Information theoretic analysis of multi-stage communication/imaging systems

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Information Theoretic Analysis of Multi-Stage Communication/Imaging Systems
by
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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE in Electrical Engineering

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I. ABSTRACT

A method for the system analysis of a multistage photographic or communication system is developed. By following the input signal through the system and estimating the output signal and the output signal without noise, the information capacity after each stage can be estimated. The relationship between the variance and the integral of the power spectrum is used in accounting for the effects of each of the component characteristics: modulation transfer function, density-log exposure relationship and granularity.

This method is implemented in a computer program which allows one to vary the characteristics of the components and determine the resultant changes in information capacity. Several variations of a specific photographic system, the color negative system, are examined and discussed. The loss in information capacity is examined at the output of the camera/film stage, printer/paper stage and the human visual system stage. One clear result is that human visual system significantly reduces the information capacity of the entire system. The technique has general application to any communication system which can meet the requirements of the assumptions.
II. INTRODUCTION

Information theoretic metrics are important in analyzing the capability of communication systems. In multistage communication systems, such as a photographic system, there are losses of information and fidelity through each stage. Quantifying and identifying these losses is a valuable part of system analysis. Once techniques for system analysis are developed, then each component of the system can be varied and the effect on the overall system evaluated. Specifications for each component can be made and evaluated, thus helping reduce bottlenecks in the transfer of information.

The objective of this research is to present a method of analyzing the information capacity loss in a multistage communication system. From these methods, a computer program is developed to estimate the information capacity at each stage. Essentially, the technique estimates signal spectra "with" and "without noise" for each stage. From these spectra, information theoretic metrics can be estimated. This analysis method is then applied to a specific communication system, the color negative photographic system. As in design of all other communications systems, there are always changes made in components of the system. Evaluating the effect of these changes is an important part of the decision making process. To exemplify this, typical variations of several of the components will be examined and the results discussed. Further, the potential for misapplication of information theoretic metrics in the analysis of photographic systems
will be presented. As in all methods of system analysis, simplifying assumptions are made to permit a tractable solution. These assumptions are described as they are introduced and are based on references, data or experience.
III. BACKGROUND MATERIAL

In figure 1 a general communication system is presented. This system can be defined as a series of components or stages which take an input signal and eventually communicate this signal to a receiver. In each of these components the signal is modified and noise added. To aid in development of these communication systems, system analysis methods have evolved. These methods allow one to examine the capability and performance of the system in its their goal of efficiently transmitting the input signal to the receiver.

Looking at figure 2, physical measurements of the signal and signal with noise of each stage can be obtained. These measurements can be used to estimate metrics which aid in system analysis. When the system is characterized, variations can be made in each component and these metrics can be monitored. All the components of the system must be considered in this analysis including the receiver.

A. INFORMATION THEORY AND INFORMATION CONTENT

Shannon (16,17) inaugurated the field of information theory and provided scientists and engineers with a new tool for system analysis. One metric which was described is the channel or information capacity. In his paper, the input signal, $x$, is a continuous function of time and the output, $y$, will be an altered version of the input. The statistics of the transmitted signal can be characterized by the probability function:

$$ p(x) $$
and those of the noise by the conditional probability function:

\[ p(y|x) \]

with the rate of information transmission, \( R \), defined as:

\[ R = H(x) - H(y|x) \]

where \( H(x) \) is the entropy of the input and \( H(y|x) \) is the conditional entropy of the equivocation. From this, the channel capacity is defined as the maximum of \( R \) as we vary the input over all members of the ensemble. Thus, after substituting the definition of entropies, we must maximize

\[
- \int p(x) \log p(x) + \int \int p(x,y) \log \frac{p(x,y)}{p(y)} \, dx \, dy
\]

which can be written as:

\[
\int \int p(x,y) \log \frac{p(x,y)}{p(x)p(y)} \, dx \, dy
\]

using the fact that:
\[
\int \int p(x,y) \log p(x) dx dy = \int p(x) \log p(x) dx
\]

the information capacity (bits/unit time) is expressed as:

\[
C = \lim_{T \to \infty} \frac{1}{T} \int \int p(x,y) \log_2 \frac{p(x,y)}{p(x)p(y)} dx dy
\]

Over the years following Shannon’s work, derivations from this metric have been made and applied to a variety of communication systems. Later in this section, these derivations as applied to a specific communication system - the color negative photographic system - will be described.

The utility of this metric can be shown in figure 2. With the appropriate measurements, estimates can be made of the information capacity of the signal as it passes through the system. Losses in this metric can be determined for each stage. These losses serve as a type of capability measure for the system. However, as pointed out by Fellgett and Linfoot (6), the true utility of this metric depends on the task that the communication system is required to do. Other aspects such as fidelity or similarity must be considered if one is trying to examine the “quality” of the system. In certain applications, information capacity, similarity and fidelity are highly correlated while in other cases they are disparate metrics of quality. Information capacity always
assumes that there is some suitable interpretation process that can extract this inherent information, no matter how complex. However, in many practical cases this interpretation process is not entirely realized.

B. THE COLOR NEGATIVE PHOTOGRAPHIC SYSTEM

As stated by Higgins (7), the photographic system can be considered a communication channel, and many of techniques developed for electronic communication systems can be applied to the photographic system. The variations in voltage as a function of time in an electronic systems correspond to variations in light as a function of distance in a photographic system. Higgins and Mees, et.al. (12) are excellent sources of information that describe the photographic system. In this section, I hope to provide a brief overview of the major components of a specific photographic system and their primary measurements as related to information capacity.

As described before and shown in figure 3, the photographic system is just another communication system. Input signals in the form of images are transmitted from stage to stage with modifications of the signal and noise addition occurring in each stage. There are many perceived attributes of the photographic system that influence the quality of the final image as seen by the receiver (i.e. a human being !). Some of them are:
Color Reproduction
Sharpness
Noise
Contrast
Tone Reproduction

As researched by Bartleson (2), all these items combine together in a non-Euclidean fashion to influence the quality of images. The color negative photographic system is shown in figure 4. An image (i.e. input signal) is captured through a camera lens on the film. After development, the resultant film image is printed (i.e. communicated) to the paper. This final image is then viewed by the photographer who compares the variations in reflected light from the print to his/her memory of the scene. In this research, three measurements will be considered because of their influence on the information capacity (to be defined later) in each stage. These are:

Density-log Exposure curve (D-LogE)
Modulation transfer function (MTF)
Granularity spectrum or noise power spectrum

The D-logE curve represents the variation in film or paper density as a function of input log exposure. A typical plot for photographic paper is shown in figure 5. Density is calculated from the transmittance (or reflectance) of the photographic material by the following equation:
\[ D = -\log_{10}(T) \]

Density and \( \log_{10} \) of exposure are used because a plot of transmittance versus exposure does not permit easy comparison of films or papers for development engineers.

The modulation transfer function (MTF) is analogous to the frequency response of a stage in an electronic communication system. It is the modulus of the fourier transform of the impulse response of the photographic material. Because the imaging communication system is two-dimensional, the corresponding input impulse function is either a point light source or a line source. These result in a point spread function (i.e. similar to the impulse response function) or the line spread function, respectively. The appropriate transform is performed and the modulation transfer function is calculated. The other measurement method is to impart sinusoidal light patterns on the component and measure the reduction in amplitude at different frequencies. This method directly gives the modulation transfer function. For the photographic components (i.e. film and paper), this measurement must be corrected for the D-logE characteristic of the component. Underlying these measurements is the assumption of linear systems. Film and paper are not linear systems but for practical purposes they can assumed to be linear as shown by Higgins (7, 8, 9) and Simonds (19). Based on a multiple stage black and white system, their results demonstrated that one can use linear systems analysis with little error as long as the slope of the density-log exposure function for the first stage is less than or equal to about 0.6. Even though the waveform may be distorted, the magnitudes of the harmonics largely cancel one
another, so that the amplitude is not affected. Examples of the modulation transfer functions for a typical camera lens, film, printer lens and paper are shown in figures 6-9.

Finally, granularity is used to describe the "noise" of the photographic process. When a uniformly exposed and processed photosensitive material is scanned with a small aperture, there is a variation in density as a function of distance resulting from the non-homogeneity of the emulsion. In the final print, this non-uniform appearance is termed "graininess". The first common method of describing granularity is in terms of the standard deviation of the density fluctuations, \( D \), from the mean density:

\[
\sigma(D) = \frac{\sum (D_i - E[D])^2}{n-1}
\]

where:
- \( \sigma(D) \) = granularity
- \( D_i \) = individual density reading
- \( E[D] \) = average density reading
- \( n \) = number of samples

The \( \sigma(D) \) contain no information on the distribution of frequencies of fluctuation since they are obtained from the amplitude of the fluctuations. To obtain the frequency
information, the granularity trace can be subjected to a type of Fourier analysis (18) to obtain a noise power spectrum. In this method of analysis, the integral of the spectrum is related to the granularity.

1. PROBLEMS AND ASSUMPTIONS IN THE ANALYSIS OF PHOTOGRAPHIC SYSTEMS

As mentioned earlier, the photographic system is typically considered a linear system. Currently, this assumption is valid in a practical engineering sense, however the validity of this assumption for future products is unknown. In a color system there are obviously 3 (or more!) light sensitive layers (i.e. red, green and blue) which are sensitized to broad regions of the visible light spectrum (i.e. "red", "green" and "blue"). In this research, only the green sensitive layer will be examined and assumed to be completely independent of the other layers. In reality, there is "cross-talk" between the layers which can become very complex. The effect of crosstalk on this research is unknown but will most likely be a relative effect as opposed to an interaction.

C. THE HUMAN VISUAL SYSTEM

The human visual system (HVS) is complex and many references examine the signal and noise aspects of it (4, 11, 21). In this research, the HVS is regarded as another
stage in a multi-stage imaging process. The methods outlined by Daly (4) are used. Components of the HVS can be specified by MTFs and noise sources which are dependent on the adaptation level. Further, the viewing distance is used to scale these values.

The HVS is broken into components representing the effects of optics, photoreceptor sampling and neural processing. Details and additional references of these components can be found in the paper by Daly. Briefly, the contribution by each component is:

**Pupil-Lens-Ocular Media**

In this component, the optical effects of the eye itself are modeled. This includes MTF degradations due to diffraction, chromatic aberration and scattering. Pupil diameter is estimated from the adaptation level. This pupil diameter is then used to estimate the MTF from white-light foveal spread functions. The resultant MTFs are shown in figure 10 for several adaptation levels. Since quantum fluctuations are considered in the next component, this component is considered noiseless.

**Photoreceptor Sampling**

This process is modeled as an MTF degradation and a noise source. Each of these is a function of the light adaptation level. The MTF effects are due to a variety of factors and these relationships are shown in figure 11. Noise in this component is based on
quantum fluctuations as modeled by a Poisson distribution where the variance equals the number of photons reaching the retina. This number is attenuated by efficiency factors and the result shown in figure 13.

Neural Processing

This last component also contains noise and MTF factors. The MTF for this stage is based on contrast sensitivity functions for the entire HVS and the MTFs of the previous two components. The result is primarily a low frequency attenuation (figure 12). A small noise component is considered which is described by (for hard-copy):

\[
\sigma = 0.003162 \cdot \text{Adaptation Light Level}
\]

One must remember that all the MTF relationships are based on evaluation of sinusoidal pattern and not complex images. In a typical, complex image the image content may influence the true human visual response function.

D. APPLICATION OF INFORMATION THEORY TO PHOTOGRAPHIC SYSTEM ANALYSIS

In the past, information theory and the information capacity and capacity metric has been modified and applied to photographic systems to different degrees. The best verbal definition of the amount of information in an image was given by Fellgett and Linfoot (6):
"...is the mathematical expectation of the logarithm of the number of distinguishable images which might arise as the object varies statistically according to the constraints or probability densities which express the prior knowledge of the object".

In 1955, Fellgett and Linfoot first applied information capacity to the assessment of optical images. However, they stressed that there is a multitude of qualities required of an image for proper assessment. One extreme is to produce an image which is directly similar to an object. The other extreme is to produce an image which contains the greatest possible information about an object, without regard to the complexity of the interpretation processes which may be needed to extract this information. The latter will be examined in this review. Fellgett and Linfoot started with a very basic definition of information capacity (content per unit area):

\[ C = \frac{I}{A} = \frac{\log N}{A} \]

where \( N \) = number of distinguishable levels as portrayed in their verbal definition and \( A \) is the area. Their work concentrated on estimating \( \log N \) for an imaging system and formed the basis for most of the researchers following them. Two images were defined:

\[ \{I_1\} = \text{original image} \]
\[ \{I_2\} = \text{observed image} \]
and two spectral powers were defined as:

\[ \Phi(u,v) = \text{spectral power of observed image} \]
\[ \Omega(u,v) = \text{spectral power of all noise in observed image} \]

The number of distinguishable levels in \( I_2 \) is by definition:

\[ \log N = (\text{entropy of } I_2) - (\text{entropy of noise in } I_2) \]

The definition of entropy was then examined. For a general variable \( Z \), the entropy of \( Z \) is:

\[ (\text{entropy of } Z) = -\int_{V} p(Z) \log p(Z) dZ \]

Where \( Z \) varies over a volume \( V \). Shannon (15) showed that for a \text{gaussian} \( p(Z) \) and an essentially bandlimited variable that in a two dimension space, this entropy can be represented by:

\[ (\text{entropy of } Z) = \frac{1}{2} |A| \left| \int_{F} \log \Psi(u,v) dudv + |A||F| 2\pi e \right| \]

where \( A \) is the bandlimited region of the input, \( F \) is the bandlimited region of any operation on the input, and \( \Psi(u,v) \) is the power spectrum of \( p(Z) \).
Now applying this relationship to determine log N results in:

$$\log N = \frac{1}{2} |A| \int \int_{F} \log \Phi(u,v) dudv + |A| \parallel F \parallel \log 2\pi e - \left( \frac{1}{2} |A| \int \int_{F} \log \Omega(u,v) dudv + |A| \parallel F \parallel \log 2\pi e \right)$$

This simplifies to:

$$\log N = \frac{1}{2} |A| \int \int_{F} \log \frac{\Phi(u,v)}{\Omega(u,v)} dudv$$

or per unit area (i.e. information capacity):

$$\frac{\log N}{|A|} \sim \frac{1}{2} \int \int_{F} \log \frac{\Phi(u,v)}{\Omega(u,v)} dudv$$

This result will be used as the information capacity metric in this thesis, though it will be simplified to one dimension. The next goal of Fellgett and Linfoot was to relate $\Phi(u,v)$ and $\Omega(u,v)$ to physical quantities. The following definitions were used:
\{\sigma_0\} = \text{original image intensities}
\{\sigma_1\} = \text{observed image intensities without noise}
\{\sigma_2\} = \text{observed image intensities with noise}
\{\eta_0\} = \text{input image noise}
\{\eta_1\} = \text{observed image noise in the final image}
\{\eta_2\} = \text{noise added in the recording process}

\epsilon_0(u,v) = F[\sigma_0 - E[\sigma_0]]
\epsilon_1(u,v) = F[\sigma_1 - E[\sigma_1]] = \tau_1 \epsilon_0(u,v)
\tau(u,v) = F[\beta] \text{ where } \beta \text{ is the point spread function of the lens}
\tau_1(u,v) = F[\beta_1] \text{ where } \beta_1 \text{ is the point spread function of the lens}
\epsilon_2(u,v) = F[\sigma_2 - E[\sigma_2]]
\nu_0(u,v) = F(\eta_0)
\nu_1(u,v) = F(\eta_1) = \tau_1 \nu_0(u,v)
\nu_2(u,v) = F(\eta_2)

F \text{ is the Fourier transform operation}

Note that all the signals are deviated from their mean. With these definitions and assuming uncorrelated and gaussian noise, one can write:

\Omega(u,v) = |\tau_1|^2 E[|\nu_0|^2] + E[|\nu_2|^2]
\[ \Phi(u,v) = |\tau |^2 (E[|\varepsilon_0|^2] + E[|\nu_0|^2]) + E[|\nu_2|^2] \]

These relationships can be substituted in the earlier definition of \( \log N \) to obtain a relationship between information capacity and measurable parameters. This substitution is the basis for most of the following references. In summary, Fellgett and Linfoot produced a fundamental relationship between \( \log N \) and either measured spectra or physical quantities. This analysis for physical quantities is limited by a gaussian input, and gaussian uncorrelated noise. The former limitation is not a difficult problem as many inputs approach a gaussian distribution and, in terms of system analysis, this assumption is not detrimental. The latter assumptions are contrary to the signal dependent nature of film and is eliminated in this thesis.

Jones (10) in 1961, evaluated the information capacity of the film alone. In his work he made some adhoc allowance for the peak limited aspects of the film. First the capacity would be estimated by a modification, in terms of notation, to Fellgett and Linfoot’s result:

\[
C = \frac{1}{2} \int \int \log \left( 1 + \frac{W_h(u,v)}{W_g(u,v)} \right) dudv
\]

where:

\( W_h(u,v) = \) two dimensional Wiener spectrum of output density

\( W_g(u,v) = \) two dimensional Wiener spectrum of granularity
In this, and all subsequent references the noise in the input signal was considered negligible. This assumption allows formulas to become tractable, however, it limits all examinations to a single stage with noise present as the input signal for subsequent stages with contain noise. This thesis eliminates this constraint and allows examination of multiple stages. The output spectrum was related to physical quantities similar to Fellgett et.al. An allowance for the clipping aspects of film was done by taking a ratio of the dynamic range of the film relative to the dynamic range of an input image. This ratio was then used in a equation to determine a factor to multiply the information capacity without clipping and obtain an estimate of the information capacity with clipping. This work requires the same assumptions as the previous references, however it does make an initial allowance for the clipping aspects of film. In this thesis, the clipping aspects of each stage in a photographic system will be considered in a more direct manner.

The formulation of Shaw’s (18) work in 1962 starts from the Fellgett and Linfoot’s equation expressed in a different form:

\[ I = B \int \int \log_2(1 + S(u,v)) du dv \text{ (bits/image)} \]

where \( S(u,v) \) is the signal-to-noise power ration given by:

\[ S(u,v) = T^2(u,v) \cdot \frac{p(u,v)}{n(u,v)} \]
p(u,v) is the spectral power of the fractional fluctuations in the object intensity distribution, and B is the emulsion area. The object in this case was regarded as the intensity distribution arriving at the surface of the film. n(u,v) is the spectral power of the photographic noise at the mean recording level. T(u,v) is the photographic contrast transfer function at this level.

As prescribed in Fellgett et al., the information capacity was evaluated in a limited frequency range. The limits were defined as points where T(u,v) becomes essentially zero. This region will be defined as H. Since film can be considered isotropic, measurements taken in one direction are sufficient for the evaluation. These assumptions resulted in the following equation:

\[ I = 2 \int_{H} \log_{2} \left( 1 + \frac{T^{2}(w) \cdot p_{o}}{n(w)} \right) w \, dw \]

where \( p_{o} \) is a constant value of \( p(w) \) within the range of frequencies \( 0 < w < H \) and \( w \) is the frequency in lines per mm. Measurements of the frequency response can result in a normalized contrast transfer function defined by:

\[ t(w) = \frac{T(w)}{T_{o}} \]
where $T_s$ is the absolute value of $T(w)$ at low spatial frequencies. As explained by Shaw, $T_s$ can also be obtained from the Density-log Exposure characteristics of the film:

$$T(w) = E \cdot \frac{dD}{dE} \cdot t(w)$$

The slope of the density-log exposure curve is given by:

$$\gamma = \frac{dD}{d(\log_{10} E)} = \frac{E \cdot dD}{0.434 \cdot dE}$$

This relationship allows one to include the sensitometric characteristics of the film in one's estimation of information capacity. The result is:

$$T(w) = 0.434 \cdot \gamma \cdot t(w)$$

The noise power can also be expressed in terms of a normalized $N(w)$ by the following relationship:

$$n(w) = n_0 \cdot N(w)$$

where $n_s$ is the noise at very low spatial frequencies.
Finally, the equation for information capacity can be written as:

\[
I = \pi \int_{-\frac{\lambda}{2}}^{\frac{\lambda}{2}} \log_2 \left( 1 + \frac{0.189 \cdot \gamma^2 \cdot \tau^2(w) \cdot p_0}{n_0 \cdot N(w)} \right) dw
\]

Using this equation Shaw took measurements of various films and examined their information capacity. Shaw’s work presents the first reference which used terms that are more familiar to the film community. It still requires the assumptions in previous references and adds some additional constraints. It does not address the limited dynamic range that Nelson did and does not address the remainder of the imaging system.

Nelson (14) in a journal article aptly titled "Photographic System as a Communication Channel" performed a similar derivation to Shaw. However, he started from Shannon’s upper limit of information capacity, C as given by:

\[
C = \Delta F \cdot \log_2 \left( 1 + \frac{P}{N} \right)
\]

where delta F is the frequency bandwidth, P is the mean power of the output signals, and N is the mean noise power of the noise. Noise and signal are uncorrelated and both gaussian. This equation is valid if the spectra are flat over the region delta F.
However, as explained by Nelson, if the signal and noise spectra are not flat over the whole region, but are continuous and flat over smaller regions, than the capacity can be estimated by adding the two regions together

\[ C = \Delta F_1 \cdot \log_2 \left( 1 + \frac{P_1}{N_1} \right) + \Delta F_2 \cdot \log_2 \left( 1 + \frac{P_2}{N_2} \right) \]

Extending this argument over a series of very small flat regions, one obtains

\[ C = \int \log_2 \left( 1 + \frac{P(f)}{N(f)} \right) df \]

where \( P(f) \) is the power spectrum of the output signal and \( N(f) \) is the power spectrum of the noise. For a two dimensional signal, such as a photographic image, the corresponding formula is:

\[ C = \frac{1}{2} \iint \log_2 \left( 1 + \frac{P(u,v)}{N(u,v)} \right) du \, dv \]

where \( P(u,v) \) represents the two dimensional power spectrum of the output signal and \( N(u,v) \) is the two dimensional power spectrum of the noise. Since photographic images can be assumed to be isotropic, the formula was simplified to:
\[ C = \pi \int \log_2 \left( 1 + \frac{P(f)}{N(f)} \right) f df \]

where \( f = \sqrt{\omega^2 + \nu^2} \). Similar to Shaw, Nelson expressed the signal to noise ratio as a function of photographic terms to obtain:

\[ C = \pi \int \log_2 \left( 1 + \frac{K(f) \cdot \gamma^2 \cdot H^2(f)}{N(f)} \right) f df \]

where \( K(f) \) is the spectrum of the input radiance modulation, \( H(f) \) is the film modulation transfer function and \( N(f) \) is the film noise spectrum. Problems in the previous references are identical here.

In an appendix to this paper, McAdams discussed some implications of a color system where he estimated that instead of three times the capacity of a monochromatic system, there should be 2.3-2.4 times the capacity.

In a short article, Barteneva (1) applied information capacity to the examination of losses in the camera components of the system and estimated the relative losses of the atmosphere, objective lens, shutter, diffraction, light scattering, image displacement and system defocusing. Using the formula derived by Nelson (with some change in notation):
\[ C = \pi \int \log_2(1 + 0.186 \cdot \left( \frac{\gamma^2 \cdot T^2(w) \cdot T_i^2(w) \cdot P_s(w)}{G_d(w)} \right) w dw \]

where:

\( w = \) frequency (cycle/mm)

\( \gamma = \) contrast coefficient (gamma) of the film

\( P_s(w) = \) input signal spectrum

\( G_d(w) = \) granularity spectrum (i.e. noise power spectrum)

\( T(w) = \) MTF of the film

\( T_i(f) = \) MTF of the ith component of the camera stage

This was one of the first attempts at examining the component contributions to the loss in information, though it only examined the camera lens. Limitations mentioned earlier also apply to this reference.

Melnychuck (11) presented an image chain model to examine the discrete nature of sampled images in digital image processing. The model included the majority of system components from the object to output image. The research focused on the losses in information capacity due degradation from improper exposure of the original image on the film and not the entire system. However, this is the first reference which outlined an entire imaging system including the human visual system. The clipping of the input scene due to film's limited range (i.e. in underexposures) was represented by a noise term in the model:
\[ \sigma(\text{clip}) = \int_{-\infty}^{c} xp(x)dx \]

A spectrum \( S_c(w) \) with the same variance was assumed and was of the form:

\[ S_c(w) = \frac{b}{(a + w^2)} \]

Melnychuck used the one-dimensional representation of the information capacity metric presented in previous references:

\[ I = \pi \int \log_2 \left( 1 + \frac{S(w)}{S_n(w)} \right) wdw \]

where

- \( S(w) \) = power spectrum of output image without noise
- \( S_n(w) \) = power spectrum of noise

An input image was measured to obtain an input spectrum, and the film MTF and power spectrum were measured at different exposure levels. The output image without noise was estimated at different exposure levels by multiplying the input spectrum by the squared MTF. Further, the \( S_n(w) \) was estimated from the measured power spectrum and the estimated noise spectrum due to clipping. From this data, information capacity numbers were estimated. These estimates were then related to
evaluations of image processed images at the various exposure levels. As outlined in the definition of information capacity, the images must be processed to try to obtain the maximum information. This research was limited by the examination of a single stage, the assumptions mentioned earlier, and the method for quantifying clipping noise.

The first application of a full system analysis without many of the previously mentioned restrictions was by Sullivan, Burns, Daly (3,4), who applied information capacity modeling in the analysis of film scanning systems. Their work provides the basis for the this thesis. The concept is to include the whole system from the scene to the human visual system and estimate the signal probability density function and signal spectrum, along with the signal-noise probability density function and signal-noise spectrum for each stage in the system. The information capacity can be calculated at each intermediate point by using:

$$\frac{1}{2} \int \int \log_2 \left( \frac{P_{s+n}(u,v)}{P_n(u,v)} \right) \, du \, dv$$

where $P_{s+n}(u,v)$ is the output signal spectrum and $P_n(u,v)$ is the noise spectrum. This equation is identical to the one outlined by Fellgett and Linfoot and only requires the constraint of an input gaussian distribution. Their application was mostly for digital microfilm systems and did not address continuous tone photographic systems. In the next section, this method will be further described and further extensions outlined as applied in the current research.
In all the previous research except the last one, the entire photographic system (i.e. from the scene to the human visual system) has not been fully addressed. The general equations could not account for the further transfer of noise in the system in estimating information capacity and could not address adequately the clipping aspects of photographic systems. Gaussian, uncorrelated noise was assumed in most analysis and this constraint will be reduced. This extension of Sullivan, et.al.'s work, provide a more direct method of accounting for these factors.
IV. DESCRIPTION OF CURRENT WORK

A. GOAL

The goal of this research is to extend the technique of Sullivan, et.al. by the development of a method and a computer program for the analysis of the color negative photographic system.

