12 bits per channel and saves files down-sampled to 8 bits per channel. Down-sampling is achieved via look-up tables (LUT), located in the firmware of the scanner.

The size of the monochrome linear image sensor is 2592 pixels, resulting in a maximum image size of 2592 x 3888 square pixels, of 9.4 x 9.4 μm size [3]. These pixel dimensions were confirmed by scanning in a target of known physical size. The Nyquist frequency ($1 / (2\Delta x)$ where $\Delta x$ is the sampling pitch) for both fast and slow scanning directions was calculated as 53.2 cycles/mm.

Only the scanner's monochrome MTF responses were evaluated because the same principles can be applied to the determination of multi-channel MTFs. The device's tonal characteristics were optimised to give a linear relationship between target transmittance and pixel values, unless stated otherwise. This was achieved by adjusting the scanner *gamma* settings [4], keeping all other parameters constant.

MTFs were evaluated for the optical resolution of the scanner (2700 dpi). Scanning exposures were optimised by the scanner while the overall integral density of the test targets were kept similar to avoid large exposure variations. MTF measurements were carried out in the centre of the frame.

### Sine Wave Method

This method involves a one-dimensional exposure distribution, $E(x)$, of the form:

$$E(x) = a + b\sin(2\pi\omega x) \qquad (1)$$

where $x$ is the distance, $a$ is the average signal level, $b$ is the amplitude and $\omega$ the spatial frequency. The recorded exposure is expressed as the transmittance distribution, $T$, of the sine target, with modulation, $M_{in}(\omega)$, given by:

$$M_{in}(\omega) = \frac{T_{\max} - T_{\min}}{T_{\min} + T_{\min}} = \frac{b}{a} \qquad (2)$$

The modulation recorded by the scanner, $M_{out}(\omega)$, is calculated by:

$$M_{out}(\omega) = \frac{PV_{\max} - PV_{\min}}{PV_{\max} + PV_{\min}} \qquad (3)$$

Provided that film transmittance is linearly related to the output pixel values, *PV*, the MTF of the scanning system, $M(\omega)$, is given by the ratio of the output to the input modulation, with respect to the spatial frequency.

The test targets [5] comprised patches of sinusoidally varying transmittance (0.75 to 128 cycles/mm), on 35 mm film. The targets also included twelve uniform transmittance steps. Two targets, A and B were used, with average modulations of 0.35 and 0.60 respectively. Target B was cemented in glass.

Scanning was performed by placing the targets in two orientations, at right angles to each other, to evaluate MTF responses for the fast and slow scanning directions. After the targets were scanned, the transfer characteristics were evaluated for each image. This was achieved by plotting transmittance against normalised pixel values, measured for each uniform grey step. The scanner's transfer functions were determined by power curve fitting procedures which gave correlation coefficients in excess of 0.999. Pixel values were converted to linear transmittance units, by applying the inverse power functions to normalised pixel values.

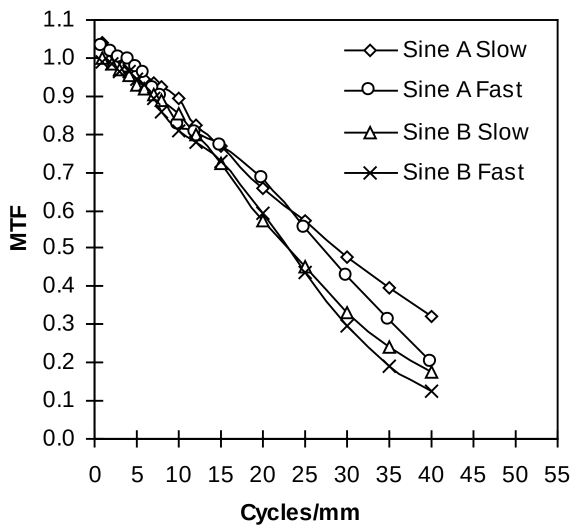


*Figure 1. MTF curves derived from sine wave targets A and B for the fast and slow scanning directions.*

