DETERMINATION OF NOISE EQUIVALENT QUANTA OF MEDICAL SCREEN-FILMS

Wan Muhamad Saridan Wan Hassan[1], Yusof Munajat[1] & Shamsul Sahibuddin[2],

[1]Department of Physics, Faculty of Science,Universiti Teknologi Malaysia, 81310 Skudai, Johor Darul Ta'zim. Tel: 07-5534191, Fax: 07-5566162, Email: saridan@dfiz2.fs.utm.my
[2]Faculty of Computer Science and Information System, Universiti Teknologi Malaysia, 81310 Skudai, Johor Darul Ta'zim.

ABSTRACT

Noise equivalent quanta (NEQ) of Lanex Regular/T Mat G and Lanex Regular/T Mat L screen-film combinations were determined using modulation transfer function (MTF) and noise power spectrum (NPS) data. To accomplish this, average gamma of the radiograph was computed, the MTF and the NPS data were linearly interpolated and these values were used to compute the NEQ by means of a computer program. The computation shows that for spatial frequency 0–0.7 cycles/mm the NEQ of Lanex Regular/T Mat G is slightly lower than that of Lanex Regular/T Mat L, for spatial frequency 0.7–1.5 cycles/mm the NEQ of both are almost the same, and for frequencies greater than 1.5 cycles/mm the NEQ of the former is greater than that of the latter. Relatively, this indicates that low frequency signals show better on Lanex Rregula/T Mat L, but high frequency signals show better on Lanex Regular/T Mat G.

Key words: diagnostic radiology, image quality, modulation transfer function, noise equivalent quanta, noise power spectrum, screen-film

ABSTRAK

Kuanta setara hingar (NEQ) bagi kombinasi skrin-filem Lanex Regular/T Mat G dan Lanex Regular/T Mat L ditentukan daripada data fungsi hantaran modulasi (MTF) dan spektrum kuasa hingar (NPS). Untuk melaksanakannya, gama purata dihitung, data MTF dan NPS diinterpolasi secara linear, dan nilai-nilai ini digunakan untuk menghitung NEQ secara berkomputer. Penghitungan menunjukkan untuk frekuensi ruang 0–0.7 kitar/mm NEQ bagi Lanex Regular/T Mat G kecil sedikit daripada NEQ bagi Lanex Regular/T Mat L, untuk frekuensi ruang 0.7–1.5 kitar/mm NEQ kedua-duanya hampir sama, dan untuk frekuansi ruang lebih besar daripada 1.5 kitar/mm NEQ bagi Lanex Regular/T Mat G lebih besar daripada NEQ bagi Lanex Regular/T Mat L. Secara relatif ini menunjukkan isyarat frekuensi rendah dipaparkan lebih jelas

di atas Lanex Regular/T Mat L, sementara isyarat frekuensi tinggi dipaparkan lebih jelas di atas Lanex Regular/T Mat G.

Kata kunci: radiologi diagnostik, kualiti imej, fungsi hantaran modulasi, kuanta setara hingar, spektrum kuasa hingar, skrin-filem

1. INTRODUCTION

Physical quality of medical images can be cast in terms of noise equivalent quanta (NEQ) [1]. The NEQ combines three specific aspects of performance; the large area transfer characteristics (the gamma), the spatial resolution characteristics (the modulation transfer function (MTF)), and the noise properties (the noise power spectrum (NPS) or the Wiener spectrum) of the imaging device into an overall measure of performance. In one dimension for small signals limit applicable to the screen-film radiography the NEQ is [2, 3]

$$\mathrm{NEQ}(u) = \frac{(\log_{10} e)^2 \gamma^2 \mathrm{MTF}^2(u)}{\mathrm{NPS}(u)} \tag{1}$$

where u is the spatial frequency in cycles/mm, e is the base of natural logarithm, γ is the average gamma, $\mathrm{MTF}(u)$ is the modulation transfer function, and $\mathrm{NPS}(u)$ is the noise power spectrum of the screen-film.

In a previous work [4] a substantial amount of digitised data of medical radiographs has been analysed in terms of MTF and NPS, but not in terms of NEQ. As NEQ is currently regarded as a basic device performance measure of the imaging system, it is useful to be determine the NEQ using those data. In this work, a PC program to determine the NEQ is developed using the MTF and NPS data previously collected. A direct application of this NEQ determination is predicting the ranking of imaging systems performance [2].