B. DESCRIPTION OF METHOD AS APPLIED TO A GENERAL COMMUNICATION SYSTEM

Figure 2 shows a general diagram for a multistage communication system. Each stage has noise addition, frequency modulation and a DC input/output characteristic. If one can estimate the signal spectra (with and without noise) for each stage, then metrics based on these spectra can be calculated. In this analysis, the system is assumed to be ergodic and is therefore wide-sensed stationary.

For these type of systems, the variance and signal spectrum can be related to each other. The variance is defined as:

\[ \text{Variance} = \int (x - E[x])^2 \cdot p(x) \, dx \]
where:

\[ E[x] = \text{mean or expected value of } x \]

\[ p(x) = \text{probability density function of } x \]

The power spectrum can be related to the variance through the following derivation.

The autocorrelation function is defined as:

\[ R(\tau) = E[x(t) \cdot x(t+\tau)] \]

This function exhibits the property that:

\[ R(0) = E[x^2(t)] \]

If \( x \) is deviated from the signal mean (i.e. \( E[x] = 0 \)), then \( R(0) \) equals the variance.

The power spectrum \( P(w) \) is related to the autocorrelation function by the following relationships:

\[ P(w) = \int R(\tau) \cdot e^{-j\omega \tau} d\tau \]

\[ R(\tau) = \frac{1}{2\pi} \int P(w) \cdot e^{j\omega \tau} dw \]

If one sets \( \tau = 0 \) then the last equation results in:
\[ R(0) = \frac{1}{2\pi} \int P(w)dw \]

or

\[ Variance = \frac{1}{2\pi} \int P(w)dw - (E[x(t)])^2 \]

In the methods outlined in the background information (see background on Fellgett and Linfoot’s research), the signal which one uses to obtain the power spectrum is always deviated from its mean. Therefore, for this research

\[ Variance = \frac{1}{2\pi} \int P(w)dw \]

because the \( E[x] \) is 0. Using this important link, a modification to either the probability density function or signal spectrum can be used to alter the other physical measurement.

In this research, three physical factors will be considered in each stage:

- DC input-output characteristics (see figure 14)
- Modulation Transfer Function (see figure 15)
- Noise Power Spectrum (see figure 16)
Let's individually consider these factors and their effect on the probability density functions and power spectra:

**Effect of DC input-output characteristics**

In the transfer of a signal from the input to the output of the stage, there is typically a DC alteration of the signal as part of that stage. This transform can be non-linear and will be used to alter the input probability density function (see figure 17). As described in Peebles (15), each point in the pdf is mapped through the transfer curve and a new pdf is constructed. The variance of the new pdf can be used to modify the signal spectra. The signal and noise data is handled in the same manner. It is assumed that the shape of the spectra is not affected. The justification for this goes back to the linearity assumptions as presented by Higgins (7, 8, 9). The technique described directly handles clipping of the input signal.

**Effect of Signal dependent noise**

In the case of signal dependent noise, a conditional probability distribution can describe this noise at the potential input signal levels (see figure 18).

\[ p(output/input) \]

This conditional probability distribution is obviously dependent on the input signal. The joint output probability distribution (see figure 19) is then estimated by:
\[ p(\text{output}, \text{input}) = p(\text{output} | \text{input}) \cdot p(\text{input}) \]

Finally, the output signal is calculated by integrating the joint probability over the input levels:

\[ p(\text{output}) = \int p(\text{output}, \text{input}) d(\text{input}) \]

The variance of the output signal can be subtracted from the variance of the input signal to obtain an estimate of the increased variance due to the noise. Given a general functional shape for the noise power spectrum and the fact that the noise has an expected value of zero, this additional variance can be expressed as a noise power function \( P(f) \), since we know that:

\[ \text{Variance} = \frac{1}{2\pi} \int P(f) df \]

This noise power spectrum is added to the estimated signal spectrum which contains noise. This will be referred to as the "signal with noise" spectrum. Inherent in this technique is the assumption that the spectrum is not dependent on signal level. In this analysis the following spectral shapes are considered: Bandlimited white noise, triangular and exponential. Examples of each of these are shown in figure 20. Each plot has the same variance.

**Modulation Transfer Function**
As shown in Peebles (15, p.185), the output power spectrum can be related to the input power spectrum by the transfer function of the component:

\[ P_{\text{output}}(w) = P_{\text{input}}(w) \cdot |H(w)|^2 \]

where \( H(w) \) is the transfer function of the component. In our terminology, the transfer function is the MTF, so MTF affects the signal spectra by the following formula:

\[ P_{\text{output}}(w) = MTF(w) \cdot MTF(w) \cdot P_{\text{input}}(w) \]

The reduction in variance can be calculated and used to modify the probability density functions.

**Information Theoretic Metrics**

Many metrics exist which can utilize the signal spectra "with" and "without noise". From the background information, the following metric was chosen:

\[ I = \pi \int \log_2 \frac{P_{s+n}(f)}{P_n(f)} f df \]
where:

$I = \text{Information capacity (bits/square millimeter)}$

$P_{s+n}(f) = \text{Spectrum of signal plus noise}$

$P_n(f) = \text{Spectrum of noise}$

$f = \text{frequency (cycles/mm)}$

This metric is for a two dimensional signal which is isotropic and separable. Based on experience, the photographic system can be assumed to have these properties.

C. APPLICATION TO THE COLOR NEGATIVE SYSTEMS

The color negative system is just another communication system which takes an input signal (i.e. an image) and transfers it to a receiver (i.e. observer). Therefore, the previous evaluation method can be applied. As noted in the background information, only the green record (i.e. group of film layers sensitive to the wavelengths of light associated with green) of the color negative system will be examined. For a more thorough analysis of a multi-color system, one would have to consider the interactions of the color recording layers and the redundancy of information between these layers. However, since the green record is a major contributor to luminance record, and to make the analysis tractable, only data from this record was examined. For a monochrome (i.e. black-and-white) system, the derived analysis method can be applied with fewer assumptions and simplifications. As in all the backbround literature, the photographic system is assumed to be ergodic. From figure 21, the
following components can be identified:

**Camera lens**
The lens is characterized by its modulation transfer function.

**Film**
The film is characterized by its modulation transfer function, granularity, power spectral shape, and DlogE curve.

**Printer lens**
The printer lens is characterized by its modulation transfer function.

**Paper**
Similar to the film, the paper is characterized by its modulation transfer function, granularity, power spectral shape, and DlogE curve.

**Human Visual System**
The human visual system is characterized by noise and its modulation transfer function which is dependent on the adaptation level.

In addition, the magnification of the film image to the print and the viewing distance are considered.
D. APPLICATION OF METHOD - GENERAL DESCRIPTION OF ANALYSIS

The theory presented in previous sections has been used to analyze a color negative system using a software program IQCN1. This analysis will examine the information capacity at various points in the color negative system:

- Output of camera/film stage
- Output of printer/paper stage
- Output of human visual system stage

The structured specification of the program is given in Appendix A. This method is one of several ways of specifying a program and a description of this method can be found in DeMarco (5). It enables someone to look at the program at different levels and provides valuable documentation. Simpler representations of the software is shown in figures 22 to 26. These figures present block diagrams of the general operation for each stage. For specific details, refer to the appendices. In Appendix B, the source code for the program is given. IQCN1 can handle several changes in the components as described in Appendix C. This flexibility allows one to quickly examine how changes in the characteristics of any component can affect the information capacity (see section F). An example session is shown in Appendix D. Results include:
Statistics

Probability density function (plots)

Power Spectra (plots)

Information capacity

These results are displayed, stored in a file and also sent to plotters (see Appendix D for detailed descriptions and examples).

E. APPLICATION OF METHOD - SPECIFIC DESCRIPTION OF ANALYSIS

To provide a detailed description of this research, an example will be used. A summary of the input to this example is shown in figure 27. Deviations by this reference case will examined in the next section.

The program starts with a specification for the input exposure signal based on the following parameters:

**Mean**

Mean exposure amount of input signal

**Variance**

Variance of input signal relative to the mean
**Power Spectral Shape**

The spectral shape as defined by the equation: \( P(f) = \frac{A}{B^n + f^n} \) where A is a scaling factor, B and N are user selectable parameters, and f is frequency.

To determine a rough estimate of these input parameters, a database of images digitized from 4.0 inch x 5.0 inch negatives was examined. The effect of the film and other components of the system were removed to obtain the effective red, green and blue input luminance for each pixel as sensed by the recording film. In this example, \( B = 3 \), \( N = 3 \), standard deviation/mean = 0.3 and the mean = 0.5. The tie between the variance and power spectrum described earlier is used to scale the shape of the power spectrum (i.e. calculate the parameter A). The cumulative probability functions and power spectra resulting from these parameters are shown in figures 28 and 29, respectively.

Following this input specification, a camera lens MTF is estimated or read in from a file. In this example, the MTF for a diffraction limited f/8.0 lens is calculated from the following equation (20):

\[
MTF(v) = \frac{2}{\pi} \cdot (\phi - \cos \phi \sin \phi)
\]
where:

\[ \phi = \cos^{-1}(\lambda \nu (2N.A.)) \text{ (radians)} \]

\[ \nu = \text{frequency (cycles/millimeter)} \]

\[ \lambda = \text{wavelength (millimeters)} \]

\[ N.A. = \text{numerical aperture} = 1/(2 \cdot f \cdot \text{-number}) \]

\[ f \cdot \text{-number} = \text{relative aperture} \]

This MTF is shown in figure 30 and is used to modify the power spectrum of the signal, and the spectrum of the signal with noise. The reduced variance is then used to modify the cumulative probability functions. The results of these operations are shown in figures 31 and 32 for the cumulative probability functions and power spectra, respectively.

Similar to the camera MTF, the film MTF is either estimated from an equation or read in from a file. In this example, a typical MTF for the green record of a color negative product is used (see figure 33). This MTF was measured by standard methods described in Mees (12). As before, the MTF is used to modify the power spectrum of the signal, and the spectrum of the signal with noise. The reduced variance is then used to modify the cumulative probability functions. The results of this operation is shown in figures 34 and 35 for the cumulative probability functions and power spectra, respectively.

Next the density-log exposure characteristic is used to transform the modified inputs to transmittance around a specific exposure point. The DlogE curve is shown in figure
36 and is measured by standard sensitometric and densitometric measurements described in Mees (12). An exposure point of 1.8 logE was used. After one maps the modified input exposure through the curve, the probability density functions and spectra in figures 37 and 38 are obtained.

The film's granularity profile is specified from either a file or an equation. Figure 39 presents the dependence of granularity on transmittance (as calculated from density) for the green record of a typical color negative product. This measurement was derived from a microdensitometer trace of the film using a Perkin-Elmer PDS microdensitometer Model 1010M. The granularity was calculated from this measurement. As described earlier, the noise of the film is added to the signal with noise cumulative probability functions. Based on a specified noise spectral shape (i.e. exponential, triangular or band-limited white noise), the associated noise spectrum is estimated from the increased variance. The image magnification to the paper is used to rescale this additional noise spectrum before adding it to the signal with noise spectrum. In this case, an exponential spectrum with a 1% peak response at 100 cycles/mm was used. This general shape is one exhibited in typical power spectra measurements of this film type. The results of this operation are shown in figures 40 and 41.

The information capacity is then calculated based on the equation described earlier. This information theoretic metric is estimated from the two image spectra (i.e. signal spectrum, signal and noise spectrum). For this example, the result is:
Next the printer lens and paper parameters are used to alter the spectra for the next stage. As in the camera stage, a printer lens MTF is estimated or read in from a file and the spectra are modified. Here, a diffraction limited f/5.6 lens MTF is estimated as shown in figure 42 and calculated in an identical manner to the camera MTF. The MTF is used to modify the power spectrum of the signal and the spectrum of the signal with noise. The reduced variance is then used to modify the cumulative probability functions. The result of these effects are shown in figures 43 and 44.

Following the printer lens MTF, the paper MTF is either estimated from an equation or read in from a data file. Here a typical paper MTF is used (see figure 45) which was measured by techniques described in Mees (12). The MTF is used to modify the power spectrum of the signal and the spectrum of the signal with noise. The reduced variance is then used to modify the cumulative probability functions. As a result of these operations, the probability density functions and spectra in figures 46 and 47 are obtained.

As in the camera/film section, the paper density-log exposure characteristic is either read from a file or estimated from an equation. Figure 48 shows a typical paper DlogE curve as measured by standard techniques described in Mees (12). An exposure point of 0.85 logE was used. After the input signal to the paper stage is passed through this curve, one obtains the results in figures 49 and 50.
The effect of paper granularity (figure 51) is then estimated. The granularity was calculated from power spectra measurements made by a special instrument developed within Eastman Kodak. This input can be either from a file or from an equation. The "noise" is added to the "signal with noise" cumulative probability functions. Based on a specified noise spectral shape, the associated noise spectrum is estimated from the additional noise variance. For the paper, band limited white noise of 20 cycles/mm was used. This shape was based upon examination of various paper power spectra. The result of this operation is shown in figures 52 and 53.

The information capacity is then calculated based on the equation described earlier. This information theoretic metric is estimated from the two image spectra (i.e. signal spectrum, signal and noise image spectrum). For this example, the result is:

\[
137 \text{ bits/square millimeter}
\]

The capacity has been reduced 23 % from the camera/film stage.

Finally, the human visual system is included in this image chain. The light level and subject distance are entered. Here, a light level of 6 foot-lamberts and a viewing distance of 355 millimeters are used. Modulation transfer functions are used to represent the effects of the three major components of human visual system: optics, photoreceptor sampling and neuron. These effects are shown in figures 54, 55 and 56.
and were derived from the equation presented in the literature review. Their total effect on the spectra is shown in figure 58 and the associated effect on the cumulative probability functions is presented in figure 57.

Using information described in the literature review, noise effects representing neuron and sampling noise are considered. For this example, their values are shown in figure 59. The cumulative probability functions is modified for these effects and an associated noise spectrum is calculated based the spectral shape parameters. This noise spectrum is added to the signal with noise spectrum. For the human visual system, band limited white noise of 20 cycles/mm was used. As a result of the human visual system effects, the probability density functions and spectra shown in figures 60 and 61 are obtained.

The information capacity is then calculated based on the equation described earlier. This information theoretic metric is estimated from the two image spectra (i.e. signal spectrum, signal and noise image spectrum). For this example, the result is:

46 bits/square millimeter

From this example, one can see the value of this method in examining the effects of changes in system components. In the next section, several variations in a check system will be presented.
V. DISCUSSION OF RESULTS

Several variations were examined using the convenient tool IQCN1. Due to the large number of factors that can be varied, several of these factors were held constant for this examination. A summary of the variations are shown in table 1 and the results listed in table 2. These variations represent changes in the components that commonly occur in the color negative system. The plots that resulted from each modeling run are in Appendix E and the associated listings in Appendix F.

Effect of Input Variance and Spectrum Shape

In variations 1 through 4, one can see the effect of a change in the input spectrum shape and increased variance. Variation 1 is the reference case for all changes. In Variation 2, the flatter spectral shape provides more signal at a higher frequencies to overcome the noise in that part of the spectrum. This results in a better signal to noise ratio at higher frequencies, and therefore better information capacity for the camera/film and printer/paper stage. However, because the human visual system is a very bandlimited, much of this high frequency improvement is eliminated. Variation 3 demonstrates an input signal with increased variance and thus more power at all frequencies. As one might anticipate, the information capacity is increased. Analogous to the comparison of variations 1 and 2, variation 4 has a flatter input spectrum with the same variance as variation 3. As before, this results in an increase in information capacity for the camera/film and printer/paper stage, but lower information capacity for the human visual system as much of the high frequency signal, whether it is signal or noise, is discarded.
Effect of Increased Magnification of the Camera/Film Image

Variation 5 demonstrates the effect of an increased magnification from the camera-film to the printer-paper stage. This change places more of the noise power at lower frequencies in the final image. In addition, magnification places increased demand of the frequency response for the various components of the system. The result of this is a significant loss in information capacity in all stages relative to variation 1 (i.e. 56% in camera/film stage, 54% in printer/paper stage and 32% at the human visual system stage). The magnification chosen here is close to the magnification used in the 110 film format while the base case is close to 35mm magnification.

Effect of Poorer Film Granularity

Variation 6 shows the effect of a 5x increase in the film granularity (see figure 62). As anticipated, the information capacity is reduced. In the camera/film stage, the capacity is decreased by 65%. For the printer/paper stage, the loss is about 64%. Finally, the human visual system loss is about 48%.

Effect of Changes in Film Exposure Point

Many times the input scene is not located at the ideal exposure point on the film. This deviation occurs frequently in the lower priced camera equipment which use color negative films. A film exposure series (see figure 63) is examined in variations 7 through 9 and the results are presented in figures 64 to 66. Figure 64 presents the information capacity plotted as a function of exposure deviation for the camera/film stage. As one underexposes the film, the granularity of the film increases and parts of the input scene become clipped. Results similar to these were obtained by Melnychuck (13) for a
black-and-white system. As part of his work, Melnychuck showed that the information content tracks the subjective quality of the processed images. At the other extreme, overexposing the film improves the granularity (in this case) and locates more of the input scene on the film DlogH curve. Similar plots for the output from the printer/paper stage and the human visual system are shown in figures 65 and 66, respectively.

Effect of Changes in Paper MTF
The effect of a improved paper MTF (see figure 67) is demonstrated in variation 10. In terms of information capacity, the improvement is small as shown in figure 61.

Effect of Changes in Paper Exposure Point
An exposure series for the paper is demonstrated in variations 11 and 12. Here is a case (i.e. 1 stop underexposed) where quality cannot be related to the information capacity due to poorer fidelity and similarity. Though the underexposed paper may have better information capacity, the fidelity of the scene (i.e. relationship between the print reflectances and the original scene) is poor. Much of the image is printed in the low density "toe" portion of the paper curve thus rendering a print which appears lighter than a more aesthetic position. With appropriate image processing one could probably extract this increased information and display it with better fidelity and similarity thus resulting in better quality. However, if the print is a little more underexposed, the information content will drop off dramatically as valuable negative information is clipped. One can see a similar effect in Variation 12 (i.e. one stop overexposed) where the information content is already reduced.
Effect of Viewing Distance

Finally, the effect of viewing distance is presented in variations 13 and 14. At the nearer viewing distance, much more information is "seen" by the human visual system. Intuitively, one sees more detail as you move closer to an image. At a further viewing distances, the information capacity drops. Remember, that the units of information capacity are bits/square millimeter. If one looks at an enlargement from a distance, even though the bits/sq mm are lower than a smaller print, the information content (i.e. bits/sq mm x area of picture) may be greater than a smaller print.

Obviously, many other variations can be examined, but these demonstrate some of the more interesting variations. The model is general enough to handle other cases such as (see Appendix C):

- Changes in camera or printer lens aperture
- Changes in paper granularity
- Changes in film MTF
- Changes in the film or paper DlogH functions
- Spectral shapes of the film or paper noise
- Viewing Light level
Table 1 - Description of Variations Examined

The following items were held constant:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera lens aperture</td>
<td>f/8</td>
</tr>
<tr>
<td>Printer lens aperture</td>
<td>f/5.6</td>
</tr>
<tr>
<td>Film MTF</td>
<td>Datafile: FILM DATA (see Notes)</td>
</tr>
<tr>
<td>Film DlogH Response</td>
<td>Datafile: FILM2 IQFILM (see Notes)</td>
</tr>
<tr>
<td>Paper DlogH Response</td>
<td>Datafile: PAPER IQPAPER (see Notes)</td>
</tr>
<tr>
<td>Paper granularity</td>
<td></td>
</tr>
<tr>
<td>Viewing distance</td>
<td>355 mm</td>
</tr>
<tr>
<td>Film spectra</td>
<td>Exponential 1% at 100 cycles/mm</td>
</tr>
<tr>
<td>Paper spectra</td>
<td>Bandlimited White Noise - cutoff 20 c/mm</td>
</tr>
<tr>
<td>Light level</td>
<td>6 foot-lamberts</td>
</tr>
<tr>
<td>Eye spectra</td>
<td>Bandlimited White Noise - cutoff 20 cycles/mm at 0.355 metre viewing distance</td>
</tr>
</tbody>
</table>

Below is a table of the variations, the abbreviations are described on the following page:

<table>
<thead>
<tr>
<th>Var</th>
<th>Scene</th>
<th>Camera/film</th>
<th>Printer/Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>0.3</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>0.7</td>
<td>3</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>8.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>11.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>12.</td>
<td></td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>13.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The following items were varied:

**Sig.** - Standard Deviation of scene exposure (relative to mean)

**N**  Parameter in input scene spectral shape \( P(f) = \frac{A}{(B^{**N} + f^{**N})} \)

**Mag.**  Magnification from camera/film stage to next stage

**Films** - Different film dlogh and granularity data (see notes)

**Film Exp. Pt** - Log exposure point on dlogh curve to locate mean of previous stage. \( N \) refers to a "normal" exposure point, -2 is 2 stops underexposed relative to a normal exposure point, -4 is 4 stops underexposed, etc.

**Paper MTF** - Name of paper MTF data file (see notes)

**Paper Exp. Pt**  Same as Film Exposure point except using paper dlogh curve.

**Viewing Distance** - Viewing distance from final image to viewer.

**Other Notes:**

**FILM DATA**  MTF data for the green layer of a typical color negative product

**FILM2 IQFILM**  Granularity and Density-Log Exposure data for the green layer of a typical color negative film product. Granularity data reduced by a factor of 5.

**FILM1 IQFILM**  Granularity and Density-log Exposure data for the green layer of a typical color negative product.

**PAPER IQPAPER**  Granularity and Density-Log Exposure data for a typical color photographic paper.

**PAPER1 DATA**  MTF data for a typical photographic paper

**PAPER2 DATA**  MTF data for an enhanced photographic paper
<table>
<thead>
<tr>
<th>Variation</th>
<th>Camera/Film Stage</th>
<th>Printer/Paper Stage</th>
<th>HVS Stage</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>177</td>
<td>137</td>
<td>46</td>
<td>Check case</td>
</tr>
<tr>
<td>2</td>
<td>260</td>
<td>183</td>
<td>43</td>
<td>1 with flatter spectrum</td>
</tr>
<tr>
<td>3</td>
<td>326</td>
<td>261</td>
<td>79</td>
<td>1 with greater Variance</td>
</tr>
<tr>
<td>4</td>
<td>508</td>
<td>365</td>
<td>76</td>
<td>3 will flatter spectrum</td>
</tr>
<tr>
<td>5</td>
<td>77</td>
<td>63</td>
<td>31</td>
<td>Greater magnification</td>
</tr>
<tr>
<td>6</td>
<td>62</td>
<td>50</td>
<td>24</td>
<td>Poorer film granularity</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>14</td>
<td>7</td>
<td>Film - Underexposed 4 stops</td>
</tr>
<tr>
<td>8</td>
<td>109</td>
<td>99</td>
<td>40</td>
<td>Film - Underexposed 2 stops</td>
</tr>
<tr>
<td>9</td>
<td>193</td>
<td>142</td>
<td>46</td>
<td>Film - Overexposed 2 stops</td>
</tr>
<tr>
<td>10</td>
<td>177</td>
<td>143</td>
<td>49</td>
<td>Sharper paper</td>
</tr>
<tr>
<td>11</td>
<td>177</td>
<td>161</td>
<td>54</td>
<td>paper - under 1 stop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
<td>30</td>
<td>paper - over 1 stop</td>
</tr>
<tr>
<td>13</td>
<td>177</td>
<td>137</td>
<td>119</td>
<td>Viewing distance 100 mm</td>
</tr>
<tr>
<td>14</td>
<td>177</td>
<td>137</td>
<td>7.9</td>
<td>Viewing distance 1000 mm</td>
</tr>
</tbody>
</table>
VI. CONCLUSIONS AND RECOMMENDATIONS

The methods described in this thesis provide a useful technique for the evaluation of multi-stage communications systems. These methods have been used to develop a computer program - IQCN1, a useful tool for examining the information capacity losses in a color negative system. Some of the results that one observes from this analysis are:

* As one might intuitively expect, the shape of the input signal spectrum affects the information transfer through the system. The efficiency of this transfer depends on the individual properties of each stage. For example, even though more information may have been passed to the printer/paper stage in variation 2, this information was in a region that the human visual system does not receive. Therefore, the information capacity at the human visual stage is reduced relative to variation 1.

* After the human visual system, there is a significant reduction in the information capacity relative to the camera/film information capacity.

* Magnification of film negatives reduces the information capacity by demanding better frequency response from the components and bringing more of the film noise within the pass band of the human visual system.

* A large amount of information is lost in film negatives which are underexposed by more than 2 stops.
* Viewing distance significantly affects the information capacity at the human visual system stage.

In the future, several different systems should be examined and evaluated to determine the utility and limit of this method in the system analysis of photographic systems. As mentioned by Fellgett and Linfoot, in certain situations information capacity may not be the correct metric for evaluating the "quality" of the system, however it does address its efficiency. These situations occur when aesthetic effects control the quality more than the information in the image. More importantly, this method should be applied to other communication systems and could be a valuable tool in their system analysis.
VII. REFERENCES


VIII. ACKNOWLEDGEMENTS

I wish to acknowledge my thesis advisor, Dr. Joseph DeLorenzo for his guidance in researching and writing this thesis, along with my advisors Dr. Rodney Shaw and Dr. Edward Salem.

I would like to thank Jim Sullivan for helping me get started on this topic, Scott Daly for his assistance in the modeling of the human visual system, and Madjid Rabbani for initiating my interest in information content by his interesting and clearly presented courses on the topic.

