

The correlation coefficient r is given by the following expression:

$$r^2 = \frac{(\sum x \sum \ln E - n^{-1} \sum x \sum \ln E)^2}{\{\sum x^2 - n^{-1}(\sum x)^2\}\{\sum (\ln E)^2 - n^{-1}(\sum \ln E)^2\}} \quad (8)$$

A value for r which is close to unity indicates a good fit of the proposed model to the experimental data.

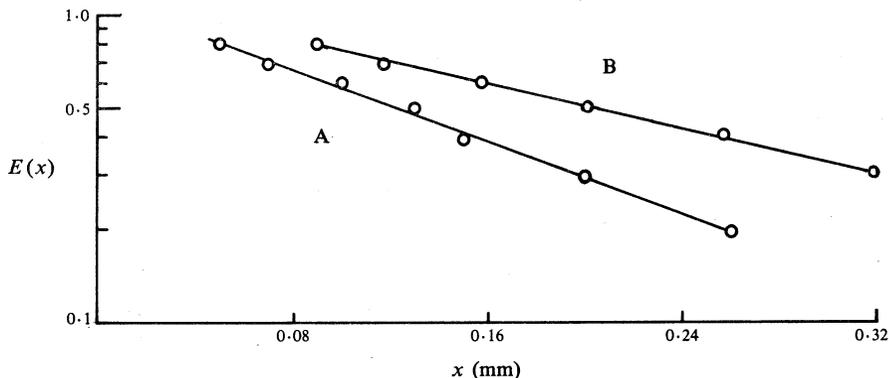


Fig. 1. Normalized LSF $E(x)$: A, Kodak Ortho G/Lanex ($b = -6.65$ and $r^2 = 1.00$); B, Dupont Cronex-2/Radelin STF-2 ($b = -4.18$ and $r^2 = 1.00$).

The MTF is calculated by finding the Fourier transform of the LSF. The normalized MTF has the following general form for a symmetric function:

$$MTF(f) = \frac{\int_0^\infty E(x) \cos(2\pi fx) dx}{\int_0^\infty E(x) dx}, \quad (9)$$

where f is the spatial frequency. Substituting equation (4) into (9) yields the normalized Fourier transform of the exponential spread function:

$$MTF(f) = \frac{1}{1 + (2\pi f/b)^2}. \quad (10)$$

Equation (10) is independent of the coefficient a , and so the LSF need not be normalized. Only the coefficient b is required to determine the MTF. It therefore serves as a figure of merit for comparing different emulsions. Equation (10) is essentially the MTF of the film/screen system. Correction for the MTF of the microdensitometer is unnecessary because its response is almost unity at the spatial frequencies of interest in X-ray work.

Since the regression technique is an implicit smoothing operation, it accommodates some scatter in the LSF data. Note that the parameter b can be calculated, albeit with much less precision, from equation (5) by graphical methods.

Comparison with Experimental Results

The model for the LSF was applied to the data of Arnold *et al.* (1976). In their report, they supported the applicability of an exponential expression to their LSF

measurements. In Fig. 1, LSFs are compared for a rare-earth screen, Kodak's Lanex Regular with Ortho G film (case A), and a high-speed calcium tungstate screen, Radelin STF-2 with Dupont Cronex-2 film (case B). For exposure, a $12\ \mu\text{m}$ slit was used with an X-ray tube voltage of 80 kVp. The slit images were scanned by a microdensitometer with a $10\ \mu\text{m}$ slit width.

Both test cases described in Fig. 1 yielded correlation coefficients of unity. Data values between 10% and 90% of the peak were used. In general, results within this range will suffer very little from the toe and shoulder nonlinearities of the characteristic curve. Arnold and coworkers (1976) extrapolated the original LSF to a truncation level of less than 1% of the maximum value. They sampled at $20\ \mu\text{m}$ intervals and computed the MTF digitally by numerical Fourier transformation. This MTF is plotted as a smooth curve for the two cases in Fig. 2. The circles represent the analytic transform of the exponential model using equation (10) and the value of b calculated from the data plotted in Fig. 1. It is evident that there is good agreement between the results.