2. METHOD AND MATERIALS

2.1 Characteristic curve, MTF, and NPS data

MTF and NPS data of Lanex Regular/T Mat G and Lanex Regular/T Mat L screen-film combinations were collected from a previous study [4], while the characteristic curve data were obtained from the manufacturer. Briefly the MTF was determined by the square wave respons function method in which a periodic square wave pattern (bar pattern) of varying spatial frequency was used as an object and the contrast of the resulting image was used to culculate the MTF via the Coltman equation [5, 6]. Figure 1 shows the MTF of Lanex Regular/T Mat G and Lanex Regular/T Mat L obtained by the method.

The NPS was determined by fast digital Fourier transform method [7, 8]. Briefly, uniformly exposed radiographs were prepared and digitised, and optical density fluctuations of the digitised image were used to culculate the NPS. To accomplish this, the optical density fluctuation values about a mean density were obtained by subtracting the mean density from the density values. The data were then low-pass-filtered by averaging pairs of pixels, followed by low-frequency filtering to eliminate very low-frequency components. A slit trace was synthesised by averaging adjacent traces and the trace was segmented to segments of 256 data points per segment with overlap of 128 data points. Data in each segment were windowed and fast Fourier transformed. The Fourier coefficients were squared and normalised to obtain the noise power spectrum. Figure 2 shows the NPS of Lanex Regular/T Mat G and Lanex Regular/T Mat L obtained by the method.

2.2   NEQ computation

The NEQ was computed by coding a program as a MATLAB M-file [9]. First, the program computes average gamma from the characteristic curve data of the screen-film using the definition [10]

$$\gamma = \frac{D_2 - D_1}{\log_{10} X_2 - \log_{10} X_1} \qquad (2)$$

where X_1 and X_2 are exposures that give net optical density of $D_1 = 1.0$ and $D_2 = 2.0$ above base plus fog level respectively.

The MTF data available at spatial frequency 0.25, 0.5, 0.6, 0.7, 0.85, 1.0, 1.2, 1.4, 1.7, 2.0, 2.4, 2.9, 3.5, 4.2 cycles/mm for Lanex Regular/T Mat G, and at 0.25, 0.5, 0.6, 0.7, 0.85, 1.0, 1.2, 1.4, 1.7, 2.0, 2.4, 2.9 cycles/mm for Lanex Regular/T Mat L are linearly interpolated by the program at spatial frequency 0, 0.1, 0.2, 0.3, … , 4.2 cycles/mm for Lanex Regular/T Mat G, and at spatial frequency 0, 0.1, 0.2, 0.3, … , 2.9 cycles/mm for Lanex Regular/T Mat L, respectively. The MTF value at 0 cycle/mm is assigned as 1. Similarly, the NPS data available at spatial frequency 0, 0.3125, 0.6250, 0.9375, … , 10.0 cycles/mm are linearly interpolated by the program at spatial frequencies 0, 0.1, 0.2, 0.3, …, 10.0 cycles/mm. This way MTF and NPS values at spatial frequency interval of 0.1 cycle/mm are ready for further computation.

Finally, the program computes the NEQ as per Equation (1), using the average gamma, the interpolated MTF, and the interpolated NPS values. Thus the computation gives NEQ at spatial frequency 0, 0.1, 0.2, 0.3, … , 4.2 cycles/mm for Lanex Regular/T Mat G, and at spatial frequency 0, 0.1, 0.2, 0.3, … , 2.9 cycles/mm for Lanex Regular/T Mat L, respectively. A listing of the M-file named 'neqcul3.m' is given in the Appendix.

3. RESULTS AND DISCUSSION

Figure 3 shows the NEQ of both screen-film combinations computed by the program. For spatial frequency 0–0.7 cycles/mm, the NEQ of Lanex Regular/T Mat G is slightly lower than that of Lanex Regular/T Mat L; for frequency 0.7–1.5 cycles/mm, the NEQ of both are almost the same; and for frequencies greater than 1.5 cycles/mm, the NEQ of the former is higher than that of the latter. This suggests that a signal with low frequency content (0–0.7 cycles/mm) shows better on Lanex Regular/T Mat L, but a signal with high frequency content (higher than 1.5 cycles/mm) shows better on Lanex Regular/T Mat G.