Finally, special thanks goes to my lab head Dr. Edward Walsh, division director - Dr. Gerhard Popp and Eastman Kodak Company for allowing me the opportunity to advance my education and work on this thesis. Without the Special Opportunity Graduate Program, I would not have been able to spend the appropriate amount of time on the course work leading up to the thesis and the thesis itself.
IX. APPENDICES

Appendix 1 - Structured Specification of IQCN1

Appendix 2 - Source listing for IQCN1

Appendix 3 - List of Possible Variations for IQCN1

Appendix 4 - Example Session

Appendix 5 - Plots of PDF and Spectra for cases described in Table 1

Appendix 6 - Numerical output and metrics for cases described in Table 1
General Diagram of a Multistage Communication System

Each Stage has the Following Characteristics:

- Frequency Response
- Input-Output Transfer Relationship
- Noise Addition
General Diagram of a Multistage Communication System
With Measurements and Metrics

Each Stage has the following characteristics:

- Frequency Response
- Input-Output Transfer Relationship
- Noise Addition
Photographic System as a Communication Channel

The Photographic System contains:

Frequency Response Effects Due to Film and Lens
Noise Contributions Due to Film and Paper
Input-Output Characteristics Due to Film and Paper
Figure 4

Color Negative Photographic System

Each stage has the following characteristics:

* Frequency Response
* Input-Output Transfer Relationship
* Noise Contributions
EXAMPLE DENSITY - LOG EXPOSURE CURVE

PHOTOGRAPHIC PAPER

Relative Log Exposure

Relative Density
TYPICAL MODULATION TRANSFER FUNCTIONS
35MM CAMERA LENS
Figure 6

FREQUENCY-IMAGE PLANE (CYCLES/MM)
MODULATION TRANSFER

FRIDAY 8APR88 11:04
TYPICAL MODULATION TRANSFER FUNCTIONS
35MM FILM

Figure 7

MODULATION TRANSFER

FREQUENCY-IMAGE PLANE (CYCLES/MM)
TYPICAL MODULATION TRANSFER FUNCTIONS

PRINTER LENS

Figure 8

FREQUENCY-IMAGE PLANE (CYCLES/MM)
TYPICAL MODULATION TRANSFER FUNCTIONS
PHOTOGRAPHIC PAPER

Figure 9

MODULATION TRANSFER

FREQUENCY-PAPER PLANE (CYCLES/MM)
Human Visual System - MTFs
For Viewing Distance of 355mm

Figure 10

Adaptation Level (foot-lamberts)

1/8
1/64
1/16
1/32
Human Visual System - MTFs

For Viewing Distance of 355mm

Adaptation Level (trol-lamberts)
Human Visual System - MTFs
For Viewing Distance of 355mm

Figure 12

Adaptation Level (foot-lamberts)
- 1/8
- 1/64
- 1/16
- 1/32

FREQUENCY ON PRINT (cycles/mm)
Human Visual System - Noise components

Figure 13

Adaptation Level (foot-lamberts)

<table>
<thead>
<tr>
<th>Level</th>
<th>Line Style</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
Input-Output Mapping Function

Input to Stage

Output of Stage

Figure 14
Modulation Transfer Function

Figure 15

Modulation Transfer

Frequency (cycles/mm)
Figure 16

Noise Power Spectrum

Noise Power

Frequency (cycles/mm)
Mapping of Input PDF through Transfer Curve
Conditional Probability Distributions

Input level

\[ P(y/x) \]

\( x = x(0) \)

\( x = x(1) \)

\( x = x(n-2) \)

\( x = x(n-1) \)

\( x = x(n) \)

Note: \( X(i) \) refers to different input signal levels
Figure 19

Joint Probability Density Function

$p(\text{input}, \text{output})$
POSSIBLE NOISE POWER SHAPES

Figure 20

The graph illustrates the possible noise power shapes as a function of frequency (cycles/mm). The shapes include:

- **Band-Limited White Noise**
- **Exponential**
- **Triangular**

The x-axis represents frequency (cycles/mm), and the y-axis represents noise power. The graph shows how the noise power changes with frequency for different shapes.
Components of the Color Negative System

Scene Luminance

Camera lens

Film Illumination

Film

Film Transmittance

Printer lens

Paper Illuminance

Paper

Paper Reflectance

Human Visual System
Note: (S) signifies modification to Spectra
(P) signifies modification to Probability Density Functions
Signal Flow Diagram - Printer/Paper Stage

Note: (S) signifies modification to Spectra
(P) signifies modification to Probability Density Functions
Signal Flow Diagram - Human Visual System  
Optics Component

Note: (S) signifies modification to Spectra  
(P) signifies modification to Probability Density Functions
Signal Flow Diagram - Human Visual System  Figure 25
Sampling Component

Output from HVS Optics Stage

signal & noise

Output from HVS Sampling Stage

Modulation Transfer Function (S)

signal & noise

Retinal Illuminance

Spatial Summation

Integration-Period

Poisson Noise (P)

Note: (S) signifies modification to Spectra
(P) signifies modification to Probability Density Functions
Signal Flow Diagram - Human Visual System  Figure 26
Neural Component

Output from HVS Sampling Stage

signal

signal & noise

Modulation Transfer Function (S)

Noise (P)

Output from HVS Neural Stage

Adaptation Level

Note: (S) signifies modification to Spectra
(P) signifies modification to Probability Density Functions
Figure 27 - Specifications for Example Case

Input Scene
B = 3
N = 3
Standard Deviation/Mean = 0.3
Mean = 0.5

Magnification to Next Stage
3.88 x

Camera Lens MTF
Diffraction limited lens at f/8

Film MTF
From file: FILM DATA. Typical MTF of green layer for a color negative film.

Film DlogH
From file: FILM2 IQFILM. Typical DlogH curve of green layer for a color negative film. Exposure point is at 1.8 relative logE.

Film Granularity
From file: FILM2 IQFILM. Typical granularity data for the green layer of a color negative film. Exponentially shaped power spectra with 1% of peak at 100 cycles/mm.

Printer Lens MTF
Diffraction limited lens at f/5.6

Paper DlogH
From file: PAPER IQPAPER. Typical DlogH curve of for color paper. Exposure point is at 0.85 relative logE.

Paper MTF
From file: PAPER1 DATA. Typical MTF for a color paper.

Paper Granularity
From file: PAPER IQPAPER. Typical granularity for color paper. Shape of power spectra is assumed to be band-limited white noise at 20 cycles/mm.

Viewing Conditions
Light level of 6 foot-lamberts is typical of consumer viewing situations. A viewing distance of 355mm is a standard viewing distance for 3.5 x 5.0 inch color reflection prints. Shape of power spectra is assumed to be band-limited white noise at 20 cycles/mm.
Cumulative Probability Function

ID = AFTER INPUT SCENE SPEC

Figure 2(c)
Power Spectra

ID=AFTER INPUT SCENE SPEC

Figure 27
Modulation Transfer Functions

ID = CAMERA LENS MTF

Frequency (Cycles/MM) On Print

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

0 1 2 3 4 5 6 7 8 9 10
Power Spectra

Figure

ID=AFTER CAMERA LENS MTF

SIGNAL + NOISE

SIGNAL
Modulation Transfer Functions

ID = FILM MTF

Frequency (Cycles/MM) On Print
Cumulative Probability Function

ID=AFTER FILM MTF

Figure 34
Power Spectra

ID=AFTER FILM MTF

Frequency

Power

IDS SIGNAL SIGNAL + NOISE
Density-Log Exposure Functions

ID=FILM DLOGH

Figure
Cumulative Probability Function

ID=AFTER FILM DLOGH

Figure 37
Power Spectra

ID = AFTER FILM DLOGH

Figure 38
Cumulative Probability Function

ID = AFTER FILM GRANULARITY
Power Spectra

ID = AFTER FILM GRANULARITY

Frequency

Power

IDS SIGNAL SIGNAL + NOISE
Modulation Transfer Functions

ID = PRINTER LENS

Frequency (Cycles/MM) On Print

[Graph showing a decreasing line from left to right, indicating a modulation transfer function.]
Cumulative Probability Function

ID = AFTER PRINTER LENS

Figure 43
Power Spectra

ID=AFTER PRINTER LENS

Figure 44
Cumulative Probability Function

ID=AFTER PAPER MTF
Power Spectra

ID = AFTER PAPER MTF

Figure 47
Granularity Functions

ID=PAPER GRANULARITY

Figure 51

Plot showing the relationship between Standard Deviation of Noise and linear value.
Cumulative Probability Function

ID=AFTER PAPER GRANULARITY

Figure 5.2
Power Spectra

ID=AFTER PAPER GRANULARITY

Figure 53
Modulation Transfer Functions

ID = HVS - SAMPLING
Modulation Transfer Functions

ID = HVS - OPTICS

Figure 55
Modulation Transfer Functions

ID=HVS-NEURAL
Cumulative Probability Function

ID = AFTER HVS MTF

Figure 57
Power Spectra

Figure

Power Spectra

Figure

IDS --- SIGNAL

SIGNAL + NOISE

IDS --- SIGNAL

SIGNAL + NOISE
Granularity Functions

ID = HVS - NOISE

Figure 59
Cumulative Probability Function

ID=AFTER HVS NOISE

Value

IDS SIGNAL SIGNAL + NOISE
Power Spectra

ID=AFTER HVS NOISE

Figure 1

Power Spectra

ID=AFTER HVS NOISE

Figure
Different Film Granularities

For datafiles FILM2 I QFILM and FILM1 IQFILM
Effect of Changes in Film Exposure Point
Camera - Film Stage

Figure 64

INFORMATION CONTENT (bits/sq mm)

Relative Exposure (stops)

0 50 100 150 200

-4 -3 -2 -1 0 1 2
Effect of Changes in Film Exposure Point
Printer - Paper Stage

Figure 65
Effect of Changes in Film Exposure Point
Human Visual System

Figure 66
COMPARISON OF MODULATION TRANSFER FUNCTIONS
For Photographic Paper

Figure 67

MODULATION TRANSFER

FREQUENCY-PAPER PLANE (CYCLES/MM)

PAPER 1

PAPER 2
Appendix A

STRUCTURED SPECIFICATION OF IQCN1

On the following pages is the structured specification as defined by the Yourdan technique (5). The software package PCSA (tm) was used to create this specification. It can be divided into 4 sections

1. **Context Diagram**
   Overall graphical description of the program. All inputs and outputs of the model are included. The inputs and outputs are further defined in the Data Dictionary (see below).

2. **Data flow diagrams**
   A layered description of the software. All input and outputs of parent diagrams and accounted for in each child. The lower level the diagram, the more simple is the task. The lowest level are primitives as defined by double circles. These primitives are explained in pseudo-code as mini-specifications (see below).

3. **Mini-specifications**
   These are very elementary operations as defined by the primitives. They are written in pseudo-code to give the programmer an understanding of what is happening rather than code for a specific programming language.

4. **Data-dictionary**
   Definitions of all variables in the data flow diagrams.

For further description of these terms, please see the reference mentioned earlier.

Page A-1
IQCNI-Program
to analyze
Information
Content

- camera-parameters
- scene-parameters
- film-parameters
- printer-parameters
- paper-parameters
- viewing-conditions
- signal-and-noise-pdf-spectrum
- signal-pdf-spectrum
- human-visual-system-parameters
- INFORMATION-CONTENT

William-R.-O'Such
October 26, 1987
Modify PDFs\Spectra for Printer Lens MTF

Modify PDFs\Spectra for Paper MTF

Modify PDFs\Spectra for Paper Sensitometry

Modify PDFs\Spectra for Paper Noise

Calculate Printer\Paper Information Theoretic Metrics

Modify PDFs\Spectra for Printer\Paper Stage : 3
Modify Spectra for Camera Lens MTF

1. Signal spectrum
2. Calculate New Variances (camera)
3. Modify PDFs for New Variances (camera)

- Magnification
- Camera parameters
- Camera-lens mtf

Modify PDF spectra for Camera Lens MTF: 2.1
Modify PDF spectra for Film Noise: 2.4
Modify Spectrum for Printer Lens MTF

Calculate New Variances (printer)

Modify PDFs for New Variance (printer)

Modify PDFs/Spectra for Printer Lens MTF : 3.1
1. Convert PDFs from Exposure to Transmittance (paper)

2. Calculate Cumulative Probability Distributions (paper)

3. Calculate Output PDFs (paper)

4. Calculate New Statistics (paper sensitometry)

5. Modify Spectra for Sensitometric Changes (paper)

Modify PDFs/Spectra for Paper Sensitometry : 3.3
Determine HVS MTF and Noise Amounts: 4.1
Modify PDFs\Spectra for HVS Sampling MTF

Modify PDFs\Spectra for HVS Neural MTF

Modify PDFs\Spectra for HVS Pupil MTF

signal\_and\_noise\_statistics
Construct Conditional Probability Distribution (HVS)

Signal-Noise pdf

Conditional probability distribution

Construct Joint Probability Distribution (HVS)

Signal-Noise pdf

Joint probability distribution

Construct Output Probability Distribution (HVS)

Signal-Noise pdf

Signal-Noise statistics

Determine Additional Variance (HVS)

Signal-Noise statistics

Determine Noise Spectrum (HVS)

Noise spectrum

Add Noise Spectrum to Signal and Noise Spectrum (HVS)

Noise spectrum

Signal-Noise spectrum

Signal-Noise spectrum

Signal-Noise spectrum

Modify PDFs Spectra for HVS Noise: 4.3
Determine HVS Noise Components: 4.1.3

- Determine Quantum Noise
  - Integration-Time
  - Adaptation-Level
  - Aperture-Length-Constant
  - Pupil-Diameter

- Combine Noise Sources
  - hvs-noise
  - quantum-noise

- Determine Neural Noise
  - NEURAL-NOISE
  - SIGNAL-AND-NOISE-MEAN
Minispec 1.1 - Create Signal pdfs

Inputs:  
  SCENE_MEAN  
  SCENE_MODULATION

Outputs:  
  signal_and_noise_statistics  
  signal_statistics  
  signal_pdf  
  signal_and_noise_pdf

Description:

\[ \text{SCENE_VARIANCE} = (\text{SCENE_MODULATION} \times \text{SCENE_MEAN})^2 \]

For all SIGNAL_VALUES

Do

  \[ \text{SIGNAL_PROBABILITY} = \frac{1}{\sqrt{2 \cdot \pi \times \text{SCENE_VARIANCE}}} \cdot \exp\left(-\frac{(\text{SIGNAL_VALUES} - \text{SCENE_MEAN})^2}{2 \times \text{SCENE_VARIANCE}}\right) \]

  \[ \text{SUM} = \text{SUM} + \text{SIGNAL_PROBABILITY} \]

End

For all SIGNAL_VALUES

Do

  \[ \text{SIGNAL_PROBABILITY} = \frac{\text{SIGNAL_PROBABILITY}}{\text{SUM}} \]

  \[ \text{SIGNAL_AND_NOISE_VALUES} = \text{SIGNAL_VALUES} \]

  \[ \text{SIGNAL_AND_NOISE_PROBABILITY} = \text{SIGNAL_PROBABILITY} \]

End

Calculate SIGNAL_MEAN
Calculate SIGNAL_VARIANCE
Calculate SIGNAL_AND_NOISE_MEAN
Calculate SIGNAL_AND_NOISE_VARIANCE

Realized in:
SCENE2 FORTRAN
Minispec 1.2 - Create Signal spectra

Inputs:  SIGNAL_VARIANCE
         spectral_shape_parameters

Outputs: signal_spectrum
         signal_and_noise_spectra

Description:

Determine INTEGRAL from 0 to 20 cycles/mm of:
   SIGNAL_POWER = 1/(B**n + FREQUENCY**N)

A = 2.*pi*SIGNAL_VARIANCE/(INTEGRAL*2)

For all FREQUENCIES
Do
   SIGNAL_POWER = A/(B**N + FREQUENCY**N)
   SIGNAL_AND_NOISE_POWER = SIGNAL_POWER
End

Realized in:
SCENE2 FORTRAN
FNC FORTRAN
Minispec 2.1.1  Modify Spectra for Camera Lens MTF

Input:  
camera lens.mtf
  signal spectrum
  signal and noise spectrum
  MAGNIFICATION

Output:  
signal spectrum
  signal and noise spectrum

Description:
For all FREQUENCIES*MAGNIFICATION
Do
  SIGNAL_POWER = MODULATION TRANSFER**2 * SIGNAL_POWER
  SIGNAL_AND_NOISE_POWER = MODULATION TRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 2.1.2 - Calculate New Variances (camera)

Input:  
- signal_spectrum  
- signal_and_noise_spectrum  
- signal_and_noise_statistics  
- signal_statistics

Output:  
- signal_and_noise_statistics  
- signal_statistics  
- variance_factors

Description:

\[ \text{NEW SIGNAL VARIANCE} = 2 \times \left( \frac{1}{2\pi} \right) \times \int \text{SIGNAL SPECTRUM} \]

\[ \text{NEW SIGNAL AND NOISE VARIANCE} = 2 \times \left( \frac{1}{2\pi} \right) \times \int \text{SIGNAL AND NOISE SPECTRUM} \]

\[ \text{SIGNAL VARIANCE FACTOR} = \frac{\text{NEW SIGNAL VARIANCE}}{\text{SIGNAL VARIANCE}} \]

\[ \text{SIGNAL AND NOISE VARIANCE FACTOR} = \frac{\text{NEW SIGNAL AND NOISE VARIANCE}}{\text{SIGNAL AND NOISE VARIANCE}} \]

\[ \text{SIGNAL VARIANCE} = \text{NEW SIGNAL VARIANCE} \]

\[ \text{SIGNAL AND NOISE VARIANCE} = \text{NEW SIGNAL AND NOISE VARIANCE} \]

Realized in:  
MTFMD1 FORTRAN
Minispec 2.1.3 - Modify PDFs for New Variances (camera)

Input:
- variance_factors
- signal_statistics
- signal_and_noise_statistics
- signal_pdf
- signal_and_noise_pdf

Output:
- signal_pdf
- signal_and_noise_pdf

Description:
For all SIGNAL LEVELS
Do
   SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE LEVELS
Do
   SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 2.2.1 - Modify Spectrum for Film MTF

Input:
	film_mtf
	signal_spectrum
	signal_and_noise_spectrum
	MAGNIFICATION

Output:
	signal_spectrum
	signal_and_noise_spectrum

Description:
For all FREQUENCIES*MAGNIFICATION
Do
	SIGNAL_POWER = MODULATION_TRANSFER**2 * SIGNAL_POWER
	SIGNAL_AND_NOISE_POWER = MODULATION_TRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 2.2.2 - Calculate New Variances (film)

Input:
- signal_spectrum
- signal_and_noise_spectrum
- signal_and_noise_statistics
- signal_statistics

Output: 
- signal_and_noise_statistics
- signal_statistics
- variance_factors

Description:

NEW_SIGNAL_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_SPECTRUM)

NEW_SIGNAL_AND_NOISE_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_AND_NOISE_SPECTRUM)

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Minispec 2.2.3 - Modify PDFs for New Variances (film)

Input:  variance_factors
         signal_statistics
         signal_and_noise_statistics
         signal_pdf
         signal_and_noise_pdf

Output: signal_pdf
        signal_and_noise_pdf

Description:
For all SIGNAL_LEVELS
Do
   SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE_LEVELS
Do
   SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 2.3.1 - Convert PDFs from Exposure to Tranmittance (film)

Input:  
CAMERA_EXPOSURE_POINT  
signal_and_noise_pdf  
signal_pdf  
film_dloge_curve

Output: intermediate_pdfs

Description:
For all SIGNAL_VALUES
Do  
Determine LOGE DIFFERENCE between SIGNAL VALUE and SIGNAL MEAN  
LOGE VALUE = LOGE DIFFERENCE + CAMERA EXPOSURE POINT  
Map LOGE VALUE through film dloge curve to obtain DENSITY  
INTERMEDIATE SIGNAL VALUE = 10.**(DENSITY)  
INTERMEDIATE SIGNAL PROBABILITY = SIGNAL PROBABILITY
End

For all SIGNAL_AND_NOISE_VALUES
Do  
Determine LOGE DIFFERENCE between SIGNAL_AND_NOISE VALUE and SIGNAL_AND_NOISE MEAN  
LOGE VALUE = LOGE DIFFERENCE + CAMERA EXPOSURE POINT  
Map LOGE VALUE through film dloge curve to obtain DENSITY  
INTERMEDIATE SIGNAL_AND_NOISE VALUE = 10.**(DENSITY)  
INTERMEDIATE SIGNAL_AND_NOISE PROBABILITY = SIGNAL_AND_NOISE PROBABILITY
End

Sort intermediate_pdfs in ascending order

Realized in: DLHMD2 FORTRAN
Minispec 2.3.2 - Calculate Cumulative Probability Distribution (film)

Inputs: intermediate.pdfs

Outputs: cumulative_distributions

Description:

For all INTERMEDIATE_SIGNAL_VALUES
Do
  CUMULATIVE SIGNAL PROBABILITY = INTERMEDIATE_SIGNAL_PROBABILITY + previous INTERMEDIATE_SIGNAL_PROBABILITY

  CUMULATIVE SIGNAL AND NOISE PROBABILITY = INTERMEDIATE SIGNAL AND NOISE PROBABILITY + previous INTERMEDIATE SIGNAL AND NOISE PROBABILITY
End

Realized in:
PDFUNL FORTRAN
Minispec 2.3.3 - Calculate Output PDFs (film)

Input: cumulative_distributions

Output: signal.pdf
        signal_and_noise.pdf

Description:

For all SIGNAL_VALUES
Do
    CELL_LOWER_LIMIT = SIGNAL_VALUE - 0.5*(1/10000)
    CELL_UPPER_LIMIT = SIGNAL_VALUE + 0.5*(1/10000)
    LOWER_CUMULATIVE_PROBABILITY = Value of CUMULATIVE_PROBABILITY_SIGNAL at CELLLOWER_LIMIT
    UPPER_CUMULATIVE_PROBABILITY = Value of CUMULATIVE_PROBABILITY_SIGNAL at CELL_UPPER_LIMIT
    SIGNAL_PROBABILITY = UPPER_CUMULATIVE_PROBABILITY = LOWER_CUMULATIVE_PROBABILITY
End

For all SIGNAL_VALUES
Do
    CELL_LOWER_LIMIT = SIGNAL_AND_NOISE_VALUE - 0.5*(1/10000)
    CELL_UPPER_LIMIT = SIGNAL_AND_NOISE_VALUE + 0.5*(1/10000)
    LOWER_CUMULATIVE_PROBABILITY = Value of CUMULATIVE_PROBABILITY_SIGNAL_AND_NOISE at CELLLOWER_LIMIT
    UPPER_CUMULATIVE_PROBABILITY = Value of CUMULATIVE_PROBABILITY_SIGNAL_AND_NOISE at CELL_UPPER_LIMIT
    SIGNAL_AND_NOISE_PROBABILITY = UPPER_CUMULATIVE_PROBABILITY = LOWER_CUMULATIVE_PROBABILITY
End

Realized in:
PDFUNL FORTRAN
Minispec 2.3.4 - Calculate New Statistics (film sensitometry)

Input: signal_pdf
        signal_and_noise_pdf

Output: signal_and_noise_statistics
        signal_statistics
        variance_factors

Description:
For all SIGNAL_VALUES
Do
    SUM_OF_X = SUM_OF_X + SIGNAL_PROBABILITY*SIGNAL_VALUE
    SUM_OF_XX = SUM_OF_XX + SIGNAL_PROBABILITY*SIGNAL_VALUE*SIGNAL_VALUE
End
NEW_SIGNAL_MEAN = SUM_OF_X
NEW_SIGNAL_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X

For all SIGNAL_AND_NOISE_VALUES
Do
    SUM_OF_X = SUM_OF_X + SIGNAL_AND_NOISE_PROBABILITY*SIGNAL_AND_NOISE_VALUE
    SUM_OF_XX = SUM_OF_XX + SIGNAL_AND_NOISE_PROBABILITY*SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_VALUE
End
NEW_SIGNAL_AND_NOISE_MEAN = SUM_OF_X
NEW_SIGNAL_AND_NOISE_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE
SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_MEAN = NEW_SIGNAL_MEAN
SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE
SIGNAL_AND_NOISE_MEAN = NEW_SIGNAL_AND_NOISE_MEAN
SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
PDFUNL FORTRAN
Minispec 2.3.5 - Modify Spectra for Sensitometric Changes (film)

Input:    signal_statistics  
          signal_and_noise_statistics  
          signal_spectrum  
          signal_and_noise_spectrum  
          variance_factors

Output:   signal_spectrum  
          signal_and_noise_spectrum

Description:

For all FREQUENCIES
Do
    SIGNAL_POWER = SIGNAL_POWER*SIGNAL_VARIANCE_FACTOR
    SIGNAL_AND_NOISE_POWER = SIGNAL_AND_NOISE_POWER*SIGNAL_AND_NOISE_VARIANCE_FACTOR
End

Realized in:
PDFUNL FORTRAN
DLHMD2 FORTRAN
Minispec 2.4.1 - Construct Conditional Probability Distribution (film)

Input: film granularity curve

Output: conditional probability distribution

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
  STANDARD DEVIATION = Value of GRANULARITY at SIGNAL_AND_NOISE_VALUE
For all OUTPUT SIGNAL_AND_NOISE_VALUES
Do
  UPPER LIMIT = (-1.*LOG10(OUTPUT SIGNAL_AND_NOISE VALUE - 0.00005) - (-1.*LOG10(SIGNAL_AND_NOISE VALUE))/STANDARD DEVIATION
  LOWER LIMIT = (-1.*LOG10(OUTPUT SIGNAL_AND_NOISE VALUE + 0.00005) - (-1.*LOG10(SIGNAL_AND_NOISE VALUE))/STANDARD DEVIATION
  CUMULATIVE PROBABILITY_LOWER = Value of CUMULATIVE_NORMAL DISTRIBUTION at LOWER LIMIT
  CUMULATIVE PROBABILITY_UPPER = Value of CUMULATIVE_NORMAL DISTRIBUTION at UPPER LIMIT
  CONDITIONAL PROBABILITY = CUMULATIVE PROBABILITY UPPER - CUMULATIVE PROBABILITY LOWER
End
End

Realized in: SNPDF3 FORTRAN
Minispec 2.4.2 - Construct Joint Probability Distribution (film)

Input:  
conditional probability distribution
signal_and_noise_pdf

Output:  
joint_probability_distribution

Description:
For all SIGNAL_AND_NOISE_LEVELS
Do
  For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
  Do
    JOINT_PROBABILITY = SIGNAL_PROBABILITY*CONDITIONAL_PROBABILITY
  End
End

Realized in:
SNPDF3 FORTRAN
Construct Output Probability Distribution (film)

Input: joint_probability_distribution

Output: signal_and_noise.pdf

Description:

For all OUTPUT SIGNAL AND NOISE LEVELS
Do
   For all SIGNAL AND NOISE LEVELS
   Do
      SIGNAL AND NOISE PROBABILITY = SIGNAL AND NOISE PROBABILITY + JOINT PROBABILITY
   End
End

For all OUTPUT SIGNAL AND NOISE LEVELS
Do
   SIGNAL AND NOISE LEVELS = OUTPUT SIGNAL AND NOISE LEVELS
End

Realized in:
SNPDF3 FORTRAN
Minispec 2.4.4 - Determine Additional Variance (film)

Input: signal and noise statistics
       signal_and_noise_pdf

Output: signal and noise statistics
        NOISE_ADDITIONAL_VARIANCE

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
   SUM_OF_X = SUM_OF_X + SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_PROBABILITY
   SUM_OF_XX = SUM_OF_XX + SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_PROBABILITY
End

NEW_SIGNAL_AND_NOISE_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X
NOISE_ADDITIONAL_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE - SIGNAL_AND_NOISE_VARIANCE
SIGNAL_AND_NOISE_MEAN = SUM_OF_X
SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
SNPDF3 FORTRAN
Minispec 2.4.5 Determine Noise Spectrum (film)

Input:
- NOISE_ADDITIONAL_VARIANCE
- film_power_spectral_shape
- MAGNIFICATION

Output: noise_spectrum

Description:

If film_power_spectral_shape = bandlimited_white_noise
For all FREQUENCIES
Do
    NOISE_POWER = (2 * PI * NOISE_ADDITIONAL_VARIANCE)/(2.*CUTOFF_FREQUENCY/MAGNIFICATION)
End

Else If film_power_spectral_shape = triangular then
Do
    CONSTANT_TRIANGULAR = MAGNIFICATION * 2 * PI * (NOISE_ADDITIONAL_VARIANCE/CUTOFF_FREQUENCY)

    For all FREQUENCIES
    Do
        NOISE POWER = CONSTANT_TRIANGULAR-(CONSTANT_TRIANGULAR/(CUTOFF_FREQUENCY/MAGNIFICATION))*FREQUENCY
    End

End

Else If film_power_spectral_shape = exponential then
Do
    CONSTANT_EXP_1 = 4.604*MAGNIFICATION/CUTOFF_FREQUENCY
    CONSTANT_EXP_2 = CONSTANT_EXP_1 * 2 * PI * NOISE_ADDITIONAL_VARIANCE/2.