Multiple one-dimensional sinusoidal traces were extracted for each spatial frequency patch. Individual cycles were identified by examining the traces. Maximum and minimum pixel values corresponding to each cycle were then extracted and averaged. These averages were used to calculate $M_{out}(\omega)$ according to Equation (3). The amount of data necessary to determine the output modulation increased with respect to spatial frequency. This is because the modulation becomes highly dependent on the phase of the sine patterns relative to the sampling array as spatial frequency increases [6]. Therefore, the number of cycles from which the output modulation was determined ranged from 30 to 300. According to Granger [7], when at least 20 samples are dedicated over a cycle, a good estimate of the MTF in digital systems is achieved. At a sampling rate of 106 samples/mm, 20 samples correspond to 10% of the Nyquist frequency. In this work, the MTF was calculated for up to 40 cycles/mm, or 75% of the Nyquist frequency.

Figure 1 shows MTF curves corresponding to the fast and slow scanning directions, for targets A and B. The frequency response of the fast and slow scans are very similar, up to 25 cycles/mm. The two test targets, however, gave different MTF responses, with target B resulting in lower scanner performance. Although the input modulation of the two targets was not the same, such a large disagreement in the MTFs should not occur. Possible explanations include: exposure flare caused the glass cover on target B lowering the response of the scanner, or significant difference in the scanning exposures of the two targets.

Figure 2 shows the slow scan MTFs, after scanning chart A when using three different scanner transfer functions and correcting the scanner responses for transfer non-linearities. It is apparent that, using this method, the measurement of the system MTF is highly repeatable. Results in Figure 2 indicate also that quantization and transfer correction does not affect the final calculated MTF curve.

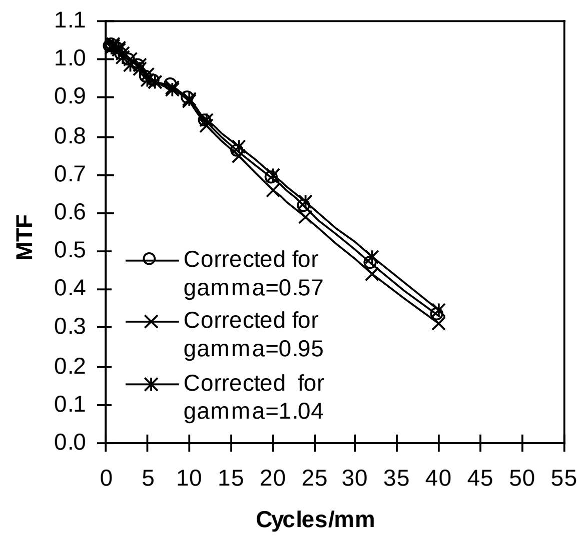


*Figure 2. MTF curves resulting from three different scans of target A, using different gamma settings and then correcting the scanner responses for the transfer non-linearities.*

**Noise Method**

For a linear system, the output noise power spectrum, $NPS_{out}(\omega)$, is related to that of the input, $NPS_{in}(\omega)$, and the MTF, $M(\omega)$, by [8]:

$$NPS_{out}(\omega) = NPS_{in}(\omega) \times M(\omega)^2 \qquad (4)$$

If the $NPS_{in}(\omega)$ is constant over the required spatial frequency range (i.e. white noise), then the $NPS_{out}(\omega)$ is simply the square of the system MTF.

Photographic grain was used to simulate white noise. Test targets were generated by photographing a grey card and a Kodak Q-13 greyscale, at different de-focused levels

[9], using Kodak T-Max P3200 film. The film may be considered as having a constant noise power spectrum up to 40-50 cycles/mm [10]. Therefore, there is little need for compensation until frequencies approach the Nyquist limit of the scanner.

A 35 mm frame was scanned and an array of 512 by 512 pixels which corresponded to the centre of the scanning frame was selected. The mean was subtracted from every pixel value of the image array to remove the DC component and slight scanning non-uniformities. The modulus of the Fast Fourier transform [11] of the data gave the two-dimensional scanner response. This was then normalized and decimated [12] by 20 points in both frequency directions, to smooth the MTF (see figure 3).