For comparison the NEQ of DuPont Cronex Detail/XRP, Par Speed/XRP, and Hi-Plus/XRP reported in reference [3], and Quanta Fast Detail/C10S screen-film combinations reported in reference [11] are shown in Figure 3. Our computed results are smaller than those compared, but the order of magnitude of the NEQ values are the same. This might be due to lower MTF values available for the computation [6].

A second computation of NEQ was performed using MTF data obtained by a different analysis in which measured square wave response function data were fitted to a curve and the fitted curve gave the analytical square wave response function to be used to calculate the MTF [12]. Figure 4 shows that the NEQ of Lanex Regular/T Mat G of the second computation is lower by 16% than that of the first computation. Similarlay, the NEQ of Lanex Regular/T Mat L of the second computation is lower by 13% than that of first computation. This agrees well with Equation (1) since the MTF values of Lanex Regular/T Mat G and Lanex Regular/T Mat L from the second computation are lower than the first by 8% and 6% respectively. This result partly reflects that computations performed by the program are correct.

4. CONCLUSION

NEQ of medical radiographs were computed by a MATLAB program given the characteristic curve, modulation transfer function, and noise power spectrum data of the medical radiographs. For spatial frequency 0–0.7 cycles/mm the NEQ of Lanex Regular/T Mat G is slightly lower than that of Lanex Regular/T Mat L; for frequency 0.7–1.5 cycles/mm, the NEQ of both are almost the same; and for frequencies greater than 1.5 cycles/mm the NEQ of the former is greater than that of the latter. The developed codes should be useful for diagnostic screen-film imaging, but might also be applicable for other imaging modalities because of general nature of the NEQ concept.
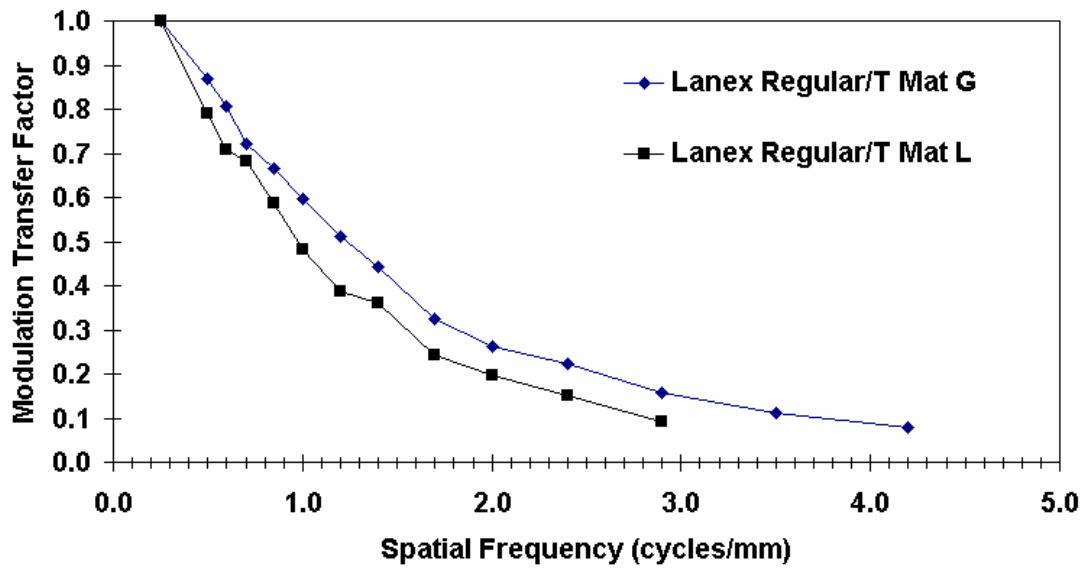
Figure 1. Modulation transfer factors of Lanex Regular/T Mat G and Lanex Regular/T Mat L screen-film combinations obtained by the square wave response function method.
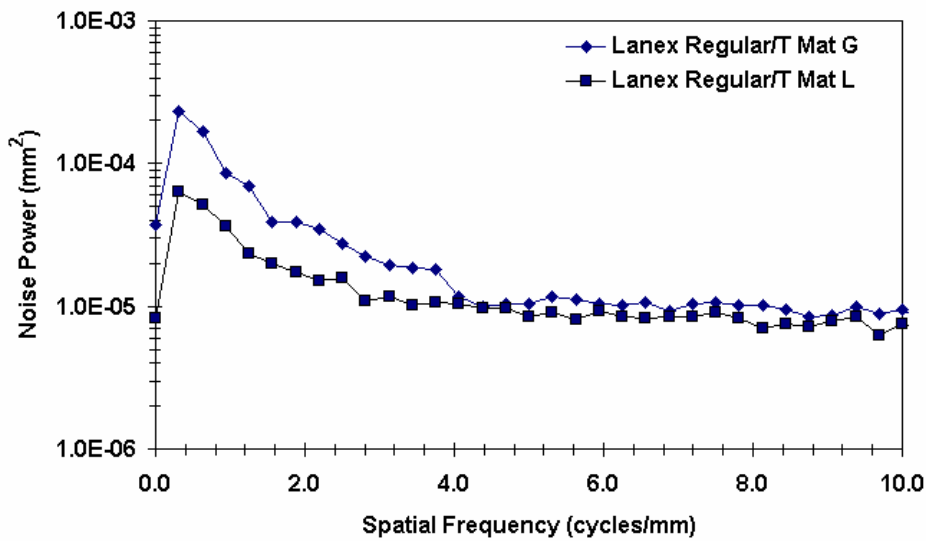