    For all FREQUENCIES
    Do
        NOISE POWER = CONSTANT_EXP_2*EXP(-1.*CONSTANT_EXP_1*FREQUENCY)
    End

End

Realized in:
SNP2 FORTRAN
Minispec 2.4.6 - Add Noise Spectrum to Signal and Noise Spectrum (film)

Input:  
- noise_spectrum
- signal_and_noise_spectrum

Output:  
- signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
  SIGNAL_AND_NOISE_POWER = SIGNAL_AND_NOISE_POWER + NOISE_POWER
End

Realized in:
SNP2 FORTRAN
Minispec 2.5 - Calculate Information Theoretic Metrics

Input:  
- signal_spectrum
- signal_and_noise_spectrum

Output: INFORMATION_CONTENT

Description:
Integrate
\[ \pi \cdot \text{FREQUENCY} \cdot \log_2 \left( \frac{\text{SIGNAL AND NOISE POWER}}{\text{SIGNAL AND NOISE POWER} - \text{SIGNAL POWER}} \right) \]
to obtain INFORMATION_CONTENT

Realized in:
INFO1 FORTRAN
Minispec 3.1.1 Modify Spectrum for Printer Lens MTF

Input:  
- printer lens mtf
- signal spectrum
- signal and noise spectrum
- MAGNIFICATION

Output:  
- signal spectrum
- signal and noise spectrum

Description:
For all FREQUENCIES*MAGNIFICATION
Do
  SIGNAL_POWER = MODULATION TRANSFER**2 * SIGNAL_POWER
  SIGNAL_AND_NOISE_POWER = MODULATION TRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 3.1.2 - Calculate New Variances (printer)

**Input:**
- signal_spectrum
- signal_and_noise_spectrum
- signal_and_noise_statistics
- signal_statistics

**Output:**
- signal_and_noise_statistics
- signal_statistics
- variance_factors

**Description:**

- NEW_SIGNAL_VARIANCE = \(2 \times (1/(2\pi)) \times \text{Integral (SIGNAL\_SPECTRUM)}\)
- NEW_SIGNAL_AND_NOISE_VARIANCE = \(2 \times (1/(2\pi)) \times \text{Integral (SIGNAL\_AND\_NOISE\_SPECTRUM)}\)
- SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE
- SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE
- SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE
- SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Minispec 3.1.3 - Modify PDFs for New Variances (printer)

Input:  
- variance_factors
- signal_statistics
- signal_and_noise_statistics
- signal_pdf
- signal_and_noise_pdf

Output:  
- signal_pdf
- signal_and_noise_pdf

Description:
For all SIGNAL_LEVELS
Do
  SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE_LEVELS
Do
  SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 3.2.1 - Modify Spectrum for Paper MTF

Input:  
- paper mtf
- signal spectrum
- signal and noise spectrum
- MAGNIFICATION

Output: 
- signal_spectrum
- signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
  SIGNAL_POWER = MODULATION_TRANSFER**2 * SIGNAL_POWER
  SIGNAL_AND_NOISE_POWER = MODULATION_TRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 3.2.2 - Calculate New Variances (paper)

Input:
- signal_specturm
- signal_and_noise_specturm
- signal_and_noise_statistics
- signal_statistics

Output:
- signal_and_noise_statistics
- signal_statistics
- variance_factors

Description:

NEW_SIGNAL_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_SPECTRUM)

NEW_SIGNAL_AND_NOISE_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_AND_NOISE_SPECTRUM)

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Minispec 3.2.3  Modify PDFs for New Variances (paper)

Input:  variance_factors
        signal_statistics
        signal_and_noise_statistics
        signal_pdf
        signal_and_noise_pdf

Output: signal_pdf
        signal_and_noise_pdf

Description:
For all SIGNAL_LEVELS
Do
   SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE_LEVELS
Do
   SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 3.3.1 - Convert PDFs from Exposure to Tranmittance (paper)

Input:  
PRINTER_EXPOSURE_POINT  
signal_and_noise_pdf  
signal_pdf  
paper_dloge_curve

Output:  
intermediate_pdfs

Description:

For all SIGNAL_VALUES
Do
  Determine LOGE DIFFERENCE between SIGNAL.VALUE and SIGNAL.MEAN
  \[ \text{LOGE.VALUE} = \text{LOGE.DIFFERENCE} + \text{PRINTER.EXPOSURE.POINT} \]
  Map LOGE.VALUE through paper_dloge.curve to obtain DENSITY
  \[ \text{INTERMEDIATE.SIGNAL.VALUE} = 10.**(-\text{DENSITY}) \]
  \[ \text{INTERMEDIATE.SIGNAL.PROBABILITY} = \text{SIGNAL.PROBABILITY} \]
End

For all SIGNAL_AND_NOISE_VALUES
Do
  Determine LOGE DIFFERENCE between SIGNAL_AND_NOISE.VALUE and SIGNAL_AND_NOISE.MEAN
  \[ \text{LOGE.VALUE} = \text{LOGE.DIFFERENCE} + \text{PRINTER_EXPOSURE.POINT} \]
  Map LOGE.VALUE through paper_dloge.curve to obtain DENSITY
  \[ \text{INTERMEDIATE.SIGNAL_AND_NOISE.VALUE} = 10.**(-\text{DENSITY}) \]
  \[ \text{INTERMEDIATE.SIGNAL_AND_NOISE.PROBABILITY} = \text{SIGNAL_AND_NOISE.PROBABILITY} \]
End

Sort intermediate_pdfs in ascending order

Realized in:
DLHMD2 FORTRAN
Minispec 3.3.2 - Calculate Cumulative Probability Distribution (paper)

Inputs: intermediate_pdfs

Outputs: cumulative_distributions

Description:

For all INTERMEDIATE SIGNAL VALUES
Do
  CUMULATIVE SIGNAL PROBABILITY = INTERMEDIATE SIGNAL PROBABILITY + previous INTERMEDIATE SIGNAL PROBABILITY
  CUMULATIVE SIGNAL AND NOISE PROBABILITY = INTERMEDIATE SIGNAL AND NOISE PROBABILITY + previous INTERMEDIATE SIGNAL AND NOISE PROBABILITY
End

Realized in:
PDFUNL FORTRAN
Minispec 3.3.3 - Calculate Output PDFs (paper)

Input: cumulative_distributions

Output: signal.pdf
        signal_and_noise.pdf

Description:

For all SIGNAL_VALUES
Do
    CELL LOWER LIMIT = SIGNAL VALUE - 0.5*(1/10000)
    CELL UPPER LIMIT = SIGNAL VALUE + 0.5*(1/10000)
    LOWER CUMULATIVE PROBABILITY = Value of CUMULATIVE_PROBABILITY SIGNAL at CELL LOWER LIMIT
    UPPER CUMULATIVE PROBABILITY = Value of CUMULATIVE_PROBABILITY SIGNAL at CELL UPPER LIMIT
    SIGNAL PROBABILITY = UPPER CUMULATIVE PROBABILITY = LOWER CUMULATIVE PROBABILITY
End

For all SIGNAL_VALUES
Do
    CELL LOWER LIMIT = SIGNAL AND NOISE VALUE - 0.5*(1/10000)
    CELL UPPER LIMIT = SIGNAL AND NOISE VALUE + 0.5*(1/10000)
    LOWER CUMULATIVE PROBABILITY = Value of CUMULATIVE_PROBABILITY SIGNAL AND NOISE at CELL LOWER LIMIT
    UPPER CUMULATIVE PROBABILITY = Value of CUMULATIVE_PROBABILITY SIGNAL AND NOISE at CELL UPPER LIMIT
    SIGNAL AND NOISE PROBABILITY = UPPER CUMULATIVE PROBABILITY = LOWER CUMULATIVE PROBABILITY
End

Realized in:
PDFUNL FORTRAN
Minispec 3.3.4 - Calculate New Statistics (paper sensitometry)

Input:  
- signal_pdf
- signal_and_noise_pdf

Output:  
- signal_and_noise_statistics
- signal_statistics
- variance_factors

Description:
For all SIGNAL_VALUES
Do
  SUM OF X = SUM OF X + SIGNAL_PROBABILITY*SIGNAL_VALUE
  SUM OF XX = SUM OF XX + SIGNAL_PROBABILITY*SIGNAL_VALUE*SIGNAL_VALUE
End
NEW SIGNAL MEAN = SUM OF X
NEW SIGNAL VARIANCE = SUM OF XX - SUM OF X*SUM OF X

For all SIGNAL_AND_NOISE_VALUES
Do
  SUM OF X = SUM OF X + SIGNAL_AND_NOISE_PROBABILITY*SIGNAL_AND_NOISE_VALUE
  SUM OF XX = SUM OF XX + SIGNAL_AND_NOISE_PROBABILITY*SIGNAL_AND_NOISE VALUE*SIGNAL_AND_NOISE_VALUE
End
NEW SIGNAL_AND_NOISE_MEAN = SUM_OF_X
NEW SIGNAL_AND_NOISE_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X

SIGNAL_VARIANCE_FACTOR = NEW SIGNAL VARIANCE/SIGNAL VARIANCE
SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW SIGNAL_AND_NOISE VARIANCE/SIGNAL AND NOISE VARIANCE

SIGNAL MEAN = NEW SIGNAL MEAN
SIGNAL VARIANCE = NEW SIGNAL VARIANCE
SIGNAL_AND_NOISE_MEAN = NEW SIGNAL AND NOISE MEAN
SIGNAL_AND_NOISE_VARIANCE = NEW SIGNAL AND NOISE VARIANCE

Realized in:
PDFUNL FORTRAN
Minispec 3.3.5 - Modify Spectra for Sensitometric Changes (paper)

Input:

signal_statistics
signal_and_noise_statistics
signal_spectrum
signal_and_noise_spectrum
variance_factors

Output:

signal_spectrum
signal_and_noise_spectrum

Description:

For all FREQUENCIES
Do
  SIGNAL_POWER = SIGNAL_POWER*SIGNAL_VARIANCE_FACTOR
  SIGNAL_AND_NOISE_POWER = SIGNAL_AND_NOISE_POWER*SIGNAL_AND_NOISE_VARIANCE_FACTOR
End

Realized in:
PDFUNL FORTRAN
DLHMD2 FORTRAN
Minispec 3.4 - Calculate Printer/Paper Information Theoretic Metrics

Input: signal_spectrum
      signal_and_noise_spectrum

Output: INFORMATION_CONTENT

Description:
Integrate
  \[ \pi \times \text{FREQUENCY} \times \log_2(\text{SIGNAL\_AND\_NOISE\_POWER}/(\text{SIGNAL\_AND\_NOISE\_POWER} - \text{SIGNAL\_POWER})) \]
to obtain INFORMATION_CONTENT

Realized in:
INFO1 FORTRAN
Minispec 3.5.1 - Construct Conditional Probability Distribution (paper)

Input: paper_granularity_curve

Output: conditional_probability_distribution

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
  STANDARD DEVIATION = Value of GRANULARITY at SIGNAL_AND_NOISE_VALUE
  For all OUTPUT_SIGNAL_AND_NOISE_VALUES
  Do
    UPPER LIMIT = (-1.*LOG10(OUTPUT SIGNAL AND NOISE VALUE - 0.00005) -
      (-1.*LOG10(SIGNAL AND NOISE VALUE))/STANDARD DEVIATION
    LOWER LIMIT = (-1.*LOG10(OUTPUT SIGNAL AND NOISE VALUE + 0.00005) -
      (-1.*LOG10(SIGNAL AND NOISE VALUE))/STANDARD DEVIATION
    CUMULATIVE PROBABILITY_LOWER = Value of CUMULATIVE_NORMAL_DISTRIBUTION
      at LOWER LIMIT
    CUMULATIVE PROBABILITY_UPPER = Value of CUMULATIVE_NORMAL_DISTRIBUTION
      at UPPER LIMIT
    CONDITIONAL PROBABILITY = CUMULATIVE_PROBABILITY_UPPER - CUMULATIVE_PROBABILITY_LOWER
  End
End

Realized in:
SNPDF3 FORTRAN
Minispec 3.5.2 - Construct Joint Probability Distribution (paper)

Input: conditional_probability_distribution
       signal_and_noise_pdf

Output: joint_probability_distribution

Description:
For all SIGNAL_AND_NOISE_LEVELS
Do
   For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
      Do
         JOINT_PROBABILITY = SIGNAL_PROBABILITY*CONDITIONAL_PROBABILITY
      End
   End
End

Realized in:
SNPDF3 FORTRAN
Minispec 3.5.3 - Construct Output Probability Distribution (paper)

Input: joint_probability_distribution

Output: signal_and_noise_pdf

Description:

For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
Do
  For all SIGNAL_AND_NOISE_LEVELS
  Do
    SIGNAL_AND_NOISE_PROBABILITY = SIGNAL_AND_NOISE_PROBABILITY + JOINT_PROBABILITY
  End
End

For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
Do
  SIGNAL_AND_NOISE_LEVELS = OUTPUT_SIGNAL_AND_NOISE_LEVELS
End

Realized in:
SNPDF3 FORTRAN
Minispec 3.5.4 - Determine Additional Variance (paper)

Input: signal and noise statistics
       signal and noise_pdf

Output: signal and noise statistics
        NOISE_ADDITIONAL_VARIANCE

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
   SUM OF X = SUM OF X + SIGNAL_AND_NOISE VALUE*SIGNAL AND NOISE PROBABILITY
   SUM OF XX = SUM OF XX + SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_PROBABILITY
End

NEW_SIGNAL_AND_NOISE_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X
NOISE_ADDITIONAL_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE - SIGNAL_AND_NOISE_VARIANCE
SIGNAL_AND_NOISE_MEAN = SUM_OF_X
SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
SNPDF3 FORTRAN
Minispec 3.5.5 - Determine Noise Spectrum (paper)

Input:  
NOISE_ADDITIONAL_VARIANCE  
paper_power_spectral_shape

Output: noise_spectrum

Description:

If paper_power_spectral_shape = bandlimited_white_noise then
For all FREQUENCIES
Do  
NOISE_POWER = (2 * PI * NOISE_ADDITIONAL_VARIANCE)/(2.*CUTOFF_FREQUENCY)
End

Else If paper_power_spectral_shape = triangular then
Do  
CONSTANT_TRIANGULAR = (2 * PI * NOISE_ADDITIONAL_VARIANCE/CUTOFF_FREQUENCY)

For all FREQUENCIES
Do  
NOISE_POWER = CONSTANT_TRIANGULAR-(CONSTANT_TRIANGULAR/(CUTOFF_FREQUENCY))*FREQUENCY
End
End

Else If paper_power_spectral_shape = exponential then
Do  
CONSTANT_EXP_1 = 4.604/CUTOFF_FREQUENCY
CONSTANT_EXP_2 = CONSTANT_EXP_1 * 2 * PI * NOISE_ADDITIONAL_VARIANCE/2.

For all FREQUENCIES
Do  
NOISE_POWER = CONSTANT_EXP_2*EXP(-1.*CONSTANT_EXP_1*FREQUENCY)
End
End

Realized in:
SNP2 FORTRAN
Minispec 3.5.6 - Add Noise Spectrum to Signal and Noise Spectrum (paper)

Input:     noise_spectrum
           signal_and_noise_spectrum

Output:    signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
  SIGNAL_AND_NOISE_POWER = SIGNAL_AND_NOISE_POWER + NOISE_POWER
End

Realized in:
SNP2 FORTRAN
Minispec 4.1.1.1 - Determine Adaptation Level

Input:  
SURROUND LIGHT LEVEL  
SIGNAL_AND_NOISE_MEAN

Output:  
ADAPTATION_LEVEL

Description:

\[ \text{ADAPTATION LEVEL} = \text{SURROUND LIGHT LEVEL} \times \text{SIGNAL AND NOISE MEAN} \]
\[ \text{ADAPTATION LEVEL} = \text{ADAPTATION LEVEL} \times 3.426 \]

Realized in:
HVS1 FORTRAN
Minispec 4.1.1.2 - Determine Pupil Diameter

Input: ADAPTATION_LEVEL

Output: PUPIL_DIAMETER

Description:

\[ PUPIL\_DIAMETER = (10^{0.8558-(4.01 \times 10^{-4})\times \log_{10}(ADAPTATION\_LEVEL) + 7.597^{3.3}) + 0.3 \]

If PUPIL_DIAMETER is less than 2.0
Then PUPIL_DIAMETER = 2.0

\[ PUPIL\_DIAMETER = PUPIL\_DIAMETER \times (1 \times 10^{-3}) \]

Realized in:
HVS1 FORTRAN
Minispec 4.1.1.3 - Determine Retinal Illuminance

Input:  
PUPIL_DIAMETER
ADAPTATION_LEVEL

Output:  
RETINAL_ILLUMINANCE

Description:
RETINAL_ILLUMINACE = 3.14159 * ((1000 * PUPIL_DIAMETER/2.)**2) * ADAPTATION_LEVEL

Realized in:
HVS1 FORTRAN
Minispec 4.1.1.4 - Determine Integration Time

Input: PUPIL DIAMETER
       RETINAL ILLUMINANCE

Output: INTEGRATION TIME

Description:
INTEGRATION TIME = -(LOG10(RETINAL ILLUMINANCE)/1.8) + 0.25
INTEGRATION TIME = ArcTan(INTEGRATION TIME)
INTEGRATION TIME = 0.09*0.5*(1.0 + INTEGRATION TIME) + 0.028

Realized in:
HVS1 FORTRAN
Minispec 4.1.2.1 - Determine Sampling Aperture MTF

Input: RETINAL_ILLUMINANCE
Output: hvs sample mtf, APERTURE_LENGTH_CONSTANT

Description:

APERTURE_LENGTH_CONSTANT = 0.0375 * EXP (- (LOG10(RETINAL_ILLUMINANCE) = 3.37/3.0))

If APERTURE_LENGTH_CONSTANT is less than 0.00475
Then APERTURE_LENGTH_CONSTANT = 0.00475

If APERTURE_LENGTH_CONSTANT is greater than 0.0375
Then APERTURE_LENGTH_CONSTANT = 0.0375

For all EYE_FREQUENCIES
Do
    HVS_SAMPLING_MODULATION_TRANSFER = (((2.*3.14159*APERTURE_LENGTH_CONSTANT*EYE_FREQUENCY**2) + 1)**(-1.5)
End

Realized in:
HVS1 FORTRAN
Minispec 4.1.2.2 - Determine Neural MTF

Input: RETINAL ILLUMINANCE 
       ADAPTATION LEVEL 
       neural_mtf_data

Output: hvs_neural_mtf

Description:
For the RETINAL_ILLUMINANCE and ADAPTATION_LEVEL
Interpolate neural_mtf_data to obtain hvs_neural_mtf

Determine PEAK VALUE MTF for hvs_neural_mtf

For all EYE_FREQUENCIES
Do
   HVS_NEURAL_MODULATION_TRANSFER = HVS_NEURAL_MODULATIONTRANSFER/PEAK_VALUE_MTF
End

Realized in:
HVS1 FORTRAN
Minispec 4.1.2.3 - Determine Pupil MTF

Input:  
PUPIL_DIAMETER
pupil_mtf.data

Output:  
hvs_pupil_mtf

Description:
Interpolate hvs_pupil_mtf from pupil_mtf.data for PUPIL_DIAMETER

Realized in:
HVS1 FORTRAN
Minispec 4.1.2.4 - Adjust MTFs for Viewing Distance

Input:  
- hvs_sampling.mtf
- hvs_neural.mtf
- hvs_pupil.mtf
- VIEWING_DISTANCE

Output:  
- hvs_sampling.mtf
- hvs_neural.mtf
- hvs_pupil.mtf

Description:

\[
\text{VIEWING\_SCALE\_FACTOR} = (\text{ArcSin}((1./(1. + \text{VIEWING\_DISTANCE}\times1000.)**2)))^{0.5}
\]

\[
\text{VIEWING\_SCALE\_FACTOR} = \text{VIEWING\_SCALE\_FACTOR}\times180/3.14159
\]

For all EYE\_FREQUENCIES
Do
  EYE\_FREQUENCIES = EYE\_FREQUENCIES \times \text{VIEWING\_SCALE\_FACTOR}
End

Realized in:
HVS1 FORTRAN
Minispec 4.1.3.1 - Determine Quantum Noise

Input: ADAPTATION LEVEL
       PUPIL DIAMETER
       INTEGRATION_TIME

Output: quantum_noise

Description:

For all SIGNAL_AND_NOISE_LEVELS
Do
   FOOT_LAMBERTS = SIGNAL_AND_NOISE_LEVEL * ADAPTATION_LEVEL
   CANDELAS_PER_SQUARE_METER = FOOT_LAMBERTS * 3.426
   RETINAL_ILLUMINANCE = 3.14159*((1000.*PUPIL_DIAMETER/2)**2)*CANDELAS_PER_SQUARE_METER
   PHOTON_FLUX = RETINAL_ILLUMINANCE * 0.000525/(0.786 * 4.432 x 10^{-13})
   PHOTONS = (0.1*INTEGRATION_TIME*(2.*3.14159*(APERTURE_LENGTH_CONSTANT**2)*PHOTON_FLUX)
   PHOTON_NOISE = PHOTONS**0.5
   F_NOISE = PHOTON_NOISE/(INTEGRATION_TIME*(2.*3.14159*(APERTURE_LENGTH_CONSTANT**2)*0.1)
   T_NOISE = F_NOISE*0.7868*(4.432 x 10^{-13}))/0.000525
   HVS_SIGMA = C_NOISE/(3.426 * FOOT_LAMBERTS)
End

Realized in:
HVS1 FORTRAN
Minispec 4.1.3.2 - Determine Neural Noise

Input: SIGNAL_AND_NOISE_MEAN

Output: NEURAL_NOISE

Description:
NEURAL_NOISE = 0.003162278*SIGNAL_AND_NOISE_MEAN

Realized in:
HVS1 FORTRAN
Minispec 4.1.3.3 - Combine Noise Sources

Input: quantum noise
       NEURAL_NOISE

Output: hvs noise

Description:

For all SIGNAL AND NOISE LEVELS
Do
   HVS.SIGMA = QUANTUM.SIGMA + NEURAL_NOISE
End

Realized in:
HVS1 FORTRAN
Minispec 4.2.1.1 Modify Spectra for HVS Sampling MTF

Input:  
- hvs_sampling.mtf
- signal_spectrum
- signal_and_noise_spectrum

Output:  
- signal_spectrum
- signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
  SIGNAL POWER = HVS_SAMPLING_MODULATIONTRANSFER**2 * SIGNAL POWER
  SIGNAL AND NOISE POWER = HVS_SAMPLING_MODULATIONTRANSFER**2 * SIGNAL_AND_NOISE POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.1.2 - Calculate New Variances (HVS Sampling)

Input:  
signal_spectrum  
signal_and_noise_spectrum  
signal_and_noise_statistics  
signal_statistics

Output:  
signal_and_noise_statistics  
signal_statistics  
variance_factors

Description:

NEW_SIGNAL_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_SPECTRUM)

NEW_SIGNAL_AND_NOISE_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_AND_NOISE_SPECTRUM)

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Im4221ec 4.2.1.3 - Modify PDFs for New Variances (HVS Sampling)