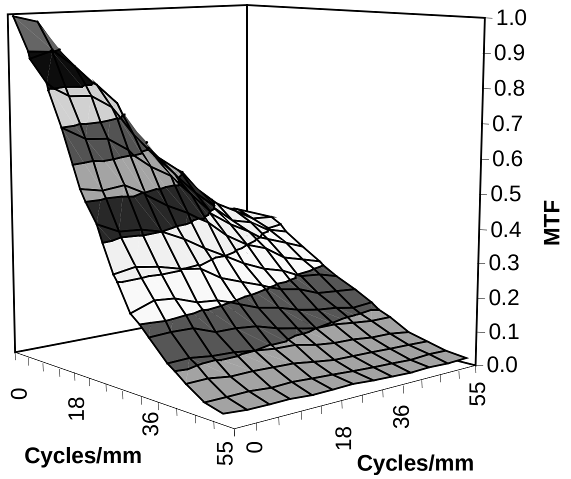


*Figure 3. Section of the rotational MTF of the scanner after decimating by 20 points in both frequency directions.*

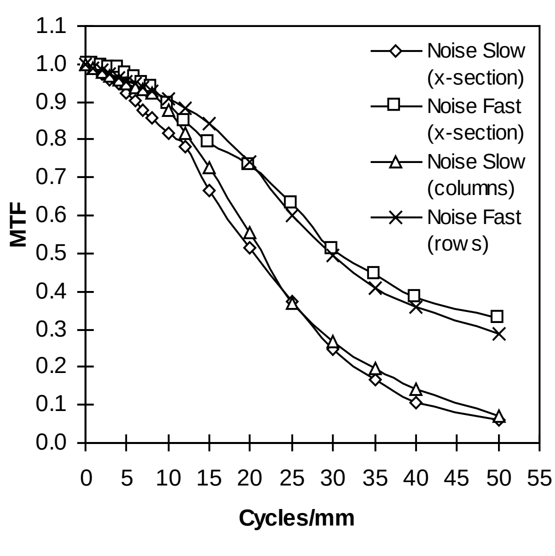


*Figure 4. MTF curves corresponding to the fast and slow scanning direction, deduced by cross sectioning the rotational MTF and by simulation of scanning with a thin long slit.*

Fast and slow scan MTFs were determined by taking the appropriate cross sections. Similar one dimensional results were obtained by averaging separately rows and columns of the digital image array to simulate scanning with a thin long slit. The mean was subtracted from the resulting data and the modulus of the one dimensional Fourier transform was calculated to obtain the fast and slow scan MTF responses.

Figure 4 shows one dimensional MTF curves for both scanning directions. The results indicate that the slow scan MTF is significantly lower than that of the fast scan. Asymmetry in the two dimensional MTF of the system was expected, but not in the MTF curves at 90$^{o}$ orientation. The lower slow scan MTF might be due to the electro-mechanical components of the scanner, necessary in this scanning direction.

Separate scans were performed with varying scanning transfer characteristics (image contrast), resulting in images of different modulations, ranging from 0.46 to 0.85. MTF responses where found identical after the normalization of the data.

**Slanted Edge SFR Plug-In Method**

The ISO 12233 slanted-edge Spatial Frequency Response plug-in can be used for the creation of one-dimensional uniformly super-sampled edge profiles and the calculation of the frequency response of a digital system. Details on the method which is based on the traditional edge technique have been published [13,14]. An account of the computational steps performed by the SFR plug-in is given by Williams [15], as well as a detailed evaluation of its precision.

When an edge exposure is reproduced on film, scanned and processed using the SFR plug-in, the resulting spatial frequency response, $SFR(\omega)$, is a combination of the frequency content of the edge-target, $MTF_{film}(\omega)$, and the response of the scanner $M(\omega)$:

$$SFR(\omega) = MTF_{film}(\omega) \times M(\omega) \qquad (5)$$

A stepped edge was printed on a high quality laser printer, as a binary digital image file, at 600 dpi. A number of density measurements were taken from the print, to ensure that the edge maintained uniform densities all along its length. The laser print was then photographed at a magnification of 0.19, using 35mm Ilford Pan-F black-and-white film, together with a Kodak Q-13 greyscale. The edge was recorded at an angle of approximately 15$^{o}$ from the vertical on the film and had a density difference of 0.9. The frequency content of the edge-target was evaluated using the traditional edge technique [16].