Figure 2. Noise power spectrum of Lanex Regular/T Mat G and Lanex Regular/T Mat L screen-film combinations obtained by the fast digital Fourier transform method.
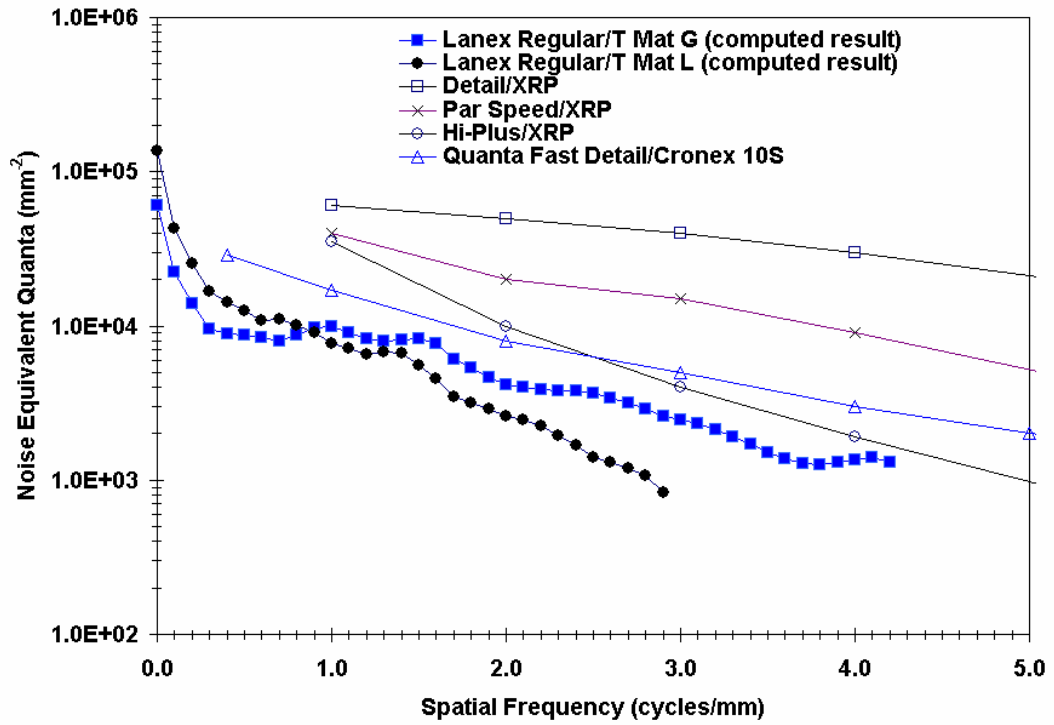
Figure 3. NEQ of Lanex Regular/T Mat G and Lanex Regular/T Mat L screen-film combinations obtained by the computation. Also shown are NEQ of DuPont Cronex Detail/XRP, Par Speed/XRP, and Hi-Plus/XRP reported in reference [3] , and Quanta Fast Detail/C10S reported in reference [11].
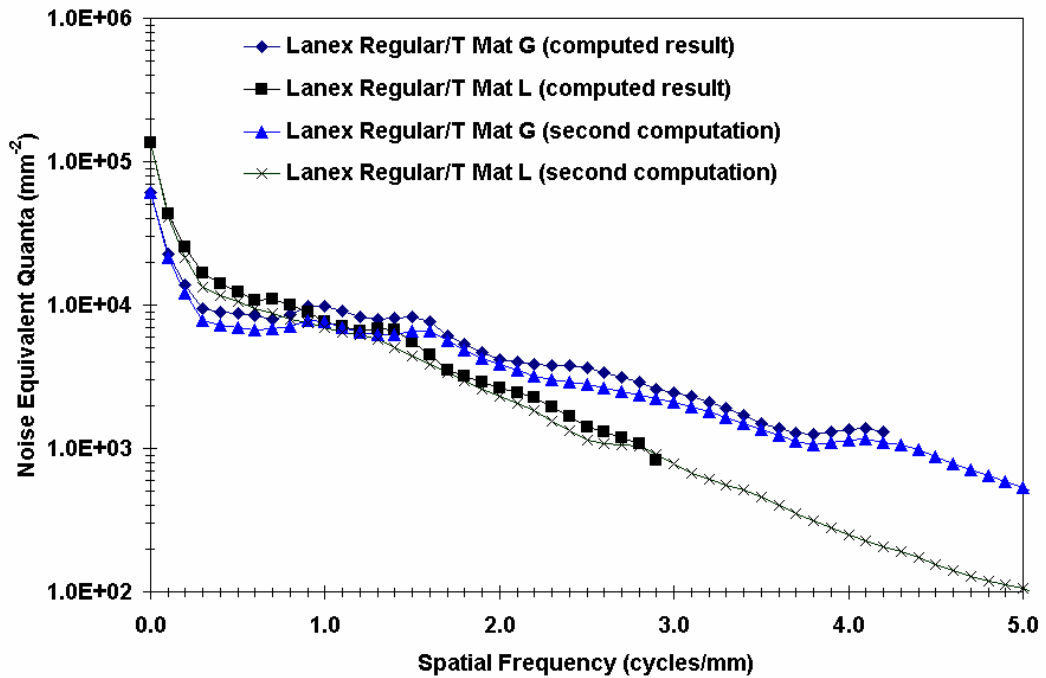