Input:  
variance_factors  
signal_statistics  
signal_and_noise_statistics  
signal_pdf  
signal_and_noise_pdf  

Output:  
signal_pdf  
signal_and_noise_pdf  

Description:  
For all SIGNAL_LEVELS  
Do  
    SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)  
End  

For all SIGNAL_AND_NOISE_LEVELS  
Do  
    SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)  
End  

Realized in:  
MTFMD1 FORTRAN
Minispec 4.2.2.1 - Modify Spectra for HVS Neural MTF

Input: hvs.neural.mtf
       signal_spectrum
       signal_and_noise_spectrum

Output: signal_spectrum
        signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
   SIGNAL_POWER = HVS_SAMPLING_MODULATION_TRANSFER**2 * SIGNAL_POWER
   SIGNAL_AND_NOISE_POWER = HVS_SAMPLING_MODULATION_TRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.2.2 - Calculate New Variances (HVS Neural)

Input: signal_spectrum
       signal_and_noise_spectrum
       signal_and_noise_statistics
       signal_statistics

Output: signal_and_noise_statistics
        signal_statistics
        variance_factors

Description:

NEW_SIGNAL_VARIANCE = 2. * Integral (SIGNAL_SPECTRUM)

NEW_SIGNAL_AND_NOISE_VARIANCE = 2. * Integral (SIGNAL_AND_NOISE_SPECTRUM)

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.2.3  Modify PDFs for New Variances (HVS Neural)

Input:    variance_factors
            signal_statistics
            signal_and_noise_statistics
            signal_pdf
            signal_and_noise_pdf

Output:   signal_pdf
            signal_and_noise_pdf

Description:
For all SIGNAL_LEVELS
Do
    SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE_LEVELS
Do
    SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.3.1 - Modify Spectra for HVS Pupil MTF

Input:  hvs_pupil.mtf
         signal_spectrum
         signal_and_noise_spectrum

Output:  signal_spectrum
         signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
   SIGNAL_POWER = HVS_SAMPLING_MODULATIONTRANSFER**2 * SIGNAL_POWER
   SIGNAL_AND_NOISE_POWER = HVS_SAMPLING_MODULATIONTRANSFER**2 * SIGNAL_AND_NOISE_POWER
End

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.3.2 - Calculate New Variances (HVS Pupil)

Input:  
- signal spectrum
- signal_and_noise_spectrum
- signal_and_noise_statistics
- signal_statistics

Output:  
- signal_and_noise_statistics
- signal_statistics
- variance_factors

Description:

NEW_SIGNAL_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_SPECTRUM)

NEW_SIGNAL_AND_NOISE_VARIANCE = 2. * (1/(2*PI)) * Integral (SIGNAL_AND_NOISE_SPECTRUM)

SIGNAL_VARIANCE_FACTOR = NEW_SIGNAL_VARIANCE/SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE_FACTOR = NEW_SIGNAL_AND_NOISE_VARIANCE/SIGNAL_AND_NOISE_VARIANCE

SIGNAL_VARIANCE = NEW_SIGNAL_VARIANCE

SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
MTFMD1 FORTRAN
Minispec 4.2.3.3 - Modify PDFs for New Variances (HVS Pupil)

Input: variance_factors
       signal_statistics
       signal_and_noise_statistics
       signal_pdf
       signal_and_noise_pdf

Output: signal_pdf
        signal_and_noise_pdf

Description:
For all SIGNAL_LEVELS
Do
   SIGNAL_LEVEL = SIGNAL_VARIANCE_FACTOR*(SIGNAL_LEVEL - SIGNAL_MEAN)
End

For all SIGNAL_AND_NOISE_LEVELS
Do
   SIGNAL_AND_NOISE_LEVEL = SIGNAL_AND_NOISE_FACTOR*(SIGNAL_AND_NOISE_LEVEL - SIGNAL_AND_NOISE_MEAN)
End

Realized in:
MTFMD1 FORTRAN
Minispec 4.3.1 - Construct Conditional Probability Distribution (HVS)

Input:  

hvs.noise

Output:  

conditional_probability_distribution

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
  STANDARD DEVIATION = Value of HVS SIGMA at SIGNAL_AND_NOISE_VALUE
  For all OUTPUT SIGNAL_AND_NOISE_VALUES
  Do
    LOWER LIMIT = ((OUTPUT SIGNAL_AND_NOISE_VALUE - 0.00005) - SIGNAL_AND_NOISE_VALUE)/HVS.SIGMA
    UPPER LIMIT = ((OUTPUT SIGNAL_AND_NOISE_VALUE + 0.00005) - SIGNAL_AND_NOISE_VALUE)/HVS.SIGMA
    CUMULATIVE_PROBABILITY_LOWER = Value of CUMULATIVE_NORMAL_DISTRIBUTION at LOWER LIMIT
    CUMULATIVE_PROBABILITY_UPPER = Value of CUMULATIVE_NORMAL_DISTRIBUTION at UPPER LIMIT
    CONDITIONAL_PROBABILITY = CUMULATIVE_PROBABILITY_UPPER - CUMULATIVE_PROBABILITY_LOWER
  End
End

Realized in:
SNPDF3 FORTRAN
Minispec 4.3.2 - Construct Joint Probability Distribution (HVS)

Input:  
conditional probability distribution  
signal and noise pdf

Output:  
joint probability distribution

Description:
For all SIGNAL_AND_NOISE_LEVELS
Do
  For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
  Do
    JOINT_PROBABILITY = SIGNAL_PROBABILITY*CONDITIONAL_PROBABILITY
  End
End

Realized in:
SNPDF3 FORTRAN
Minispec 4.3.3 - Construct Output Probability Distribution (HVS)

Input: joint_probability_distribution

Output: signal_and_noise_pdf

Description:

For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
Do
   For all SIGNAL_AND_NOISE_LEVELS
   Do
      SIGNAL_AND_NOISE_PROBABILITY = SIGNAL_AND_NOISE_PROBABILITY + JOINT_PROBABILITY
   End
End

For all OUTPUT_SIGNAL_AND_NOISE_LEVELS
Do
   SIGNAL_AND_NOISE_LEVELS = OUTPUT_SIGNAL_AND_NOISE_LEVELS
End

Realized in:
SNPDF3 FORTRAN
Minispec 4.3.4 - Determine Additional Variance (HVS)

Input:  
signal_and_noise_statistics  
signal_and_noise_pdf

Output:  
signal_and_noise_statistics  
NOISE_ADDITIONAL_VARIANCE

Description:

For all SIGNAL_AND_NOISE_VALUES
Do
  SUM_OF_X = SUM_OF_X + SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_PROBABILITY
  SUM_OF_XX = SUM_OF_XX + SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_VALUE*SIGNAL_AND_NOISE_PROBABILITY
End

NEW_SIGNAL_AND_NOISE_VARIANCE = SUM_OF_XX - SUM_OF_X*SUM_OF_X
NOISE_ADDITIONAL_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE - SIGNAL_AND_NOISE_VARIANCE
SIGNAL_AND_NOISE_MEAN = SUM_OF_X
SIGNAL_AND_NOISE_VARIANCE = NEW_SIGNAL_AND_NOISE_VARIANCE

Realized in:
SNPDF3 FORTRAN
Minispec 4.3.5 - Determine Noise Spectrum (HVS)

Input:
- NOISE_ADDITIONAL_VARIANCE
- hvs_power_spectral_shape

Output: noise_spectrum

Description:

If hvs_power_spectral_shape = bandlimited white_noise then
For all FREQUENCIES
  Do
    NOISE_POWER = (2 * PI * NOISE_ADDITIONAL_VARIANCE)/(2.*CUTOFF_FREQUENCY)
  End

Else If hvs_power_spectral_shape = triangular then
  Do
    CONSTANT_TRIANGULAR = (2 * PI * NOISE_ADDITIONAL_VARIANCE/CUTOFF_FREQUENCY)
    For all FREQUENCIES
      Do
        NOISE_POWER = CONSTANT_TRIANGULAR-(CONSTANT_TRIANGULAR/(CUTOFF_FREQUENCY))*FREQUENCY
      End
    End

Else If hvs_power_spectral_shape = exponential then
  Do
    CONSTANT_EXP_1 = 4.604/CUTOFF_FREQUENCY
    CONSTANT_EXP_2 = CONSTANT_EXP_1*2*PI*NOISE_ADDITIONAL_VARIANCE/2.
    For all FREQUENCIES
      Do
        NOISE_POWER = CONSTANT_EXP_2*EXP(-1.*CONSTANT_EXP_1*FREQUENCY)
      End
    End

Realized in:
SNP2 FORTRAN
Minispec 4.3.6 - Add Noise Spectrum to Signal and Noise Spectrum (paper)

Input:       noise spectrum
             signal_and_noise_spectrum

Output:     signal_and_noise_spectrum

Description:
For all FREQUENCIES
Do
    SIGNAL_AND_NOISE_POWER = SIGNAL_AND_NOISE_POWER + NOISE_POWER
End

Realized in:
SNP2 FORTRAN
Minispec 4.4 - Calculate HVS Information Theoretic Metrics

Input:  
- signal_spectrum
- signal_and_noise_spectrum

Output:  INFORMATION_CONTENT

Description:
Integrate
\[ \pi \cdot \text{FREQUENCY} \cdot \log_2(\text{SIGNAL AND NOISE POWER}/(\text{SIGNAL AND NOISE POWER} - \text{SIGNAL POWER})) \]

to obtain INFORMATION_CONTENT

Realized in:
INFO1 FORTRAN
ADAPTATION-LEVEL = * light level to which the eye is adapted to *

APERTURE-LENGTH-CONSTANT = * constant for sampling aperture *

CAMERA-EXPOSURE-POINT = * Relative exposure level which the camera would expose an 18% gray card *

CUTOFF-FREQUENCY = * Frequency where power is 0 for band limited white and triangular, and 1% for exponential *

INFORMATION-CONTENT = * the integral of
\[ p^T(s_{signal-noise-spectrum}/noise-spectrum) \cdot f \], result is in bits per square mm *

INTEGRATION-TIME = * The integration for the human visual system *

MAGNIFICATION = * magnification of image from film stage to paper stage *

NEURAL-NOISE = * Noise generated from the neural component of the human visual system *

NOISE-ADDITIONAL-VARIANCE = * Additional variance in signal and noise pdf/spectrum due to noise *

PRINTER-EXPOSURE-POINT = * Point in relative log exposure to the paper that the mean of the film image will be printed *

PUPIL-DIAMETER = * Diameter of pupil after allowance for adapted light level *

RETINAL-ILLUMINANCE = * Illuminance at the retina *

SCENE-MEAN = * Mean of input scene, ranges from 0 to 1 relative log exposure *

SCENE-MODULATION = * Variance divided by mean *

SCENE-VARIANCE = * Variance of input signal in terms of relative log exposure units *

SIGNAL-AND-NOISE-MEAN = * Mean of signal with noise *

SIGNAL-AND-NOISE-VARIANCE = * Variance of signal with noise *

SIGNAL-AND-NOISE-VARIANCE-FACTOR = * new signal and noise variance / old signal and noise variance *

SIGNAL-MEAN = * Mean of signal *

SIGNAL-VARIANCE = * Variance of signal *

SIGNAL-VARIANCE-FACTOR = * new signal variance/old signal variance *

SURROUND-LIGHT-LEVEL = * Light level in foot-lamberts of the surround *
VIEWING-DISTANCE = * Viewing distance from print to subject (in meters) *

band-limited-white-noise = NOISE-POWER + FREQUENCIES
* noise will be constant from 0 to cutoff frequency *

camera-lens-mtf = [lens-mtf-equation | mtf-file]

camera-parameters = camera-lens-mtf + MAGNIFICATION + CAMERA-EXPOSURE-POINT

conditional-probability-distribution = SIGNAL-AND-NOISE-VALUES + CONDITIONAL-PROBABILITY
* Probability of noise given input values *

cumulative-distributions = INTERMEDIATE-SIGNAL-VALUES + CUMULATIVE-SIGNAL-PROBABILITY + CUMULATIVE-SIGNAL-AND-NOISE-PROBABILITY

dlogE-arctan-function = DENSITY + LOGEVALUE
* DlogE based on the ARCTAN function *

dlogE-datafile = DENSITY + LOGEVALUE
* DlogE data from a file *

dlogE-straight-line = DENSITY + LOGEVALUE
* straight line dlogE with a D-min, D-max and a gamma (slope) from D-min to D-max *

exponential-noise = NOISE-POWER + FREQUENCIES  * Noise has an exponential shape with 1% of DC power at the cutoff frequency *

eye-parameters = PUPIL-DIAMETER + RETINAL-ILLUMINANCE + INTEGRATION-TIME + ADAPTATION-LEVEL

film-dlogE-curve = [dlogE-straight-line | dlogE-arctan-function | dlogE-datafile]

film-granularity-curve = [granularity-equation | granularity-file]

film-mtf = [mtf-equation | mtf-file]

film-power-spectral-shape = [band-limited-white-noise | triangular-noise | exponential-noise] + CUTOFF-FREQUENCY

granularity-equation = GRANULARITY + SIGNAL-AND-NOISE-VALUE
* granularity as a function of signal-and-noise-value which was converted from density - based on an equation *

granularity-file = GRANULARITY + SIGNAL-AND-NOISE-VALUE
* granularity as a function of signal-and-noise-value which was converted from density *

human-visual-system-parameters = hvs-power-spectral-shape + hvs-mtf-data

hvs-mtf-data = neural-mtf-data + pupil-mtf-data

hvs-mtfs = hvs-sampling-mtf + hvs-neural-mtf + hvs-pupil-mtf
hvs-neural-mtf = HVS-NEURAL-MODULATION-TRANSFER + FREQUENCIES
hvs-noise = HVS-SIGMA + SIGNAL-AND-NOISE-LEVELS

hvs-power-spectral-shape = [band-limited-white-noise | triangular-noise | exponential-noise]

hvs-pupil-mtf = HVS-PUPIL-MODULATION-TRANSFER + FREQUENCIES
hvs-sampling-mtf = HVS-SAMPLING-MODULATION-TRANSFER + FREQUENCIES

* Results from passing PDFs through DlogE curve... needs to be converted to proper PDFs *

joint-probability-distribution = SIGNAL-AND-NOISE-LEVELS + OUTPUT-SIGNAL-AND-NOISE-LEVELS + JOINT-PROBABILITY
* P(y|x)P(x)  Conditional probability x input probabilities *
lens-mtf-equation = MODULATION-TRANSFER + FREQUENCY
* from diffraction limited equation *

mtf-equation = MODULATION-TRANSFER + FREQUENCY
* Gaussian MTF based on sigma *

mtf-file = MODULATION-TRANSFER + FREQUENCY
* mtf from a data file *

neural-mtf-data = NEURAL-MODULATION-TRANSFER + HVS-FREQUENCIES
* data is a function of adaptation level *

noise-spectrum = NOISE-POWER + FREQUENCIES
* Estimated noise power spectrum from any component *

paper-dloge-curve = [dloge-straight-line | dloge-arctan-function | dloge-datafile]
paper-granularity-curve = [granularity-equation | granularity-file ]
paper-mtf = [mtf-equation | mtf-file]
paper-parameters = paper-mtf + paper-granularity-curve + paper-dloge-curve + paper-power-spectral-shape

paper-power-spectral-shape = [band-limited-white-noise | triangular-noise | exponential-noise] + CUTOFF-FREQUENCY

pdfs/spectra = signal-pdf/spectrum + signal-and-noise-pdf-spectrum

printer-lens-mtf = [lens-mtf-equation | mtf-file]
printer-parameters = printer-lens-mtf + PRINTER-EXPOSURE-POINT

pupil-mtf-data = PUPIL-MODULATION-TRANSFER + HVS-FREQUENCIES
* data is a function of pupil-diameter *

quantum-noise = HVS-SIGMA + SIGNAL-AND-NOISE-LEVELS
* Human visual system noise resulting from quantum aspects of the
scene-parameters = SCENE-MEAN + SCENE-MODULATION + spectral-shape-parameters

signal-and-noise-pdf = SIGNAL-AND-NOISE-PROBABILITIES + SIGNAL-AND-NOISE-VALUES
* Probability density function of signal with noise included *


signal-and-noise-spectrum = SIGNAL-AND-NOISE-POWER + FREQUENCIES
* Signal and noise power spectrum *


signal-pdf = SIGNAL-PROBABILITIES + SIGNAL-VALUES
* Probability density function of signal *

signal-spectrum = SIGNAL-POWER + FREQUENCIES
* Signal Power spectrum *

signal-statistics = SIGNAL-MEAN + SIGNAL-VARIANCE

spectral-shape-parameters = HALF-POWER + CORRELATION
* these parameters are used in the function \( P = \frac{1}{B^{**N}} + F^{**N} \) where \( B = \) half power, \( N = \) correlation, \( F = \) frequency *

triangular-noise = NOISE-POWER + FREQUENCIES
* noise is triangular in shape from 0 to the cutoff frequency *
variance-factors = SIGNAL-VARIANCE-FACTOR
+ SIGNAL-AND-NOISE-VARIANCE-FACTOR

viewing-conditions = SURROUND-LIGHT-LEVEL + VIEWING-DISTANCE
APPENDIX B

SOURCE PROGRAM LISTING

The following pages contain the source listing in alphabetical order for the program IQCN1. The following table of contents describes each subroutine briefly:

**EXECs for IBM-CMS Operating System**

IQCN1   Sets up file definitions and runs program

**FORTRAN Programs for IBM-CMS Operating System**

IQCN1   Main line program

GETSYS   Obtains title, plot types

SCENE2   Prompts user for description of input scene, creates pdf, spectra and statistics.

Calls:
CAMFL1   Cascades the effect of the camera lens and film
PRTPA1   Cascades the effect of printer lens and paper
HVS1     Cascades the effect of the human visual system
INFO1    Calculate Information Theoretic Metrics
PDFPL1   Plots probability density function
SPTPL1   Plot power spectrum

CAMFL1   Calls:
LNSMT1   Obtains lens MTF
GAUMT1   Obtains photographic material MTF
MTFMD1   modifies pdf/spectra for MTF
GETDLH   Obtains DlogE curve
DLHMD2   Modifies pdf/spectra for DlogE
GRAN1    Obtains granularity data
GRNMD1   Modifies pdf/spectra for granularity
OUTSPT   Outputs Spectra to a file for later analysis
OUTPDF   Outputs PDFs to a file for later analysis
OUTMTF   Outputs MTFs to a file for later analysis
OUTDLH   Outputs DlogH curves to a file for later analysis
OUTGRN   Outputs granularity data to a file for later analysis

PRTPA1   Calls:
LNSMT1   Obtains lens MTF
GAUMT1   Obtains photographic material MTF
MTFMD1   modifies pdf/spectra for MTF
GETDLH   Obtains DlogE curve
DLHMD2   Modifies pdf/spectra for DlogE
GRAN1    Obtains granularity data
GRNMD1   Modifies pdf/spectra for granularity
HVS1
Calls:
MTFMD1 modifies pdf/spectra for MTF
GRNMD1 Modifies pdf/spectra for noise

PDFPL1 Calls
PLTXY2 Plots data

SPTPL1 Calls
PLTXY2 Plots data

LNSMTF1 Calls:
RDMTF1 Reads MTF from file
FINT Interpolates data
ASKI Prompts user for input

GAUMT1 Calls:
RDMTF1 Reads MTF from file

GETDLH Calls:
FINT Interpolates data

GRAN1 Calls:
FINT Interpolates data

GRNM1 Calls:
SNPDF3 Modifies PDF for granularity
SNP2 Calculates noise spectrum and adds to signal+noise

DLHMD2 Calls:
PDFUNL Renormalizes distribution

Page B-2
SUBROUTINE CAMFL1

Purpose: To Modify the PDFs/SPECTRA for the effects of Camera
lens MTF, film MTF, film granularity and film DlogH response.

Main Program: IQCN1

Subroutines called: ASKI LNSMT1 MTFMD1 CLEAR GAUMT1 GETDLH DLHMD2 GRAN1 GRNMD1

Passed variables: NONE

Commoned data:
COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMean
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/SYSVAR/XMAG
COMMON/SAMP/HCUT, NB

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL HMTF(100), BD(21), HDBIN(10000)
REAL FLOFH(61), FDENS(61)

CHARACTER*80 QUE
CHARACTER*30 IDENT
INTEGER TYPE, CHANGE, SKIP

C OBTAIN MAGNIFICATION TO NEXT STAGE INFORMATION

XMAG = 3.88
WRITE(6,*) '** Enter Magnification to next stage'
WRITE(6,10) XMAG

10 FORMAT(' ',DEFAULT: Magnification = ',F5.2)
WRITE(6,*), 'CHANGE? 1-yes 0-no'
QUE = '---'
IDEF = 0
CALL ASKI(QUE, IDEF)

IF (IDEF.NE.0) THEN
  WRITE(6,*), 'Enter new magnification'
  READ (5,*), XMAG
ENDIF

WRITE(9,1000) XMAG

1000 FORMAT('0', 'Magnification to next stage : ',F5.2)

C OBTAIN CAMERA LENS MTF

WRITE(6,*) '** Camera Lens MTF Specification'
WRITE(9,1001)

1001 FORMAT('0', 'Camera Lens MTF Specification')

CALL LNSMT1(HMTF, XMAG, 8.0)

C WRITE OUT DATA

IDENT = 'CAMERA LENS MTF'
CALL OUTMTF(IDENT, XMAG, HMTF)

C MODIFY INPUT SIGNAL SPECTRA/PDF AND INPUT SIGNAL+NOISE SPECTRA AND PDF FOR MTF. THE SPECTRA IS FILTERED BY THE MTF AND THE PDF VARIANCE IS SCALED TO MATCH THE INTEGRAL OF THE SPECTRA

CALL MTFMD1(HMTF, HCUT)

C OUTPUT PDF AND SPECTRA

IDENT = 'AFTER CAMERA LENS MTF'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C OBTAIN FILM MTF RESPONSE

CALL CLEAR
WRITE(6,*) '** Film MTF specification'
WRITE(9,1002)

1002 FORMAT('0', 'Film MTF Specification')
CALL GAUMT1(250.,HMTF,XMAG)

C OUTPUT FILM MTF DATA
IDENT = 'FILM MTF'
CALL OUTMTF(IDENT,XMAG,HMTF)

C MODIFY SPECTRA AND PDF FOR FILM MTF
CALL MTFMD1(HMTF,HCUT)

C OUTPUT PDF AND SPECTRA
IDENT = 'AFTER FILM MTF'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C OBTAIN FILM DLOGH CHARACTERISTIC
CALL GETDLH(1.0,6.0,3.0,1.4,FLOGH,FDENS,EXPPT)

C OUTPUT DLOGH DATA TO A FILE
IDENT = 'FILM DLOGH'
CALL OUTDLH(IDENT,FLOGH,FDENS,EXPPT)

C TRANSFORM PDF THROUGH DLOGH CURVE AND MODIFY SPECTRA FOR CHANGE IN CAM015
C VARIANCE
CALL DLHMD2(FLOGH,FDENS,EXPPT)

C OUTPUT PDF AND SPECTRA
IDENT = 'AFTER FILM DLOGH'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C OBTAIN FILM GRANULARITY INFORMATION
WRITE(6,*) '** Film granularity specification'
RMAG = 3.88
CALL GRAN1(1,XMAG,RMAG,0.,1.0,0.01)

C WRITE OUT GRANULARITY DATA
IDENT = 'FILM GRANULARITY'
CALL OUTGRN(IDENT,XMAG)

C MODIFY PDF/SPECTRA FOR NOISE
CALL GRNM1(XMAG)

C OUTPUT PDF AND SPECTRA
IDENT = 'AFTER FILM GRANULARITY'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

WRITE(6,*) 'Completed Camera/Film Calculations'

RETURN
END
SUBROUTINE CLIP1(ELOW, EHIGH, CODE, HCUT) 

Purpose: To clip signal and signal & Noise PDFs. Packing 
Clipped values in the lowest and highest bins available 
Calculate news statistics and noise power spectra. 