The edge-target was scanned, in positive scanning mode, with the edge falling horizontally with respect to the scanning array and positioned in the centre of the scanning frame. Pixel values corresponding to individual steps of the greyscale were averaged and plotted against respective film transmittances. A third degree polynomial successfully fitted the measured data to develop a 256 step LUT, which served as the *Opto-Electronic Conversion Function* [17]. A rectangular *region-of-interest* [18] covering 200 by 1200 pixels was selected, over which the calculations of the SFR plug-in (version 7.1) were performed. The vertical to horizontal aspect ratio of the *region-of-interest* was kept as high as possible to increase the signal-to-noise ratio of the SFR estimates [15].

Multiple scans, with slight horizontal translation of the edge with respect to the scanning frame were performed. They were processed in the above way and then averaged to determine the average SFR of the centre of the scanning frame, for the fast scanning direction. To evaluate the slow scan SFR, a number of scans were produced and calculated in the above way, by rotating the edge-target 90°. The resulting SFRs were corrected for the frequency content of the edge-target. MTF curves are illustrated in Figure 5.

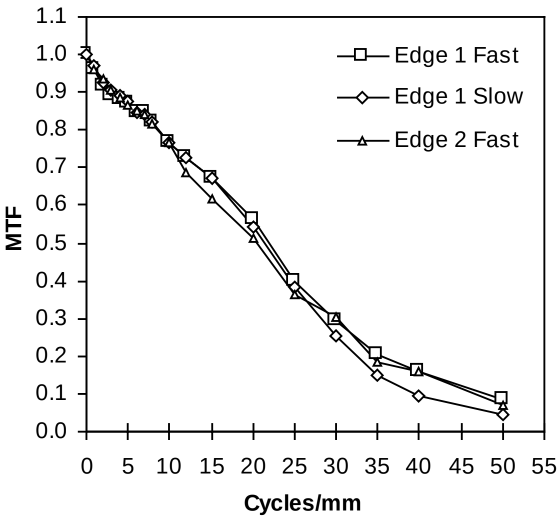


*Figure 5. MTF curves of fast and slow scans, calculated with the SFR technique. 'Edge 2 Fast' is an MTF curve produced from a second edge- target, with density difference of 0.75.*

Figure 5 shows that the fast and slow scan MTFs are similar. The use of edge-targets with little difference in contrast gave agreeing results. While experimenting with this method it was noticed that the SFR curves corresponding to individual displaced scans of the edge-target were almost identical. This is an indication of the consistency of the response of the scanner within the scanning frame.

## Comparison of the Three Methods

MTF curves for the fast and slow scanning directions, evaluated by the three methods, are shown in Figures 6 and 7 respectively. The results indicate that each method gave different frequency responses. The variation in the MTFs is shown to be less in the slow than in the fast scanning direction. Figure 8 illustrates mean MTFs for the fast and slow scans, up to 40 cycles/mm. The mean MTF corresponding to the fast scan was higher than that of the slow scan, beyond 10-15 cycles/mm.

An interesting result is the particularly high fast scan MTF, determined by the noise method, in comparison with all the other MTFs (Figure 6). Apart from this, MTFs evaluated using sine waves were higher than those evaluated with the other methods (Figures 6,7). The reason may be that the maximum and minimum responses extracted from individual cycles included noise effects, resulting in higher output amplitudes.