Figure 4. Comparison of NEQ obtained by the first and the second computations.

REFERENCES

[1]   ICRU. 1995. Medical Imaging – The Assessment of Image Quality, ICRU
        Report 54. Bethesda, Maryland: International Commission on Radiation Units
        and Measurements.

[2]   Metz, C. E., R. F. Wagner, K. Doi, D. G. Brown, R. M. Nishikawa, and K. J.
        Myers. 1995. Toward consensus on quantitative assessment of medical
        imaging systems. Medical Physics. 22: 1057–1061.

[3]   Sandrik, J. M., and R. F. Wagner. 1982. Absolute measures of physical image
        quality: Measurement and application to radiographic magnification. Medical
        Physics. 9: 540–549.

[4]   Hassan, W. M. S. W. 1998. Measurement of modulation transfer function and
        Wiener spectrum of diagnostic X-ray screen-film systems in a hospital setting.
        Ph.D. thesis University of Aberdeen.

[5]   Coltman, J. W. 1954. The specification of imaging properties by response to a
        sine wave input. Journal of the Optical Society of America. 44: 468–471.

[6]   Morishita, J., K. Doi, R. Bollen, P. C. Bunch, D. Hoeschen, G. Sirand-rey and
        Y. Sukenobu. 1995. Comparison of two methods for accurate measurement of
        modulation transfer functions of screen-film systems. Medical Physics. 22:
        193–200.

[7]   Doi, K., G. Holje, L. N. Loo, H. P. Chan, J. M. Sandrik, R. J. Jennings, and R.
        F. Wagner. 1982. MTF's and Wiener spectra of radiographic screen-film
        systems, HHS publication FDA 82-8187. Rockville, Maryland: U.S.
        Department of Health and Human Services, Public Health Service, Food and
        Drug Administration, Bureau of Radiological Health.

[8]   Hassan, W. M. S. W. 2001. Measurement of Wiener spectrum of radiographic
        screen-film systems. Jurnal Teknologi. 34(C): 35-42.

[9]   Etter, D. M. 1997. Engineering problem solving with Matlab, 2nd. edition.
        Upper Saddle River, New Jersey: Prentice Hall.

[10]   Johns, H. E., and J. R. Cunningham, 1983. The Physics of Radiology, 4th.
        edition. Springfield, Illinois: Charles C. Thomas Publisher. p. 580.