Main Program: IQCN1

Subroutines called:
TRUN1

Passed variables:
ELOW = 
EHIGH = 
CODE = 
HCUT = 

Commoned data:
HSIGNAL: HSP = Spectrum of signal 
HSIGNAL: HSPDF = PDF of signal 
HSIGNAL: HSVAR = Signal variance 
HSIGNAL: HSMEAN = Signal mean 
HSIGNAL: HSANDN: HSNP = Spectrum of signal and noise 
HSIGNAL: HSNPDF = PDF of signal and noise 
HSIGNAL: HSNVAR = Signal and noise variance 
HSIGNAL: HSNMEN = Signal and noise mean 
INDVAR: HSBIN = Value of signal for PDF 
INDVAR: HSNBIN = Values of signal with noise for S+N PDF 
FREQ = Frequencies for spectra 
SWGT = Frequencies for spectra 
TYPE = Frequencies for spectra 

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COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN 
COMMON/HSANNDN/HSNP, HSNPDF, HSNVAR, HSNMEN 
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE 

REAL HSP(100), HSPDF(10000) 
REAL HSNP(100), HSNPDF(10000) 
REAL HSBIN(100), HSNBIN(10000) 
REAL FREQ(100), SWGT(2) 
REAL MEAN 

INTEGER TYPE, CODE, TEST 

HFAC=1./(2.*HCUT) 
TEST=CODE*(CODE-1)
IF(TEST.EQ.O) THEN
  MEAN=HSMEAN
  VAR=HSVAR
  CALL TRUN1(HSBIN,HSPDF,MEAN,VAR,ELOW,EHIGH)
  WRITE(6,*) ELOW,EHIGH,HSMEAN,MEAN,HSVAR,VAR
  DO 10 I=1,100
    HSP(I)=HSP(I)-(HSVARI-VAR)*HFAC
    IF(HSP(I).LT.0.0) HSP(I)=0.0
  CONTINUE
  HSMEAN=MEAN
  HSMAR=VAR
ENDIF
C
C TEST=CODE*(CODE-3)
IF(TEST.EQ.O) THEN
  MEAN=HSMEN
  VAR=HSMVAR
  CALL TRUN1(HSNBIN,HSNPDF,MEAN,VAR,ELOW,EHIGH)
  DO 30 I=1,100
    HSNP(I)=HSNP(I)-(HSMVAR-VAR)*HFAC
    IF(HSNP(I).LT.0.0) HSNP(I)=0.0
  CONTINUE
  HSMEN=MEAN
  HSMVAR=VAR
ENDIF
C
RETURN
END
SUBROUTINE DEVICE (IDEV)

Purpose: To initialize plotting devices

Subroutines called:
CLEAR IBM32 BANGLE BSHIFT PAGE NOBRDR CMSFVS KRIOMG
ZETA QMS2 VT240

Several of these subroutines are part of DISSPLA library

Passed variables:
IDEV = device number (if 0, then user queried for device)

Commoned data:
NONE

CALL CLEAR IBM3279 (TERMINAL)

IF (IDEV.EQ.0) THEN
10 CONTINUE
WRITE(6,1000)
1000 FORMAT(' ENTER OUTPUT DEVICE CODE'/
 1 '0 ------ TERMINATE PROCESS'/
 2 '1 ------ IBM 3279 Terminal'/
 3 '2 ------ ZETA Plotter (3rd floor)'/
 4 '3 ------ QMS Laser Printer (1st floor)'/
 5 '4 ------ VT240 Emulation (?171 Protocol Converter)'/
 6 '5 ------ Tektronix 4105 emulator (?171 Converter)'/
READ(5,*) IDEV
IF (IDEV.LT.0 .OR. IDEV.GT.5) GO TO 10
ENDIF

IF (IDEV.EQ.0) STOP
IF (IDEV.EQ.1) THEN
CALL IBM32(3289,0,0)
ANG = 0.
XADD = 0.
YADD = 0.
XP = 11.
YP = 8.5
CALL BANGLE(ANG)
CALL BSHIFT(XADD,YADD)
CALL PAGE(XP,YP)
CALL NOBRDR

C
C--FOR ANY ZETA PLOTTER
C--CREATE OUTPUT FILE FOR DATA, CALL DRIVER, SET IDEV TO 5
C
ZETA PLOTTER

IF (IDEV.EQ.2) THEN
   CALL CPFVS('SP PRT RCS',NRC)
   CALL CPFVS('TAG DEV PRT P0164',NRC)
   CMS = 'FILEDEF 66 PRINT'
   CMS = 'FILEDEF 66 DISK $$ZETA$$ $$ZETA$$ Z'
   CALL CMSFVS(CMS,IERR)
   IRST = 1
   CALL KRIOMG(IRST,ISP,NAME,IFM,IPROT,IOUN,IMODEL,IRC)
   CALL ZETA (8,1,66)
   ANG=90.
   XADD=6.25
   YADD=-.75
   XP=8.5
   YP=11.
   CALL BANGLE(ANG)
   CALL BSHIFT(XADD,YADD)
   CALL PAGE(XP,YP)
   CALL NOBRDR
ENDIF

IF(IDEV.EQ.3) THEN
   CALL CPFVS('SP PRT RCS',NRC)
   CALL CPFVS('TAG DEV PRT P01CG',NRC)
   CMS = 'FILEDEF 97 PRINT (OPTCD J'
   CMS = 'FILEDEF 97 PRINT (OPTCD J'
   CALL CMSFVS(CMS,IERR)
   CALL KRIOMG(2,5,'$$QMS$$$$$$DATA$$Z',2,0,97,IMODL,IRC)
   IRST = 2
   ISP = 5
   NAME = '$$QMS$$$$$$DATA$$Z'
   IFM = 0
   IPROT = 0
   IOUN = 97
   CALL KRIOMG(IRST,ISP,NAME,IFM,IPROT,IOUN,IMODEL,IRC)
   CALL QMS2
   ANG=0.
   XADD=0.
   YADD=0.
   XP=11.
   YP=8.5
   CALL BANGLE(ANG)
   CALL BSHIFT(XADD,YADD)
   CALL PAGE(XP,YP)
   CALL NOBRDR
ENDIF
C VT240 EMULATION

IF (IDEV.EQ.4) THEN
  IRST = 2
  ISP = 0
  NAME = 'NONE'
  IFM = 0
  IPROT = 4
  IOUN = 0
  CALL KRIOMG(IRST,ISP,NAME,IFM,IPROT,IOUN,IMODEL,IRC)
  CALL VT240
  ANG = 0.
  XADD = 0.
  YADD = 0.
  XP = 11.
  YP = 8.5
  CALL BANGLE(ANG)
  CALL BSHIFT(XADD,YADD)
  CALL PAGE(XP,YP)
  CALL NOBRDR
ENDIF

C Tektronix 4105 emulation

IF (IDEV.EQ.5) THEN
  IRST = 2
  ISP = 0
  NAME = 'NONE'
  IFM = 0
  IPROT = 4
  IOUN = 0
  CALL KRIOMG(IRST,ISP,NAME,IFM,IPROT,IOUN,IMODEL,IRC)
  CALL TK41(4105)
  ANG = 0.
  XADD = 0.
  YADD = 0.
  XP = 11.
  YP = 8.5
  CALL BANGLE(ANG)
  CALL BSHIFT(XADD,YADD)
  CALL PAGE(XP,YP)
  CALL NOBRDR
ENDIF

C SUPPRESS MESSAGES
CALL SETDEV(0,0)
RETURN
END
SUBROUTINE DLHMD2(LOGH, DENS, EXPPT)

Purpose: To modify the PDF and SPECTRA for the Density-log exposure response

Subroutines called:
AIXDD PDFUNL

Passed variables:
LOGH = Log Exposure array
DENS = Density values corresponding to log exposure values
EXPPT = Point on DlogE curve that input signal’s mean is placed at

Commoned variables:
HSIGNL: HSP = Spectrum of signal
HSIGNL: HSPDF = PDF of signal
HSIGNL: HSVAR = Signal variance
HSIGNL: HSMEAN = Signal mean
HSANDN: HSNP = Spectrum of signal and noise
HSANDN: HSNPDF = PDF of signal and noise
HSANDN: HSNVAR = Signal and noise variance
HSANDN: HSNMEN = Signal and noise mean
INDVAR: HSBIN = Value of signal for PDF
INDVAR: HSNBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra
SYSVAR: XMAG = Magnification to next stage
SAMP: HCUT = Cutoff frequency
NB =

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COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/SYSVAR/XMAG
COMMON/SAMP/HCUT, NB

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL LOGH(61), DENS(61), DENS2(183)
REAL HSOUT1(10000), HSOUT2(10000), HSPDF1(10000), HSPDF2(10000)

INTEGER TYPE, CHANGE, SKIP, LOW, HIGH
REASSIGN DOGE CURVE TO ARRAY COMPATIBLE WITH ISEL Routines

DO 10 I = 1, 61
  DENS2(I) = DENS(I)

TRANSFORM EXPOSURE VALUES THROUGH DLOGE CURVES

DO 20 I = 1, 10000

PASS SIGNAL VALUES THROUGH CURVE

DIFF1 = LOG10(HSBIN(I)) - LOG10(HSMEAN)
BLOGE1 = EXPPT + DIFF1
CALL AIXDD (0, BLOGE1, DENS2, 4)

KEEP IN ASCENDING ORDER

HSOUT1(10000-I+1) = 10.**(-1.*BLOGE1)
HSPDF1(10000-I+1) = HSPDF(I)

PASS SIGNAL AND NOISE VALUES

DIFF2 = LOG10(HSINBIN(I)) - LOG10(HSNUMEN)
BLOGE2 = EXPPT + DIFF2
CALL AIXDD (0, BLOGE2, DENS2, 4)

KEEP IN ASCENDING ORDER

HSOUT2(10000-I+1) = 10.**(-1.*BLOGE2)
HSPDF2(10000-I+1) = HSINPDF(I)

CONTINUE

REASSIGN NEW VALUES TO COMMON ARRAYS FOR SIGNAL, SIGNAL AND NOISE

DO 30 I = 1, 10000
  HSPDF(I) = HSPDF1(I)
  HSINPDF(I) = HSPDF2(I)
  HSBIN(I) = HSOUT1(I)
  HSINBIN(I) = HSOUT2(I)

CONTINUE

RECALCULATE PDF SO THAT INTERVALS ARE EQUAL

CALL PDFUNL(CS, CSN)

RESCALE SPECTRUM BASED ON NEW VARIANCE VALUES

DO 40 I = 1, 100
  HSP(I) = HSP(I)*CS
  HSINP(I) = HSINPDF(I)*CSN

CONTINUE

WRITE(6,*) 'Finished Modification due to DlogE curve'
FILE: DLHMD2 FORTRAN AI

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PAUSE

RETURN

END
SUBROUTINE FINT(Y,X,XINT,YINT,NP,NPINT)

REAL Y(NP),X(NP),XINT(NPINT),YINT(NPINT)
INTEGER UV,LV

C START FROM BOTTOM OF ARRAY AND FIND NEIGHBORHOOD

UV=1
DO 100 I=1,NPINT
   DO 200 J=UV,NP
      IF (X(J).GT.XINT(I)) THEN
         UV=J
         LV=J-1
         GO TO 210
      END IF
   200 CONTINUE
C X VALUE TO INTERPOLATE IS LARGER THAN X ARRAY
JMI= J-1
IF (JMI.LT.1) JMI=1
YINT(I)= Y(JMI)
GO TO 100

210 IF (LV.LE.0) THEN
C X VALUE TO INTERPOLATE IS SMALLER THAN X ARRAY SET TO SMALLEST
C Y VALUE
YINT(I) = Y(1)
ELSE
C LINEAR INTERPOLATION
  SLOPE = (Y(UV) - Y(LV))/(X(UV) - X(LV))
  CEPT = Y(UV) - SLOPE*X(UV)
  YINT(I) = SLOPE*XINT(I) + CEPT
ENDIF
100 CONTINUE
RETURN
END
DOUBLE PRECISION FUNCTION FNC(FREQ)

Purpose: Calculate F(X) where F(X) = 1/(DB**N + X**N)

Subroutines called:
NONE

Passed variables:
FREQ = frequency

Commoned data:
SPEC:  A = parameter in equation
       B = parameter in equation
       N = parameter in equation

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COMMON/SPEC/A,B,N

REAL*8 FREQ,DB

DB=DBLE(B)
FNC=1/(DB**N+FREQ**N)

RETURN
END
SUBROUTINE GAUMT1(DSIG, HMTF, XMAG)

C**************************************************************
C SUBROUTINE GAUMT1
C
C Purpose: Obtain MTF data from a film or calculate from a
C gaussian function
C
C Subroutines called: ASK1 RDMTF1 FINT
C
C Passed variables:
C DSIG = Default sigma for gaussian MTF
C HMTF = MTF
C XMAG = magnification to next stage
C
C Commoned data:
C SPEC: A = parameter in equation
C B = parameter in equation
C N = parameter in equation
C
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C**************************************************************

COMMON /INDVAR/HSBIN,HSNBIN,FREQ,SWGT,TYPS

CHARACTER*80 QUE
REAL HMTF(IOO)
REAL HSBIN(IOO00),HSNBIN(IOO00)
REAL FREQ(IOO),SWGT(2)
REAL DFRQ(20),DMTF(20),XFINT(100)
INTEGER TYPE

1 WRITE(6,*),' from a FILE - 1'
WRITE(6,*),' from a FUNCTION - 2'
QUE = '='
IDEF = 2
CALL ASKI(QUE,IDEF)

IF (IDEF.NE.1.AND.IDEF.NE.2) GO TO 1
GO TO (100,200),IDEF

READ FROM FILE

100 CALL RDMTF1(DFRQ,DMTF)

DO 120 I=1,IOO
HMTF(I)=0.0
120 XFINT(I)=FREQ(I)*XMAG

CALL FINT(DMTF,DFRQ,XFINT,HMTF,20,IOO)
GO TO 999

200 WRITE(6,*) 'Gaussina MTF - Default XSIG = ',DSIG
WRITE(6,*) '** Change? 1-YES 0-NO'
QUE = '====>
IF (IQUE.EQ.0) THEN
   XSIG = DSIG
ELSE
   WRITE(6,*) 'ENTER NEW XSIG'
   READ(5,*) XSIG
ENDDIF

DO 210 I=1,100
   HMTF(I)=0.0
   XF=FREQ(I)
   XHF=(XF/XSIG)**2/2.
   IF(XHF.LE.23.0259) THEN
      HMTF(I)=EXP(-XHF)
   ELSE
      HMTF(I)=0.0
   ENDIF
   WRITE(9,*),I,FREQ(I),XF,HMTF(I)
210 CONTINUE

WRITE(9,1000)XSIG
1000 FORMAT('0','Gaussian MTF - Sigma = ',F6.2)

RETURN
END
SUBROUTINE GETDLH(ISTAGE, DGAMMA, DDMIN, DMAX, DEXPPT, LOGE, DENS, XEXPPT)

Purpose: Obtain the Density-log exposure relationship from either a function or a datafile. The function can either be a straight line or an arc tangent function.

Subroutines called:
CLEAR ASKI SEQOP2 FINT PLTLNH

Passed variables:
ISTAGE = Which stage
DGAMMA = Default gamma (slope) value
DDMIN = Default Dmin
DDMAX = Default Dmax
DEXPPT = Default Exposure point
LOGE = Array of Log Exposure values
DENS = Array of Density values at each LogE value
EXPT = Exposure point

Commoned data:
NONE

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character*80 QUE
character*8 FNAME, FTYPE, RECFM
real FLOG(21), FDEN(21)
real LOGE(61), DENS(61)

CALL CLEAR
1 WRITE(6,*) '** Density - Log Exposure specification'
WRITE(6,*) ' from a FILE - 1'
WRITE(6,*) ' from a FUNCTION (STRAIGHT LINE) - 2'
WRITE(6,*) ' from a FUNCTION (ARC TAN ) - 3'
QUE = '==='
IDENT = 2
CALL ASKI(QUE, IDENT)

IF (IDENT.NE.1.AND.IDENT.NE.2.AND.IDENT.NE.3) GO TO 1

GO TO (100, 200, 200), IDENT

C OBTAIN FILENAME AND FILETYPE, THEN OPEN FILE

100 WRITE(6,*) '** Enter Filename for datafile'
READ(5, fmt='(A8)') FNAME
WRITE(6,'*') '**  Enter Filetype for datafile'
READ(5,FMT='(A8)') FTYPE
RECFM = ' 
LUNIT = 20
CALL SEQOP2 (FNAME,FTYPE,LUNIT,RECFM,NERR)
IF (NERR.NE.0) THEN
    WRITE(6,'*') 'Error in opening file'
    GO TO 100
ENDIF
C
READ DATA FROM FILE 21 STEP

DO 110 I = 1,21
    READ(20,120) FLOG(I),FDEN(I)
 120    FORMAT(F5.2,1X,F5.2)
    FLOG(I) = FLOG(I) + 3.
 110    CONTINUE
CLOSE (UNIT=20)
C
INTERPOLATE TO A 61 STEP CURVE THAT IS 0 TO 4 LOGE

DO 130 I=1,61
    LOGE(I) = (I-1)*0.066666666
 130    CONTINUE
CALL FINT(FDEN,FLOG,LOGE,DENS,21,61)
WRITE(9,1000)FNAME,FTYPE
 1000 FORMAT(' ', 'Read DLogE data from file: ',A8,1X,A8)
GO TO 500
C
USE FUNCTIONS (STRAIGHT LINE CURVE)

WRITE(6,210) DGAMMA,DDMIN,DDMAX
 210 FORMAT(' ', '**  Defaults: GAMMA = ',F10.5,' DMIN = ',F10.5,
      X' DMAX = ',F10.5)
WRITE(6,'*') '** Change? 1-yes 0-no'
QUE = '*-->'
IDEF = 0
CALL ASKI(QUE,IDEF)
IF (IDEF.EQ.0) THEN
    GAMMA = DGAMMA
    DMIN = DDMIN
    DMAX = DDMAX
ELSE
    WRITE(6,'*') '** Enter new Gamma, Dmin, Dmax'
    READ(5,*) GAMMA,DMIN,DMAX
ENDIF
DO 240 I=1,61
LOGE(I) = (I-1)*0.066666666
DENS(I) = LOGE(I) * GAMMA
IF(DENS(I).LT.DMIN) DENS(I) = DMIN
IF(DENS(I).GT.DMAX) DENS(I) = DMAX

240 CONTINUE

WRITE(9,1001) GAMMA,DMIN,DMAX
1001 FORMAT('A,'/1X,'Straight Line Curve used for DlogE',
X/1X,'Gamma = ',F6.2,
X/1X,'D-Min = ',F6.2,
X/1X,'D-Max = ',F6.2)

C PLOT RESULTING CURVE

500 CALL PLTDLH(ISTAGE,LOGE,DENS)

WRITE(6,*),'** At what LogE value should the mean be placed'
WRITE(6,510) DEXPPT
510 FORMAT(' ','** Default: ',F4.2)
WRITE(6,*),'** Change? 1=yes 0=no'
QUE = '==='
IDEF = 0
CALL ASKI(QUE,IDEF)

IF (IDEF.EQ.0) THEN
  EXPPT = DEXPPT
ELSE
  WRITE(6,*),'** Enter new exposure point (LogE)'
  READ(5,*) EXPPT
ENDIF

WRITE(9,1002)EXPPT
1002 FORMAT( ' ',/1X,'Exposure Point is at ',F6.2)

RETURN
END
SUBROUTINE GETSYS(IPT, POINT, PLOT, IPTPDF, IPTSPE)

C********************************************************
**SUBROUTINE GETSYS
**Purpose: Obtain the following information:
**  number of stages
**  component (film or paper) for each stage
**  plotting information
**  type of plots

Subroutines called:
CLEAR

Passed variables:
IPT =
POINT =
PLOT =
IPTPDF = Type of plot for PDFs
IPTSPE = Type of plot for spectra

Commoned data:
NONE

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C********************************************************

INTEGER POINT(20), PLOT(20)

CALL CLEAR

WRITE(6,1000) 1000 FORMAT('1',1X,'List of possible components:'//
X5X,'1....lens-film'/5X,'2....lens-paper')

WRITE(6,1002) 1002 FORMAT(/1X,** Enter number of components:')
READ(5,*) IPT

WRITE(6,1003) 1003 FORMAT(1X,** Enter sequence of components (i.e. 1,2)')
READ(5,*) (POINT(J),J=1,IPT)

DO 10 J = 1,IPT
IF (POINT(J).NE.1.AND.POINT(J).NE.2) GO TO 1
CONTINUE

WRITE(6,1004) 1004 FORMAT(1X,** For each component, specify if you would like',
X1X,'a plot - (1 - yes , 0 - no)')
READ(5,*) (PLOT(J),J=1,IPT)
DO 20 J = 1, IPT
   IF (PLOT(J).NE.0.AND.PLOT(J).NE.1) GO TO 2
20 CONTINUE

WRITE(6,1005)
1005 FORMAT(1X,** Specify type of plot for PDF,SPECTRA:’,
         X/1X,’Linear-Linear = 0 Linear-Logarithmic = 1 ’,
         X/1X,’Logarithmic-Linear = 2 Logarithmic-Logarithmic = 3’)
         READ(5,* ) IPTPDF,IPTSPE

IF(IPTPDF.LT.0.OR.IPTPDF.GT.3) GO TO 3
IF(IPTSPE.LT.0.OR.IPTPDF.GT.3) GO TO 3
RETURN
END
SUBROUTINE GRAN1(ISTAGE, XMAG, RMAG, DA, DN, DB)

Purpose: Obtain granularity data as a function of linear scale (i.e. transmittance or reflectance). Can be obtained from a datafile or a function.

Subroutines called:
CLEAR ASKI SEQOP2 FINT PLTGRN

Passed variables:
ISTAGE = stage identification
XMAG = magnification to next stage
RMAG = reference magnification
DA = default value for parameter A
DN = default value for parameter N
DB = default value for parameter B

Commoned data:
INDVAR: HSBIN = Value of signal for PDF
HSNBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra
GRANUL: HGR = granularity data
SAMP: HCUT = Cutoff frequency
NB =

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COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/GRANUL/HGR
COMMON/SAMP/HCUT, NB

REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL HGR(10000)
REAL FGRN(21), FDEN(21), DENSIT(1), GRANUL(1)

INTEGER TYPE

CALL CLEAR
WRITE(6,*) '*** Granularity specification'
WRITE(6,*) ' from a FILE - 1'
WRITE(6,*) ' from a FUNCTION - 2'

QUE = '==='
IDEF = 2
CALL ASKI(QUE, IDEF)

IF (IDEF.NE.1.AND.IDEF.NE.2) GO TO 1

GO TO (100,200), IDEF

C GRANULARITY FROM DATAFILE
C OPEN FILE

100 WRITE(6,*) '** Enter Filename for datafile'
     READ(5,FMT='(A8)') FNAME
     WRITE(6,*) '** Enter Filetype for datafile'
     READ(5,FMT='(A8)') FTYPE
     RECFM = ,
     LUNIT = 20
     CALL SEQOP2 (FNAME, FTYPE, LUNIT, RECFM, NERR)
     IF (NERR.NE.0) THEN
       WRITE(6,*) 'Error in opening file'
       GO TO 100
     ENDIF

C READ IN DATA

DO 110 I = 1,21
     READ(20,120) FDEN(I), FGRN(I)
120 FORMAT(30X,F5.2,1X,F10.8)
110 CONTINUE

CLOSE (UNIT=20)
SNORM = 1

C INTERPOLATE GRANULARITY VALUES FOR EACH DENSITY VALUE

DO 130 I=1,10000
     DENSIT(I) = -1.*LOG10(HSNBIN(I))
     CALL FINT(FGRN,FDEN,DENSIT(I),GRANUL(1),21,1)
     HGR(I)=SNORM*GRANUL(1)
130 CONTINUE

WRITE(9,1000)FNAME, FTYPE
1000 FORMAT( ,/1X,'Granularity data from file: ',A8,1X,A8)

GO TO 999

C USE FUNCTION

200 WRITE(6,*) 'Function ---- Granularity = A*(D**N) + B'
     WRITE(6,201) DA, DN, DB
201 FORMAT( ,,'Defaults A = ',F10.5,' N = ',F10.5,' B = ',F10.5)
     WRITE(6,*) '** Change? 1-yes 0-no'
     QUE = '==='
IFN = 0
CALL ASKI(QUE,IFN)

IF(IFN.EQ.1) THEN
   WRITE(6,*) '** Enter new values for A, N and B'
   READ(5,*) XA,XN,XB
ELSE
   XA=DA
   XN=DN
   XB=DB
ENDIF

SNORM=1.

C CALCULATE GRANULARITY

DO 210 I=1,10000
   DENSIT(I) = -1.*LOG10(HSNBIN(I))
   HGR(I)=SN0RM*(XA*DENSIT(I)**XN+XB)
210 WRITE(10,*) 'GRN ',I,HSNBIN(I),DENSIT(I),HGR(I)
CONTINUE

WRITE(6,*) 'OBTAINED GRANULARITIES FOR MAG, RMAG ,XMAG,RMAG
WRITE(9,1001)XA,XN,XB
1001 FORMAT(' ',/1X,'Granularity data from function:','
   X/1X,'Sigma = ','F6.3,',' Density ** ','F6.3,',' + ','F6.3)
999 CONTINUE

C PLOT GRANULARITY DATA
C CALL PLTGRN(ISTAGE)
RETURN
END
SUBROUTINE GRNM1(XMAG)

C**********************************************************************
C SUBROUTINE GRNM1
C
C Purpose : To call subroutines to modify pdf/spectra for noise
C
C Subroutines called:
C SNPDF3 SNP2
C
C Passed variables:
C XMAG = magnification to next stage

C Commoned data:
C NONE

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C 10/01/87
C
C**********************************************************************

IFLAG=1

C MODIFY PDF AND RETURN ADDITIONAL VARIANCE
C
CALL SNPDF3(IFLAG,HNV,IERR)
IF(IERR.EQ.1) WRITE(6,*) ’WARNING:SNPDF3 - LOSS OF DATA(LOW)’
IF(IERR.EQ.2) WRITE(6,*) ’WARNING:SNPDF3 - LOSS OF DATA(HIGH)’

C CALCULATION OF NEW SIGNAL & NOISE SPECTRA: -NOISE IS ASSUMED TO BE UNCORRELATED
C WITH ITSELF AND THE SIGNAL. NOISE SPECTRA IS VARIANCE/BANDWIDTH.

C ASSUME WHITE NOISE
C
HEN=HNV/40.

C ADD ADDITIONAL NOISE TO SPECTRA
C
CALL SNP2(XMAG,HNV)

RETURN
END
SUBROUTINE HVS1(TITLE, IPTPDF, IPTSPE)

Purpose: To Modify the PDFs/SPECTRA for the effects of the human visual system. Viewing distance and adaptation level are used to estimate MTFs for the optical, sampling and neural components. Noise is estimated for the neural and sampling components.

Extra notes: FILE KCSF and FILE KOTF are required. They contain the MTF data at different adaptation levels.