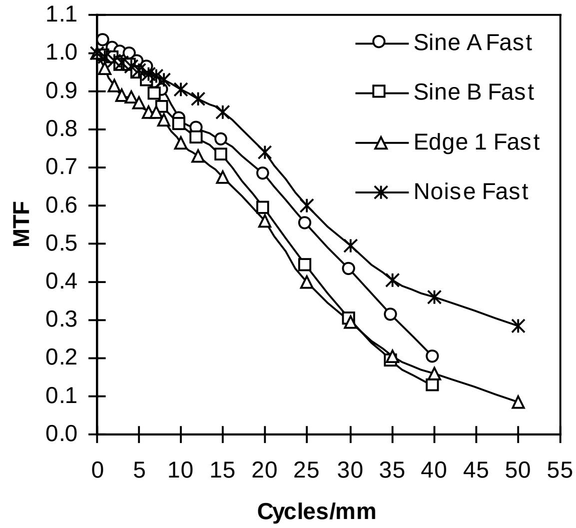


*Figure 6. MTF curves of the fast scan, determined with the three methods.*

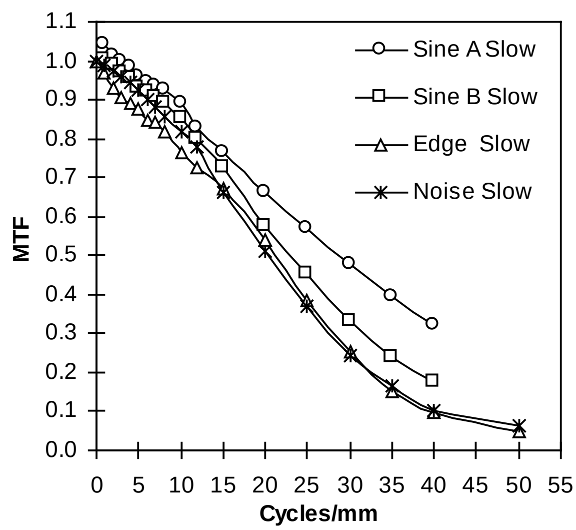


*Figure 7. MTF curves of the slow scan, determined with the three methods.*

Although all methods gave highly repeatable results within ±6%, further work on the experimental accuracy for each method is being carried out. Before this work is completed, a rigorous conclusion cannot be reached on the comparability of the MTFs.

The advantage of the sine wave method for measuring digital MTFs is that calibrated targets are used, for which the modulation is provided. This method, however, is very time consuming. Also, for the precise evaluation of the frequency response of different parts for the scanning frame, frequency patches need to be scanned and evaluated individually. The MTF is not measurable after 70-80% of the Nyquist limit of the system, due to phase and noise effects. Different sine wave targets may give different results.

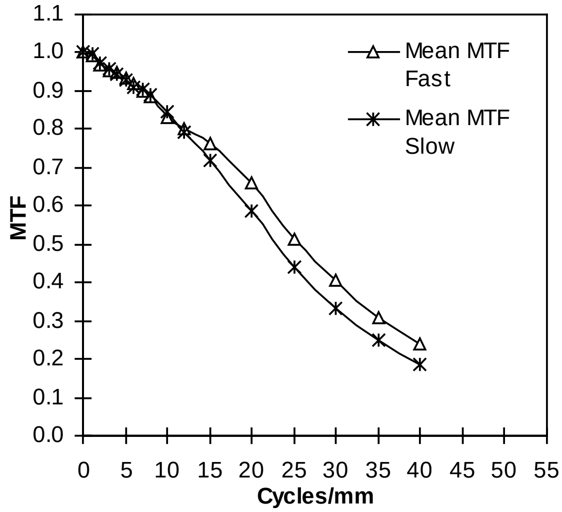


*Figure 8. Mean MTFs corresponding to the fast and slow scans.*

Advantages of the noise method include: Test targets are simple to make and the device's MTF is easily calculated with appropriate software. Also, as a two-dimensional frequency response is obtained, the MTF can be extracted for every scanning angle. By selecting individual parts of the scanned image, the MTF of different parts of the scanning frame can be evaluated. Finally, there is no need for device transfer correction, as long as the resulting MTFs are normalized. On the other hand, film grain is used only as an approximation of white noise and thus compensation for the frequency content of the target may be needed at high spatial frequencies.

The SFR plug-in gives an average spatial frequency response of the device. It is very easy to apply and returns reliable SFRs of the area of the CCD where the edge falls. Repeated scanning by translating the edge is needed for the determination of the frequency response of various areas of the scanning frame. The plug-in is largely insensitive to edge angle [15] and theoretically estimates SFRs to four times the Nyquist limit of the system. Precise estimation of the *Opto-electronic Conversion Function* is essential for the correct SFR computations. Compensation for the frequency content of the edge-target is needed to cascade the system MTF.

## Conclusion

For this work, sine waves, photographic noise and the SFR plug-in were used for the determination of the spatial frequency response of a 35 mm scanner. The three methods gave different MTFs for both fast and slow scanning directions. MTFs determined using sine waves were generally highest. The mean spatial frequency response of the fast scan was found slightly better than that of the slow scan. This is mostly due to the surprisingly high MTF curve calculated with the noise method. Comparison of the results was found difficult. Further work is needed to calculate experimental errors for each method.

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