[11]   FAXIL. 1994. Physical evaluation of the imaging performance of Dupont
        ultra-vision screen-film system, MDA Evaluation Report MDA/94/40. Leeds:
        Facility for the Assessment of X-ray Imaging at Leeds University, The General
        Infirmary.

[12]   Hassan, W. M. S. W. 2002. Calculation of the modulation transfer function
        from the square wave response function data with an interactive curve fitting
        software. Physica Medica. 18(1): 25-32.

Appendix

```
% ==================================
% ====== neqcul3.m =================
% ====== by W. M. S. W. Hassan =====
% ====== 23 Nov 2002 ===============
% ==================================
% Codes to compute noise equivalent quanta (NEQ), given the characteristic
% curve, modulation transfer function (MTF), and noise power spectrum (NPS)
% data.
%

% Read in the MTF data from a text file. First column of file: spatial
% frequency values in cycles/mm, second column: MTF values.
% Edit the path accordingly.
  mtf_file = 'e:\matlab6p1\work\mtf.txt';

% Read in the NPS data from a text file. First column of file: spatial
% frequency values in cycles/mm, second column: NPS values in (mm^2).
% Edit the path accordingly.
  ws_file = 'ws.txt';

% Read in the charateristic curve data from a text file.
% First column of file: dose in micro Gray, second column: optical density.
% Edit the path accordingly.
  char_curve = 'tmg.chr';

% Name of text file to write the NEQ results. Result will be written with
% first column: spatian frequency (in cycles/mm), second column: NEQ
% (in quanta/mm^2).
% Edit the path accordingly.
  neq_file = 'hasilneq.txt';

% Calculate average gamma:
% Read text file
  [dose_asal,od_asal] = textread(char_curve,'%f%f');
  log_dose_asal = log10(dose_asal);
% Linear interpolation
  x1 = interp1(od_asal,log_dose_asal,1,'linear');
  x2 = interp1(od_asal,log_dose_asal,2,'linear');
  gamma = 1/(x2-x1)

% Calculate the MTF:
% Read text file
  [u0,mtf0] = textread(mtf_file,'%f%f');
% Get the highest spatial frequency in the data
  bildata = length(u0);
  u0_maks = u0(bildata);
% Assign MTF(0) = 1
  u1(1) = 0;
  mtf1(1) = 1;
  for n=1:bildata
    u1(n+1) = u0(n);
    mtf1(n+1) = mtf0(n);
  end
  u1 = u1';
  mtf1 = mtf1';

% Prepare the spatial frequencies
  u2 = 0:0.1:u0_maks;
```

```
  u2 = u2';
  biltitik = length(u2);
% Linear interpolation of the MTF
  mtf2 = interp1(u1,mtf1,u2,'linear');
% Plot the MTF
  figure;
  subplot (3,1,1);
  plot(u0,mtf0,'or',u2,mtf2,'-xb');
  xlabel('Spatial Frequency (mm^-^1)', 'VerticalAlignment', 'middle');
  ylabel('MTF');
  text(0.7,1.15,'Average gradient = ')
  title(num2str(gamma))

% Calculate the NPS:
% Read a text file
  [u3,ws0,takdiguna] = textread(ws_file,'%f%f%f');
% Linear interpolation
  ws1 = interp1(u3,ws0,u2,'linear');
% Plot the NPS
  subplot(3,1,2);
  semilogy(u3(1:16),ws0(1:16),'or', u2,ws1,'-xb');
  xlabel('Spatial Frequency (mm^-^1)', 'VerticalAlignment', 'middle');
  ylabel('NPS (mm^2)');

% Calculate the NEQ:
  neq3 = mtf2.*mtf2;
  neq2 = neq3./ws1;
  yy = log10(exp(1));
  neq = neq2*yy^2*gamma^2;
% Plot the NEQ
  subplot (3,1,3);
  semilogy (u2,neq,'-xb');
  xlabel('Spatial Frequency (mm^-^1)', 'VerticalAlignment', 'middle');
  ylabel('NEQ (mm^-^2)');

% Write the NEQ file:
  tem_u = u2';
  tem_neq = neq';
  hasil = [tem_u; tem_neq];
  fid = fopen(neq_file,'w');
  fprintf(fid,'%6.2f %12.5e\n',hasil);
  fclose(fid);
```