Subroutines called:
CLEAR ASKI ASKR LOGINT LININT FINT MTFMD1 SNPDF3 SNP2 INFO1 PDFPLT SPTPLT

Passed variables:
NONE

Commenced data;
HSIGNL:  HSP  = Spectrum of signal
         HSPDF  = PDF of signal
         HSVAR  = Signal variance
         HSMEAN = Signal mean

HSENDN:  HSNP  = Spectrum of signal and noise
         HSNPDF = PDF of signal and noise
         HSNVAR = Signal and noise variance
         HSNMEN = Signal and noise mean

INDVAR:  HSBIN = Value of signal for PDF
         HSNBIN = Values of signal with noise for S+N PDF

DEV:     IDEV  = Plotting device

GRANUL:  HGR   = Array of noise values

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DERIVED FROM HVS SUBROUTINE WRITTEN BY SCOTT DALY
REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100)

INTEGER TYPE
C PARAMETERS AND DIMENSIONS FOR STAND ALONE HVS ROUTINE
C
PARAMETER (NPUPIL=5, NPOINT=180, NADAPT=7)
PARAMETER (JPOINT=100, JPT2=10000, NDISMX=20)
REAL OTF(NPUPIL, NPOINT), MTF(EYE(NPOINT))
REAL PUPSIZ(NPUPIL)
REAL NEUMTF(NADAPT, NPOINT), ADAPT(NADAPT), NEURAL(NPOINT)
REAL CDEG(NPOINT), CONSAM(NPOINT), CMM(NPOINT)
REAL HVSMTF(JPOINT), HGR(JPT2), VIEW(NDISMX)
REAL LIGHT, NEUMAX
REAL HSP1(JPOINT), HSPDF1(JPT2)
REAL HSNP1(JPOINT), HSNPD1(JPT2)
REAL FREQ1(JPOINT)
REAL HSBIN1(JPT2), HSNBIN1(JPT2)
REAL INFOR(3, NDISMX)
REAL VTEST(3, NDISMX), POWTES(3, NDISMX)
REAL ILLUM
IDPLOT = 'HUMAN VISUAL SYSTEM'
C
C -- CONSTANTS FOR GENERAL USE
C
GAIN = 1.0
PI = 3.14159265
WAVE = 525.0E-9
FMAX = 20.0
XMAGNI = 1.0
C
C -- CONSTANTS FOR QUANTUM NOISE
C
VWAVE = 0.786
EFFIC = 0.1
WYSZEK = 4.432E-13
C
C -- CONSTANTS FOR VIEWING DISTANCE LOOP
C
VIEW(1) = 0.355
VIEW(2) = 0.500
VIEW(3) = 1.0
NDIST = 1
C
C----READ IN HVS DATA
C
FILE IN FORM OF AMPLITUDE MODULATION SENSITIVITY UNITS
OPEN (UNIT=8, FILE='KCSF')
READ(8,*) (ADAPT(I), I=1, NADAPT)
FILE: HVS1 FORTRAN A1  Last edited on: 12/08/87 16:47:25

DO 20 J=1,NPOINT
READ(8,*),(CDEG(J),(NEUMTF(I,J),I=1,NADAPT)
20 CONTINUE
CLOSE(8)

--- VOS DATA FILE INPUT ----------------------------------------

FILE IN FORM OF MTF1,MTF2,MTF3,...MTFNPUPIL (FROM SMALL PUP TO BIG)

OPEN(UNIT=8,FILE='KOTF')
READ (8,*) N,(PUPSIZ(I),I=1,NPUPIL)
IF(N.NE.NPOINT) THEN
WRITE(6,1042)
END IF

1042 FORMAT(‘O+ DATA NOT CORRECT FOR OTF IN HVS SUBROUTINE’)!
DO 10 J=1,NPOINT
READ (8,*)OTFDEG,(OTF(I,J),I=1,NPUPIL)
DEGTES=OTFDEG-CDEG(J)
IF(DEGTES.GT.0.02) THEN
WRITE(6,1043)
1043 FORMAT(‘OMISMATCH IN CY/DEG IN THE HVS SUBROUTINE’)!
GO TO 9999
END IF
10 CONTINUE
CLOSE (8)

--- TEST IF DISPLAY SUBROUTINE WAS CALLED ----------------------

C

IF(GAIN.LE.0.) THEN
WRITE(6,1000)
GO TO 9999
1000 FORMAT(‘OGAIN IS LESS THAN ZERO; DISPLA ROUTINE NEEDS TO BE CALLEDHVS014 X FOR HVS EVALUATION’)!

--- STORING OF ALL RELEVANT COMMON PARAMETERS-----------------

C (NECESSARY BECAUSE OF THE VIEWING DISTANCE LOOP)

C

HSVARI = HSVAR
HSMENI = HSMEN
HSIVAI = HSNVAR
HSMV01 = HSNMEN
GAINI = GAIN

C

DO 3 L=1,JPOINT
C HSP1(L) = HSP(L)
C HSNP1(L) = HSNP(L)
C FREQ1(L) = FREQ(L)
3 CONTINUE

C

DO 4 L=1,JPT2
C HSPDF1(L) = HSPDF(L)
C HSNPDF1(L) = HSNPDF(L)
4 CONTINUE
**FILE:** HVS1 FORTRAN A1 Last edited on: 12/08/87 16:47:25

```
C **HSBIN1(L) = HSBIN(L)**
C **HSNBII(L) = HSNBIN(L)**
C4 CONTINUE

C ******* MEAN LEVEL OF ADAPTATION DETERMINATION ***************
C ** SOFT COPY- ADAPT TO IMAGE MEAN **
C ** HARD COPY- ADAPT TO SURROUND ILLUMINANCE **

CALL CLEAR
WRITE(6,** '*** Human Visual System Specification')
WRITE(6,7316)
7316 FORMAT('O** Soft copy or hard copy application? SOFT-1, HARD-0')
QUE = '=='
ISHC = 0
CALL ASKI(QUE,ISHC)
C IF(ISHC.EQ.O) THEN
WRITE(6,7317)
7317 FORMAT('O** Enter surround illuminance in footlamberts')
QUE = '=='
FOOTLA = 6.
CALL ASKR(QUE,FOOTLA)
LIGHT= 3.426*FOOTLA
WRITE(9,1010) FOOTLA
1010 FORMAT('O', 'HardCopy - Adapted to ', F8.2, ' Foot-Lamberts')
ELSE

C ******* MEAN LIGHT LEVEL OF IMAGE ****************************
C ** LIGHT IS MEAN IN FT-L, CONVERT TO CD/M**2 **

WRITE(6,** 'ENTER MEAN LEVEL OF ILLUMINATION (FOOTLAMBERTS) ?')
READ(5,**) ILLUM
LIGHT= HSNMEN*ILLUM
LIGHT= LIGHT * 3.426
WRITE(6,** 'LIGHT ',FOOTLA,LIGHT)
WRITE(9,1011) LIGHT
1011 FORMAT('O', 'SoftCopy - Adapted to ', F8.2, ' ??????????????')

C ENDIF

C

C *************** PUPIL DIAMETER ***************
C ** PUPIL DIAMETER IS CALCULATED IN METERS **

PUPIL=(10**(.8558-4.01E-4*(ALOG10(LIGHT)+7.597)**3.))+.3
IF(PUPIL.LT.2.0) THEN
  PUPIL=2.0
END IF
```
PUPIL=1E-3*PUPIL

**RETRANAL ILLUMINANCE**

INPUT INTENSITY IN CD/M**2 AT THE CORNEA : OUTPUT TROLANDS

TROLAN= PI*((1000.*PUPIL/2.)**2.)*LIGHT
PFLUX=TROLAN*WAVE/(VWAVE*WYSZEX)

**INTEGRATION TIME**

INPUT RETINAL ILLUMINANCE : OUTPUT INT TIME IN SECONDS

TSHAPE=1.8
XOFFSE=-.25
YOFFSE=.028
YGAIN= .09
TDLOG= ALOG10(TROLAN)/TSHAPE
TIME= -TDLOG-XOFFSE
TIME= ATAN(TIME)
TIME= YGAIN*0.5*(1.0+TIME)+YOFFSE

**PHOTORECEPTOR-NETWORK SAMPLING**

CALCULATION OF EXPONENTIAL APERTURE LENGTH CONSTANT (LAMBDA)

TROLOG= ALOG10(TROLAN)
XLAM= .0375*(EXP(-(TROLOG+3.37)/3.0))
IF(XLAM.LT.0.00475) XLAM= .00475
IF(XLAM.GT.0.0375) XLAM= .0375

CALCULATION OF SAMPLING APERTURE MTF

DO 5 J=1,NPOINT
   CONSAM(J)= (((2.*PI*XLAM*CDEG(J))**2.)+1.)**(-1.5)
5 CONTINUE

CALCULATION OF EFFECTIVE SUMMATION AREAS FOR SAMPLING APERTURE

CAREA=2.*PI*(XLAM**2.)

**NEURAL MTF**

--- CHOOSE APPROPRIATE NEURAL MTF FOR ADAPTATION LEVEL ---

CALL LOGINT(TROLAN,ADAPT,NEUMTF,NADAPT,NPOINT,NEURAL)

----- NORMALIZE NEURAL MTF AND SAVE PEAK VALUE AS NEURAL GAIN ----

GAINEU= NEURAL GAIN
FILE: HVS1 FORTRAN A1 Last edited on: 12/08/87 16:47:25

GAINEU=-100
DO 22 I=1,NPOINT
   IF (NEURAL(I).GT.GAINEU) THEN
      GAINEU= NEURAL(I)
   END IF
22 CONTINUE
DO 24 I=1,NPOINT
   NEURAL(I)=NEURAL(I)/GAINEU
24 CONTINUE

C *********** OPTICAL MTF ******************************
C *********** PUPIL MTF INTERPOLATIONS ****************
CALL LININT(PUPIL,PUPSIZ,OTF,NPUPIL,NPOINT,MTFEYE)
C -----GAIN OF OTF FROM PUPIL AREA (NORMALIZED TO 2.0 MM)------
GAIOTF=(1000.*PUPIL/2.)*2.

C *********** VIEWING MAGNIFICATION LOOP *******************
C .......... INCLUDING INFO CONTENT CALCULATION ............
C ------- SETTING LOOP DISTANCES ---------------
WRITE (6,7319)
7319 FORMAT( 'ODefault viewing distance: 0.355 meters' )
WRITE (6,7320)
7320 FORMAT( 'O** Change viewing distances? enter - 1, else - 0' )
ICHOOZ = 0
QUE = '==='
CALL ASKI(QUE,ICHOOZ)
   IF (ICHOOZ.EQ.1) THEN
      WRITE(6,7321)
7321 FORMAT( 'OENTER NUMBER OF DISTANCES ' )
READ(5,*) NDIST
   IF (NDIST.GT.NDISMX) THEN
      NDIST=NDISMX
      WRITE(6,7322)
7322 FORMAT( 'ONUMBER OF DISTANCES CHOSEN IS TOO LARGE MAX IS: ' )
      WRITE(6,*) NDISMX
   END IF
WRITE(6,7330)
7330 FORMAT( 'OENTER NEW VIEWING DISTANCES (METERS)' )
READ(5,*) (VIEW(I),I=1,NDIST)
ENDIF

C DO 300 K=1,NDIST
FILE: HVS1 FORTRAN 77 Last edited on: 12/08/87 16:47:25

```fortran
SCALEF = (ARCSIN((1./(1.+(VIEW(K)*1000.)**2.)))**0.5)
SCALEF = SCALEF*180./PI
WRITE(9,1012) VIEW(K)

1012 FORMAT('O','For Viewing Distance of ',F6.3,' meters')

C MULTIPPLY HVS MTF FREQUENCY IN CYCLES/DEG BY SCALEF TO GET CYCLES/MM

DO 305 I=1,NPOINT
  CMM(I) = CDEG(I)*SCALEF
305 CONTINUE

C ------ EYE-LENS-PUPIL STAGE --------- (STAGE 1 OF HVS; STAGE 7 OF KIMSIQ)

ISTAGE=7
CALL FINT(MTFEYE,CMM,FREQ,HVSMFT,NPOINT,JPOINT)
C WRITE(10,*)'PUPIL MTF'
C WRITE(10,991)(FREQ(I),HVSMFT(I),I=1,JPOINT)

WRITE(6,310)
310 FORMAT('O','Modify PDF/SPECTRA for Optical MTF Effects of HVS')

C OUTPUT MTF DATA TO A FILE
IDENT = 'HVS-OPTICS'
CALL OUTMTF(IDENT,1.0,HVSMFT)

CALL MTFMD1(HVSMFT,FMAX)

C ------ SAMPLING STAGE --------------- (STAGE 2 OF HVS; STAGE 8 OF KIMSIQ)

CALL FINT(CONSAM,CMM,FREQ,HVSMFT,NPOINT,JPOINT)
C WRITE(10,*)'SAMPLING MTF'
C WRITE(10,991)(FREQ(I),HVSMFT(I),I=1,JPOINT)

991 FORMAT('O',2(F10.5,IX))

WRITE(6,311)
311 FORMAT('O','Modify PDF/SPECTRA for Sampling MTF Effects of HVS')

IDENT = 'HVS-SAMPLING'
CALL OUTMTF(IDENT,1.0,HVSMFT)

CALL MTFMD1(HVSMFT,FMAX)

C VTEST(1,K)= HSNVAR
POWTE(1,K)= HSNP(100)
C QUANTUM NOISE DETERMINATION FOR EXPOSURE BINS (SIGMA)
HGR ARRAY CONTAINS THE STANDARD DEVIATIONS

DO 350 L=1,JPT2
  FTLAM = ((FLOAT(L)-.5)/10000.) * FOOTLA
```

C     CALCULATION OF SIGMA NOISE ASSOCIATED WITH HSNMEN
C
C     FTLMAM = HSNMEN * FOOTLA
CDM2  = FTLAM  * 3.426
TROLAN = PI*((1000.*PUPIL/2.)**2.)*CDM2
PFLUX  = TROLAN*WAVE/(VWAVE*WYSZEK)
PHOTON = (EFFIC*TIME*CAREA*PFLUX)
C     PNOISE = (PHOTON)**0.5
C     FNOISE = PNOISE/(TIME*CAREA*EFFIC)
FNOISE = PNOISE/(TIME*CAREA)
TNOISE = (FNOISE*WAVE/WYSZEK)/WAVE
C     CNOISE = TNOISE/(PI*(1000.*PUPIL/2.)**2.)
FLNOIS = CNOISE/3.426
HGR(L)  = FLNOIS / FOOTLA

C     IFLAG=0
C
C     OLD CALL SNPDF3(IFLAG,HNV)
C
C     CONVERT HN, TO VARIANCE/BANDWIDTH - NOISE POWER SPECTRA
C
C     HN= SHN*SHN/(2.0 * FMAX)

C     VTEST(2,K)= HSNVAR
POWTES(2,K)= HSNP(100)

C     -------------- NEURAL SYSTEM -------------------
C
C     NEURAL NOISE- SIGNAL INDEPENDENT; 2.5 LOG UNITS BELOW MEAN
C     ADD TO CURRENT GRANULARITY
DO 370 I=1,JPT2
GNEU  = 0.003162278*HSNMEN
GONE  = HGR(I)
HGR(I) = GNEU + HGR(I)
C     WRITE(10,*) 'GRN NEURAL ',I,GONE,GNEU,HGR(I)
370  CONTINUE
C
C     WRITE NOISE DATA TO A FILE

IDENT = 'HVS-NOISE'
CALL OUTGRN(IDENT,1.0)
CONVERT FROM S.D TO VARIANCE/BANDWIDTH = NOISE POWER SPECTRA

\[ \text{HN}= \frac{\text{HGR}(1)^2}{2.0 \times \text{FMAX}} \]

FREQUENCY INTERPOLATION OF NEURAL MTF

\[ \text{CALL FINT(NEURAL,CMM,FREQ,HVSMTF,NPOINT,JPOINT)} \]

\[ \text{WRITE(10,*), 'NEURAL MTF', FMAX} \]

\[ \text{WRITE(10,991)(FREQ(I),HVSMTF(I),I=1,JPOINT)} \]

312 FORMAT('O', 'Modify PDF/SPECTRA for Neural MTF Effects of HVS')

IDENT = 'HVS-NEURAL'

\[ \text{CALL OUTMTF(IDENT,1.0,HVSMTF)} \]

\[ \text{CALL MTFMD1(HVSMTF,FMAX)} \]

IDENT = 'AFTER HVS MTF'

\[ \text{CALL OUTPDF(IDENT)} \]

\[ \text{CALL OUTSPT(IDENT)} \]

ADD GRANULARITY NOISE TO PDF THEN SPECTRA

IFLAG = 0

313 FORMAT('O', 'Modify PDF/SPECTRA for noise effects of HVS')

\[ \text{CALL SNPDF3(IFLAG,HNV,IERR)} \]

\[ \text{HEN= HNV/40.} \]

\[ \text{XMAG = 1.} \]

\[ \text{CALL SNP2(XMAG,HNV)} \]

VTEST(3,K)= HSNVAR

POWTES(3,K)= HSNP(100)

OUTPUT PDF AND SPECTRA

IDENT = 'AFTER HVS NOISE'

\[ \text{CALL OUTPDF(IDENT)} \]

\[ \text{CALL OUTSPT(IDENT)} \]

\[ \text{CALL INFO1(TITLE,IDPLOT,99)} \]

\[ \text{PAUSE} \]

\[ \text{INFOR(3,K)-XINFO} \]

\[ \text{WRITE(6,3115)VIEW(K)} \]

3115 FORMAT('OSTAGE 7 (HVS): VIEWING DISTANCE (METERS) = ',F5.3)

\[ \text{CALL PPDFLT(TITLE,IPTPDF,99)} \]

\[ \text{CALL SPTPLT(TITLE,IPTSPE,99)} \]
C --- RESTORE ORIGINAL VALUES IN COMMON FILES-----------------------------------
C
HSVAR = HSVAR1
HSMEAN = HSMEN1
HSNVAR = HSNVA1
HSNMEAN = HSNME1
GAIN = GAIN1
C
DO 400 L=1,JPOINT
    HSP(L) = HSP1(L)
    HSNP(L) = HSNP1(L)
    FREQ(L) = FREQ1(L)
C400    CONTINUE
C
DO 410 L=1,JPT2
    HSPDF(L) = HSPDF1(L)
    HSNPDF(L) = HSNPDF1(L)
    HSBIN(L) = HSBIN1(L)
    HSNBIN(L) = HSNBIN1(L)
C410    CONTINUE
C300    CONTINUE
C
C ------- END OF VIEWING DISTANCE-INFO CAPACITY LOOP -------------------------
C
C ------- WRITE OUT RELEVANT ROUTINE PARAMETERS -----------------------------
C
OPEN(UNIT=10,FILE='KINFO')
C
WRITE(10,1030)
1030 FORMAT(' HSNMEN VSNMEN GAIN
*LIGHT')
C
WRITE(10,*) HSNMEN,VSNMEN,GAIN,LIGHT
C
WRITE(10,*)
C
WRITE(10,1031)
1031 FORMAT(' PUPIL TROLAND PHOTON QUANTUM
* NOISE MEAN REL')
C
WRITE(10,*) PUPIL,TROLAND,PHOTON,SVN
C
WRITE(10,*)
C
WRITE(10,1040)
1040 FORMAT(' SUM AREA INT TIME
*')
C
WRITE(10,*) CAREA,TIME
C
WRITE(10,*)
C
WRITE(10,1034)
1034 FORMAT(' MTFEYE(1) CONSAM(1) NEURAL(1)
* GAIN')
C
WRITE(10,*) MTFEYE(1),CONSAM(1),NEURAL(1),GAINEU
C
WRITE(10,*)
C
WRITE(10,1032)
1032 FORMAT(' DISTANCE(M) HVS SYSTEM INFO-CAPACITY ') DO 600 I=1,NDIST DO 610 J=1,3 C WRITE(10,*) VIEW(I),J,INFOR(J,I)
CONTINUE
510 CONTINUE

C WRITE(10,*)
500 CONTINUE

C WRITE(10,1037)
1037 FORMAT(' DISTANCE(M) ', 10X, 'HVS SYSTEM VSNVAR ', 'VSNP(100) ')

DO 501 I=1,NDIST
DO 511 J=1,3

WRITE(10,*) VIEW(I),J,VTEST(J,I),POWTES(J,I)

CONTINUE
WRITE(10,*)

CONTINUE

CLOSE(10)

RETURN

END
SUBROUTINE INFO1(TITLE, ID, NSTAGE)

Purpose: Calculate Information Theoretic Metrics

Subroutines called:
CLEAR DATE TIME

Passed variables:
TITLE = Title for output
ID =
NSTAGE = Stage number (99 for HVS)

Commoned data:
COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/SAMP/HCUT, NB
COMMON/INTINF/NTYPE, CUTOFF

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL*8 HS, HSN, HN, FR, H(7)

CHARACTER*30 ID
CHARACTER*8 TITLE(2), CDATE, CTIME

INTEGER TYPE
DATA PI/3.14159265/

FBAND=FREQ(2)-FREQ(1)

C CALCULATE ONE-DIMENSIONAL IMAGE QUALITY MEASURES
C
DO 10 I=1,7
  H(I)=0.0
10 CONTINUE

IF(TYPE.EQ.3) NB=1

F1 = 2.*PI*FBAND
F2 = 4.*FBAND
F3 = PI*FBAND
CON = ALOG(2.)

DO 20 I=1,100
  H(I)=0.0
20 CONTINUE

C ONLY USE VALID FREQUENCIES FOR INTEGRATION
C IF BAND-LIMITED OR TRIANGULAR ONLY GO TO THE LOWEST CUTOFF
C FREQUENCY

  HS=DBLE(HSP(I))
  HSN=DBLE(HSNP(I))
  HN=HSN-HS
  IF(HN.LT.0.0) HN=0.0
  FR=DBLE(FREQ(I))
ENDIF

C INTEGRATE CURVE
C INTEGRATE SQRT(SIGNAL)*FREQUENCY
  H(1)=H(1)+DSQRT(HS)*FR
C INTEGRATE NOISE*FREQUENCY
  H(2)=H(2)+HN*FR
C INTEGRATE SIGNAL*FREQUENCY
  H(3)=H(3)+HS*FR
C INTEGRATE SIGNAL*NOISE*FREQUENCY
  H(4)=H(4)+HS*HN*FR
C INTEGRATE (SIGNAL/NOISE)*FREQUENCY
  IF(HN.NE.0.0) H(5)=H(5)+HS/HN*FR
C INTEGRATE (SIGNAL/SIGNAL + NOISE)*FREQUENCY
IF(HSN.NE.0.0) H(6)=H(6)+HS/HSN*FR
C INTEGRATE LN(SIGNAL+NOISE/NOISE)*FREQUENCY

IF(HN.NE.0.0) THEN
RATIO =SNGL(HSN/HN)
AINT = SNGL((DLOG(HSN/HN)/DBLE(CON)))*FR)
H(7)=H(7)+(DLOG(HSN/HN)/DBLE(CON)))*FR
WRITE(99,1111) FR,HS,HSN,RATIO,AINT,H(7)
1111 FORMAT(’,’F6.2,1X,5(E13.4,1X))
C ELSE
C IF(HS.GT.0.0) H(7)=H(7)+NB*FR
ENDIF

20 CONTINUE
C CALCULATE METRICS

HAMP=SNGL(F1*H(1)**2/H(2))
HQUAD=SNGL(H(3)/H(2))
HSDEC=F1*SNGL(H(3)*2/H(4))
HDMAT=F1*SNGL(H(5))
HSMAT=F1*SNGL(H(6))
C ASSUMES ISOTROPIC RESPONSE (I.E. PI*INTEGRAL((F * (S+N)/N) DF))
HINFO=F3*SNGL(H(7))
C
CALL CLEAR
CALL DATE(CDATE)
CALL TIME(CTIME)
WRITE(6,990) TITLE,CDATE,CTIME
WRITE(9,990) TITLE,CDATE,CTIME
990 FORMAT(’,’,/1X,2A8,10X,A8,2X,A8)

WRITE(6,999) NSTAGE,ID
999 FORMAT(’,’,’Stage ’,13,1X,’ Output of ’,A20)

WRITE(6,1000)
WRITE(9,1000)

1000 FORMAT(’,’,’METRIC’,8X,’VALUE’)
WRITE(6,1001)
WRITE(9,1001)

1001 FORMAT(’,’,’--------- --------- ’)
C WRITE(6,1002) HAMP
C WRITE(9,1002) HAMP
C WRITE(6,1003) HQUAD
C WRITE(9,1003) HQUAD
C WRITE(6,1004) HSDEC
C WRITE(9,1004) HSDEC
C WRITE(6,1005) HDMAT
C WRITE(9,1005) HDMAT

C
FILE: INFO1   FORTRAN A1   Last edited on: 2/08/88 8:10:33
C     WRITE(9,1005) HDMAT
1005 FORMAT(’ ’,’Match(D) ’,1X,3(F10.4,1X))
C     WRITE(6,1006) HSMAT
C     WRITE(9,1006) HSMAT
1006 FORMAT(’ ’,’Match(S) ’,1X,3(F10.4,1X))
     WRITE(6,1007) HINFO
     WRITE(9,1007) HINFO
1007 FORMAT(’ ’,’Info Content’,1X,3(F10.2,1X))
     RETURN
     END
PROGRAM IQCN1

Purpose:
This program predicts the final and intermediate information content values for a color-negative system. For each stage the output signal+noise pdf and spectra, and output signal pdf and spectra are estimated. The variance is the tie between the spectra and pdfs. Various operations such as MTF, noise, clipping etc. are performed on either the pdf or spectra whichever is easier to handle and the variance is used to connect them. The first element is the scene and the final element is the Human Visual System.