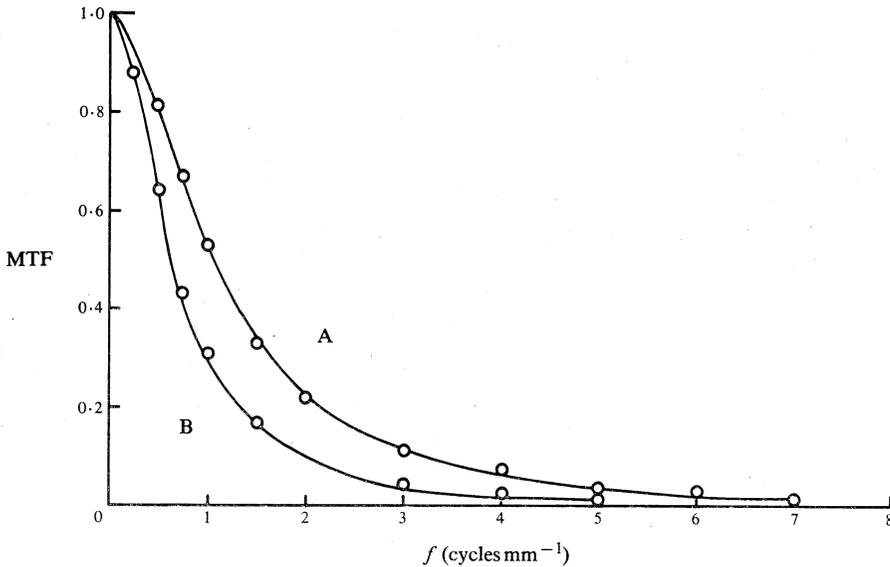


Fig. 2. Normalized MTF. Predictions from equation (10) are represented by the circles (values of b were determined from the data plotted in Fig. 1). Smooth curves represent results of numerical Fourier transformation (Arnold *et al.* 1976): A, Kodak Ortho G/Lanex; B, Dupont Cronex-2/Radelin STF-2.

Discussion

All the LSFs measured by Arnold *et al.* (1976) are adequately described by an exponential model. The analytic Fourier transform can therefore be used to calculate the MTF. The simplicity of the model is probably a consequence of the characteristically thick emulsions of X-ray films. This means that we can neglect any transmitted specular component of the light flux, which for a thin emulsion would necessarily require a compensating term in the equation. If a case should arise where the experimental data do not conform to the model, the value of the correlation coefficient would be significantly less than unity and it therefore acts as a warning signal.

One advantage of the model is that it eliminates some of the problems associated with the traditional technique of using a computer to calculate the numerical Fourier transform. These problems include a decision on the proper truncation level and sampling interval for the LSF. In order to avoid truncation errors, most of the LSF must be available for numerical analysis. For evaluation at low levels, and since the toe and shoulder regions of the characteristic curve are inadequate for precise measurements, multiple exposures are generally necessary. The final LSF is a composite of these separate exposures. This is avoided when using the model because points well away from the peak and tail regions may be chosen for calculating the parameter b .

Calculation of the numerical transform can be a lengthy exercise, even by computer, depending on the precision required and the computer memory and processing speed. In addition, a large sample size is required. The marginal loss in precision arising from the use of the model is compensated for by its simplicity and operational convenience. A program for the HP-25 calculator was used to compute b , r^2 and the MTF. Only six or seven points from the LSF were necessary for determining the MTF.

Conclusions

The LSF of the X-ray film/screen system can be characterized by a simple exponential expression. The analytic Fourier transform of the LSF yields the MTF. The model was applied to data for commercial X-ray films exposed in their regular cassettes. For the data tested, predictions using the theoretical model show good agreement with results obtained by numerical Fourier transformation. The model has been used for rapid assessments of the MTF, and in estimating the MTF variability due to random noise sources such as quantum mottle and granularity.

References

- Arnold, B. A., Eisenberg, H., and Bjärngard, B. E. (1976). *Radiology* **121**, 473.
- Bayer, B. E., Simonds, J. L., and Williams, F. C. (1961). *Photog. Sci. Eng.* **5**, 35.
- Enge, H. (1966). 'Introduction to Nuclear Physics' (Addison-Wesley: Cambridge, Mass.).
- Frieser, H. (1960). *Photog. Sci. Eng.* **4**, 324.
- James, T. H. (1977). 'Theory of the Photographic Process' (Macmillan: New York).
- Paris, D. P. (1961). *J. Opt. Sci. Am.* **51**, 988.
- Rossmann, K. (1964). *Phys. Med. Biol.* **9**, 551.