Subroutines called:
DEVICE GETSYS SCENE2 PDFPLT SPTPLT CAMFL1 PRTPA1 INFO1 HVS1
QUITPL KRDONE
ASKI RDMTF1 FINT

Commoned data:
SYSVAR: XMAG = magnification to next stage

WILLIAM R. O'SUCH
10/05/87

COMMON/SYSVAR/XMAG
COMMON/CRT/DGAIN
CHARACTER*1 CONT,CHAIN
CHARACTER*1 HV
CHARACTER*30 IDSTAG
CHARACTER*8 TITLE(2)

INTEGER POINT(20),PLOT(20),BEGIN,END,STAGE,SKIP,IPT,ISC

10 IDEV=0
CONT = 'N'

C INITIALIZE OUTPUT DEVICE FOR PLOTS

HV = 'H'
PAGEX = 0.0
PAGEY = 0.0
ISEL = 0
CALL DEVICE(IDEV)

C GET DESCRIPTION OF SYSTEM

CALL GETSYS(IPT,POINT,PLOT,IPTPDF,IPTSPE)

NSTAGE=0
C GET TITLE
WRITE(6,1005)
READ(5,1006)(TITLE(J),J=1,2)

C STORE IN SUMMARY FILE
WRITE(9,1009)(TITLE(J),J=1,2)

1009 FORMAT('1','Model to Estimate Information Content for a two stage
X//1X, 'Photographic System',
X//1X, 'William R. O'Such',
X//1X, 'Title for this run:',2(A8))

C OBTAIN SCENE PDF AND SPECTRA, THEN PLOT THEM
CALL SCENE2
CALL PDFPLT(TITLE,IPTPDF,0)
CALL SPTPLT(TITLE,IPTSPE,0)

C MODIFY PDF AND SPECTRA FOR EACH SPECIFIED STAGE
STAGE = 1
DO 110 NSTAGE = 1,IPT
WRITE(6,*), 'Component ',POINT(NSTAGE)
GO TO (30,40),POINT(NSTAGE)

30 CONTINUE
WRITE(6,*), 'Entering camera/film section'
WRITE(9,1010)
1010 FORMAT('1','CAMERA-FILM SECTION ')
PAUSE
CALL CAMFL1
IDSTAG = 'CAMERA LENS AND FILM'
GO TO 100

40 CONTINUE
WRITE(6,*), 'Entering printer/paper section'
WRITE(9,1011)
1011 FORMAT('1','PRINTER-PAPER SECTION ')
PAUSE
CALL PRTPA1
IDSTAG = 'PRINTER LENS AND PAPER'
GO TO 100

100 CONTINUE

C CALCULATE AND DISPLAY INFORMATION METRICS
CALL INFO1(TITLE,IDSTAG,NSTAGE)
C IF REQUESTED, PLOT PDF AND SPECTRA
    IF(PLOT(NSTAGE).EQ.1) THEN
        CALL PDFPLT(TITLE,IPTPDF,POINT(NSTAGE))
        CALL SPTPLT(TITLE,IPTSPE,POINT(NSTAGE))
    ENDIF
110 CONTINUE
C EXAMINE OUTPUT WITH THE HUMAN VISUAL SYSTEM
    WRITE(9,1012)
1012 FORMAT(1,'HUMAN VISUAL SYSTEM SECTION ')
    CALL HVS1 (TITLE,IPTPDF,IPTSPE)
C CLOSE PLOT FILE AND SEND OFF PLOTS
    CALL DONEPL
    CALL QUITPT
C CALL KRDONE
C ASK IF USER WOULD LIKE TO RUN ANOTHER SIMULATION
    WRITE(6,1007)
    READ(5,1008) CONT
    IF(CONT.EQ. 'Y') GO TO 10
C FORMATS
1005 FORMAT(1X,** Enter 16 character title')
1006 FORMAT(2A8)
1007 FORMAT(1X,'TO CONTINUE ENTER-Y, ELSE-N')
1008 FORMAT(A1)
    STOP
    END
SUBROUTINE LININT(PUP, PUPSIZ, OTF, NPUP, NPOIN, EMTF)

Purpose: Perform linear interpolation for HVS routine

Subroutines called: NONE

Passed variables:
- PUP
- PUPSIZ
- OTF
- NPUP
- NPOIN
- EMTF = estimated MTF

REAL OTF(NPUP, NPOIN), EMTF(NPOIN), PUPSIZ(NPUP)

INTEGER LV, UV

LV = NPUP - 1
IF (PUP.GT.PUPSIZ(NPUP)) THEN
  PUP = PUPSIZ(NPUP)
END IF
IF (PUP.LT.PUPSIZ(1)) THEN
  PUP = PUPSIZ(1)
END IF
DO 10 I = 1, NPUP
  IF (PUP.GT.PUPSIZ(I)) GO TO 10
    LV = I - 1
  GO TO 15
10 CONTINUE

15 UV = LV + 1

DO 20 I = 1, NPOIN
  OTL = OTF(LV, I)
  OTU = OTF(UV, I)
  SLOPE = (OTU - OTL) / (PUPSIZ(UV) - PUPSIZ(LV))
  CEPT = OTU - (SLOPE * PUPSIZ(UV))
  EMTF(I) = SLOPE * PUP + CEPT
20 CONTINUE

RETURN
END
SUBROUTINE LINT(X1, X2, Y1, Y2, X, Y)

   SLOPE = (Y2 - Y1) / (X2 - X1)
   CEPT = Y1 - SLOPE * X1
   Y = SLOPE * X + CEPT

RETURN
END
SUBROUTINE LNSMT1(HMTF, XMAG, DFNO)

Purpose: Obtain the lens MTF from either a theoretical equation or a datafile.

Subroutines called:
ASKI RDITF1 FINT

Passed variables:
HMTF = Estimated MTF
XMAG = Magnification to next stage
DFNO = Default F-number

Common data:
INDVAR: HSBIN = Value of signal for PDF
HSBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra

WILLIAM R. O'SUCH
10/01/87

COMMON /INDVAR/HSBIN,HSNBIN,FREQ,SWGT,TYPE

CHARACTER*80 QUE

REAL HMTF(100)
REAL HSBIN(10000),HSNBIN(10000)
REAL DFRQ(20),DMTF(20),XFINT(100)
REAL FREQ(100),SQGT(2)

INTEGER TYPE

DATA PI/3.14159265/

WRITE(6,*) '*** Lens MTF specification'
WRITE(6,*) 'From a FILE - 1'
WRITE(6,*) 'From a FUNCTION - 2'
QUE = '***'
IDEF = 2
CALL ASKI(QUE,IDEF)

IF (IDEF.NE.1.AND. IDEF.NE.2) GO TO 1

GO TO (100,200), IDEF

READ FROM A FILE
FILE: LNSMT1 FORTRAN A1 Last edited on: 2/04/88 15:59:58

100 CALL RDMTFL(DFRQ,DMTF)

C INITIALIZE FREQUENCY INTERVALS OF FINAL ARRAY

DO 120 I=1,100
   HMTF(I)=0.0
120 XFINT(I)=FREQ(I)*XMAG

C INTERPOLATE DATA FROM FILE FOR PROGRAM FREQUENCY INTERVALS

CALL FINT(DMTF,DFRQ,XFINT,HMTF,20,100)

GO TO 999

C USE DIFFRACTION LIMITED EQUATIONS

200 WRITE(6,205) DFNO
205 FORMAT('0','Diffraction limited lens - Default is F-',F5.2)

WRITE(6,*) '*** Change? 1-YES 0-NO'
QUE = '==,'
IDEF = 0
CALL ASK1(QUE,IDEF)

IF (IDEF.EQ.0) THEN
   FNO = DFNO
ELSE
   WRITE(6,*) '*** Enter new F-number'
   READ(5,*), FNO
ENDIF

C DIFFRACTION LIMITED EQUATION

C XNA = NUMERICAL APERTURE

XNA = 1/(2.*FNO)
CUT=2.*XNA/0.00055

DO 210 I=1,100
   HMTF(I)=0.0
   XF=FREQ(I)*XMAG
   IF(XF.LT.CUT) THEN
      OMEGA=XF/CUT
      HMTF(I)=(2./PI)*ARCCOS(OMEGA)-(OMEGA)\(1.-OMEGA**2)**0.5)
   ENDIF
210 CONTINUE

WRITE(9,1000) FNO
1000 FORMAT('0','Lens MTF - Diffraction Limited at ',F4.1)

999 CONTINUE

RETURN
END
SUBROUTINE LOGINT(BG, ADAPT, MTF, NADAPT, IRANGE, NEURAL)

REAL MTF(NADAPT, IRANGE), NEURAL(IRANGE), ADAPT(NADAPT)
REAL MTL, MTU

INTEGER LV, UV

LV=NADAPT-1
IF (BG.GT. ADAPT(NADAPT)) THEN
  DISP=ALOG10(BG)-ALOG10(ADAPT(NADAPT))
  DO 3 J=1, IRANGE
    NEURAL(J)=ALOG10(MTF(NADAPT, J))-DISP
    NEURAL(J)=10.*NEURAL(J)
  CONTINUE
  GO TO 30
END IF
IF (BG.LT. ADAPT(1)) THEN
  BG=ADAPT(1)
END IF
DO 10 I=1, NADAPT
  IF (BG.GE. ADAPT(I)) GO TO 10
  LV=I-1
  GO TO 15
10 CONTINUE

UV=LV+1

BGLOG=ALOG10(BG)
ADAU=ALOG10(ADAPT(UV))
ADAL=ALOG10(ADAPT(LV))

DO 20 I=1, IRANGE
  MTL= ALOG10(MTF(LV, I))
20 CONTINUE
MTU = ALOG10(MTF(UV, I))
SLOPE = (MTU - MTL) / (ADAU - ADAL)
CEPT = MTU - (SLOPE * ADAU)
NEURAL(I) = SLOPE * BGLOG + CEPT
NEURAL(I) = 10. ** NEURAL(I)

20 CONTINUE

C

30 RETURN

END
SUBROUTINE MTFMD1

Purpose: Modify PDF and Spectra for MTF

Subroutines called:

CLIPI, BINMD1

Passed variables:

HMTF = Modulation transfer function
HCUT =

Commoned data:

HSIGNL: HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HSMEAN = Signal mean

HSANDN: HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSNMEN = Signal and noise mean

INDVAR: HSBIN = Value of signal for PDF
HSNBin = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra

WILLIAM R. O'SUCH
10/01/87

COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL HMTF(100)

INTEGER TYPE, HIGH, LOW

DATA PI/3.141592654/
VHS=0.0
VHSN=0.0
FBAND=FREQ(2)-FREQ(1)

MODIFY SPECTRA AND CALCULATE NEW VARIANCES

WRITE(6,*) 'MTFMD1: Modifying PDFs for MTF'
C MODIFY SPECTRA FOR MTF AND CALCULATE NEW VARIANCE

DO 10 I=1,100
C WRITE(10,*), MTFMD1 ',FREQ(I),HMTF(I)
   HSP(I) = HSP(I)*HMTF(I)**2
   HSNP(I) = HSNP(I)*HMTF(I)**2
   VHS = VHS+HSP(I)
   VHSN=VHSN+HSNP(I)
10 CONTINUE

C CALCULATE VARIANCE

   VHS = (1./(2.*PI))*(VHS*FBAND*2.0)
   VHSN = (1./(2.*PI))*(VHSN*FBAND*2.0)

C CALCULATE RELATIVE CHANGE IN VARIANCE

   RHS=(VHS/HSVAR)**0.5
   RHSN=(VHSN/HSNVAR)**0.5

C WRITE, 'RELATIVE COMPRESSION RHS, RHSN: ', RHS, RHSN
C WRITE(6,100) HSNVAR, HSNVAR

100 FORMAT( ', ''Before modification: '',
   X/IX, 'Signal Variance = ',F8.5,' Signal + Noise Variance = ',F8.5)

C MODIFY PDF'S BY A LINEAR TRANSFORMATION OF SIGNAL BINS
C IF BINS EXTEND PASSED 0-100, THE PDF'S ARE CLIPPED AND
C A NEW SET OF 100 BINS ARE GENERATED BY INTERPOLATION

C MODIFY SIGNAL PDF

   HIGH=10001
   LOW=0
   DO 20 I=1,10000
   HSBIN(I)=RHS*(HSBIN(I)-HSMEAN)+HSMEAN
   IF(HSBIN(I).LT.0.0) LOW = MAX(LOW,I)
   IF(HSBIN(I).GT.1.0) HIGH = MIN(HIGH,I)
20 CONTINUE

   IF(LOW.GT.0.OR.HIGH.LT.10001) THEN
      CALL CLIP1(0.0,1.0,1,Hicut)
      CALL BINMD1(HSBIN,HSPDF,LOW,HIGH)
   ENDIF

C MODIFY SIGNAL AND NOISE PDF

   HIGH=10001
   LOW=0
   DO 40 I=1,10000
   HSNBIN(I)=RHSN*(HSNBin(I)-HSNmen)+HSNmen
   IF(HSNBIN(I).LT.0.0) LOW=MAX(LOW,I)
   IF(HSNBIN(I).GT.1.0) HIGH=MIN(HIGH,I)
40 CONTINUE
FILE: MTFMD1 FORTRAN A1  Last edited on: 4/08/88  9:30:05
40 CONTINUE

    IF(LOW.GT.0. OR. HIGH.LT.10001) THEN
        CALL CLIP1(0.0,1.0,3,Hcut)
        CALL BINMD1(HSNBIN, HSNPDF, LOW, HIGH)
    ENDIF

    WRITE(6,105) HSNVAR, HSNVAR
105 FORMAT(’ ’, ’After modification:’,
          X/1X,’Signal Variance = ’,F8.5,’ Signal + Noise Variance = ’,F8.5)
    PAUSE

    WRITE(9,1000) HSMEAN, HSVAR, HSNMEN, HSNVAR
1000 FORMAT(’ ’, ’Results from MTF effects’,
           X/1X,’ Mean Variance’,
           X/1X,’Signal ’,F6.4,1X,F8.6,
           X/1X,’Signal and Noise ’,F6.4,1X,F8.6)

RETURN
END
SUBROUTINE OUTDLH IDENT, LOGE, DENS, EXPPT

Purpose: Outputs DLogH data to file 92 as defined in the startup EXEC - IQCN1.

Subroutines called:

Passed variables:
IDENT = Identification for stage
LOGE = Array of Log Exposure values
DENS = Array of Density values at each LogE value
EXPPT = Exposure point

Commoned data:
NONE

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12/07/87

CHARACTER*30 IDENT
REAL LOGE(61), DENS(61)

DO 10 I = 1, 61
WRITE(91, 100) IDENT, EXPPT, LOGE(I), DENS(I)
100 FORMAT(’ ', A30, 1X, F10.5, 1X, F10.5, 1X, F10.5)
10 CONTINUE
RETURN
END
SUBROUTINE OUTGRN(IDENT)

C Purpose : Output granularity data to file 92 as defined in IQCN1 EXEC.

C Subroutines called:

C Passed variables:
IDENT = output identification

C Commoned data:

C COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/GRANUL/HGR
COMMON/SAMP/HCUT, NB

REAL HSBINC10000), HSNBIND10000)
REAL FREQC100), SWGTC2)
REAL HGRC10000)
REAL FRGN(21), FDENC21), DENSITCl), GRANULCD

INTEGER TYPE

DO 10 I=1,10000
IF(100.*(I-1)/100).EQ.(I-1)) THEN
   WRITE(92,100)IDENT, HSNBIN(I), HGR(I)
100   FORMAT(’’,A30,F10.5,1X,F10.7)
ENDIF
CONTINUE
RETURN
END
SUBROUTINE OUTMTF

C Purpose: Output the MTF to a file 91 which is defined in the startup exec and will be located on the temporary disk. It will have the filetype MTFDATA.

Commoned data:
INDVAR: HSBIN = Value of signal for PDF
        HSNBIN = Values of signal with noise for S+N PDF
        FREQ = Frequencies for spectra
        SWGT = Frequencies for spectra
        TYPE = Frequencies for spectra

COMMON /INDVAR/ HSBIN, HSNBIN, FREQ, SWGT, TYPE

CHARACTER*30 IDENT

REAL HMTF(100)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)

INTEGER TYPE

DO 10 I = 1, 100
   WRITE(90, 100) IDENT, FREQ(I), HMTF(I)
10  FORMAT(A30, 1X, F6.3, 1X, F5.3)
CONTINUE
RETURN
END
SUBROUTINE OUTPDF(IDENT)

Purpose: Output PDF to a file as cumulative frequency into file 93 as defined in IQCN1 EXEC

Subroutines called:

Passed variables:
ident = Identification information

Commoned data:
HSIGNL: HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HSMEAN = Signal mean
HSANDN: HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSNMEN = Signal and noise mean
INDVAR: HSBIN = Value of signal for PDF
HSNBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWG = Frequencies for spectra
TYPE = Frequencies for spectra

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10/01/87

COMMON/HSIGNL/HSP,HSPDF,HSVAR,HSMEAN
COMMON/HSANDN/HSNP,HSNPDF,HSNVAR,HSNMEN
COMMON/INDVAR/HSBIN,HSNBIN,FREQ,SWG,TYPE

REAL HSP(100),HSPDF(10000)
REAL HSNP(100),HSNPDF(10000)
REAL HSBIN(10000),HSNBIN(10000)
REAL FREQ(100),SWG(2)
REAL HMTF(100)

REAL*8 CUMS,CUMSN
CHARACTER*30 IDENT
CHARACTER*14 IDS,IDSN

INTEGER TYPE
CUMS = 0.0
CUMSN = 0.0
IDS = 'SIGNAL'
IDSN = 'SIGNAL + NOISE'
DO 10 I=1,10000

CUMS = CUMS + DBLE(HSPDF(I))
CUMSN = CUMSN + DBLE(HSNPDF(I))

IF(100.*((I-1)/100).EQ.(I-1)) THEN
   WRITE(93,100) IDENT, IDS, HSBIN(I), CUMS, HSPDF(I)
100  FORMAT(’ ’,A30,1X,A14,1X,F10.8,1X,F10.8,1X,F10.8)
   WRITE(93,101) IDENT, IDSN, HSNBIN(I), CUMSN, HSNPDF(I)
101  FORMAT(’ ’,A30,1X,A14,1X,F10.8,1X,F10.8,1X,F10.8)
ENDIF
10 CONTINUE

RETURN
END
SUBROUTINE OUTSPT(IDENT)

Purpose: Output Spectra to a file as cumulative frequency specifically file 94 as defined in IQCN1 EXEC

Subroutines called:

Passed variables:
ident = Identification information

Commoned data:
HSIGNAL:  HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HSMEAN = Signal mean
HSANDN:  HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSNMEAN = Signal and noise mean
INDVAR:  HSBIN = Value of signal for PDF
HSBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra

COMMON/HSIGNAL/HSP, HSPDF, HSNVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEAN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL HMTF(100)

CHARACTER*30 IDENT
CHARACTER*14 IDS, IDSN

INTEGER TYPE

IDS = 'SIGNAL'
IDSN = 'SIGNAL + NOISE'

DO 10 I=1,100
WRITE(94, 100) IDENT, IDS, FREQ(I), HSP(I)
100 FORMAT( ' ', A30, 1X, A14, 1X, F10.4, 1X, F10.7)
WRITE(94,101) IDENT, IDSN, FREQ(I), HSNP(I)
101 FORMAT( ' ', A30, 1X, A14, 1X, F10.4, 1X, F10.7)
10 CONTINUE

RETURN
END
SUBROUTINE PDFPLT(TITLE,LF,POINT)

Purpose: Produce cumulative frequency plot

Subroutines called:
ASKI ASKR PLTXY2

Passed variables:
TITLE = Title for output
LF =
POINT =

Commoned data:
HSIGNL: HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HSMEAN = Signal mean
HSANDN: HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSNMEN = Signal and noise mean
INDVAR: HSBIN = Value of signal for PDF
HSNEBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra
PVAR: LEG =
X =
Y =
AMIN =
AMAX =
BMIN =
BMAX =

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10/01/87

COMMON/HSIGNL/HSP,HSPDF,HSVAR,HSMEAN
COMMON/HSANDN/HSNP,HSNPDF,HSNVAR,HSNMEN
COMMON/INDVAR/HSBIN,HSNEBIN,FREQ,SWGT,TYPE
COMMON/PVAR/LEG,X,Y,AMIN,AMAX,BMIN,BMAX

REAL HSP(100),HSPDF(10000)
REAL HSNP(100),HSNPDF(10000)
REAL HSBIN(10000),HSNEBIN(10000)
REAL YS(10000),YSN(10000),AMIN,AMAX,BMIN,BMAX,XS(10000),XSN(10000)
REAL FREQ(100)

CHARACTER*16 LEG(2),X(2),Y(2)
FILE: PDFPLT  FORTRAN  A1    Last edited on:  10/20/87 17:04:53

INTEGER  LF,NP,TYPE,POINT

WRITE(6,*),'Creating plot of PDF -- Please wait'

C SET NUMBER OF POINTS
C SET MINIMUM AND MAXIMUM VALUES FOR X AXIS (AMIN,AMAX)
C SET MINIMUM AND MAXIMUM VALUES FOR Y AXIS (BMIN,BMAX)

NP = 10000

ISK = 1
QUE = '** Scale plot from 0 to 1 (1) or Best Fit (2)'
CALL ASKI(QUE,ISK)

IF(ISK.EQ.1) THEN
  AMIN=0.0
  AMAX=1.0
ELSE
  QUE = '** Enter range around mean'
  RANGE = 0.4
  CALL ASKR(QUE,RANGE)
  AMIN = HSMEAN - 0.5*RANGE
  AMAX = HSMEAN + 0.5*RANGE
C AMIN = AMAX1(0.,AMIN)
C AMAX = AMIN1(1.,AMAX)
ENDIF

BMIN=0.001
BMAX=1.0
NP=10000

C CREATE PLOTTING ARRAY OF CUMULATIVE PROBABILITY FROM
C CELL PROBABILITIES

YS(1)=HSPDF(1)
XS(1)=HSBIN(1)
YSN(1)=HSNPDF(1)
XSN(1)=HSNBin(1)
DO 10 I=2,NP
  YS(I)=HSPDF(I) + YS(I-1)
  XS(I)=HSBIN(I)
  YSN(I)=HSNPDF(I) + YSN(I-1)
  XSN(I)=HSNBin(I)
10 CONTINUE

C SET AXIS LABELS

NMP=2
X(1) = '(L)INEAR  (V)ALUE'
Y(1) = '(C)UMUL.  (P)ROB.'
LEG(1)='SIGNAL $'
C PLOT DATA
CALL PLTXY2(TITLE,XS,XSN,YS,YSN,LF,NP,NMP,POINT,O)
RETURN
END
SUBROUTINE PDFUNL(CONS, CONSN)

Purpose: Take a distribution \( p(x) \) with non-uniform \( x \) increments and construct PDF with equal increments

Subroutines called:
RLIN

Passed variables:
CONS =
CONSN =

Commoned data:
HSIGNL: HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HSMEAN = Signal mean
HSANDN: HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSMEN = Signal and noise mean
INDVAR: HSBIN = Value of signal for PDF
HSBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWG = Frequencies for spectra
TYPE = Frequencies for spectra
CUMPRB: CUM =

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10/01/87

COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/CUMPRB/CUM

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL FREQ(100), SWGT(2)
REAL HSBIN(10000), HSNBIN(10000)

REAL*8 CUM(10000)
REAL*8 AL, AU, PL, PU, ALM
REAL*8 SUMS, SUMSN, SSX, SSNX, SSXX, SSNXX

INTEGER TYPE

C CALCULATE CUMULATIVE DISTRIBUTION (DOUBLE PRECISION)
NOTE WHERE INPUT PDF VALUES START AND END TO SPEED UP LATER CALCULATIONS

*** SIGNAL PDF ***

ISCLP = LOCATION WHERE CUMULATIVE DISTRIBUTION IS EQUAL TO 1.0

CUM(1) = HSPDF(1)
ISCLP = 0
NSBIN = 10000

DO 10 I = 2,10000

IF(ISCLP.EQ.0.AND.HSBIN(I).EQ.HSBIN(I-1)) THEN
  ISCLP = 1
ENDIF

IF(HSBIN(I).GT.HSBIN(I-1)) THEN
  NSBIN = I
  ISCLP = 2
ENDIF

IF(ISCLP.EQ.2.AND.HSBIN(I).EQ.HSBIN(I-1)) THEN
  ISCLP = 3
  NSBIN = I-1
ENDIF

IF (ISCLP.EQ.1) THEN
  CUM(I) = CUM(I-1) + DBLE(HSPDF(I))
  CUM(I-1) = 0.0
ENDIF

IF (ISCLP.EQ.2) THEN
  CUM(I) = CUM(I-1) + DBLE(HSPDF(I))
ENDIF

IF (ISCLP.EQ.3) THEN
  CUM(NSBIN) = CUM(NSBIN) + DBLE(HSPDF(I))
  CUM(I) = CUM(NSBIN)
ENDIF

WRITE(11,999) I,ISCLP,NSBIN,HSBIN(I),HSPDF(I),CUM(I)
999 FORMAT(9999,'EPDF',3(i5,1x),1x,6(e10.4,1x))

WRITE(10,999) I,HSBIN(I),HSPDF(I),CUMS(I)
C X,HSBIN(I),HSPDF(I),CUMS(I)
999 FORMAT(9999,'EPDF',i5,1x,6(e10.4,1x))

CONTINUE

WRITE(6,*) 'Signal ** Cumulative distribution determined'
C RECALCULATE CELL PROBABILITY IN EQUAL INCREMENTS SO THAT
C STATISTICS CAN BE CORRECTLY CALCULATED
SUMS = 0.0
IBEGS = 1
DO 20 I = 1,10000
C DETERMINE MEAN, LOWER LIMIT AND UPPER LIMIT FOR
C EQUAL INCREMENT CELLS
ALM = (I-0.5)/10000.
AL = ALM - (1./10000)*0.5
AU = ALM + (1./10000)*0.5
C INTERPOLATE CUMULATIVE DISTRIBUTION FOR UPPER AND LOWER LIMIT
C AND DETERMINE PROBABILITY OF CELL
C FOR SIGNAL ONLY PDF
IF (AL.LT.HSBIN(1).AND.AU.LT.HSBIN(1)) THEN
ICHECK = 1
HSPDF(I) = 0.0
ENDIF
IF (AL.LT.HSBIN(1).AND.AU.GE.HSBIN(1)) THEN
ICHECK = 2
CALL RLINC(1,AU,PU,IBEGS,IBEGJ,NSBIN)
HSPDF(I) = SNGL(1) - PL
ENDIF
IF (AL.GE.HSBIN(1).AND.AU.LE.HSBIN(10000)) THEN
ICHECK = 3
CALL RLINC(1,AL,PL,IBEGS,IBEGJ,NSBIN)
CALL RLINC(1,AL,PL,IBEGS,IBEGJ,NSBIN)
HSPDF(I) = SNGL(1) - PL
ENDIF
IF (AL.LT.HSBIN(10000).AND.AU.GT.HSBIN(10000)) THEN
ICHECK = 4
CALL RLINC(1,AL,PL,IBEGS,IBEGJ,NSBIN)
HSPDF(I) = SNGL(CUM(10000) - PL)
ENDIF
IF (AL.GT.HSBIN(10000).AND.AU.GT.HSBIN(10000)) THEN
ICHECK = 5
HSPDF(I) = 0.0
ENDIF
C TO SIMPLIFY LATER CALCULATIONS TRANSFER VERY SMALL VALUES TO 0.0
IF (HSPDF(I).LT.(0.000001)) HSPDF(I) = 0.0
SUMS = SUMS + HSPDF(I)
C WRITE(11,*), 'NS PDF ', I, ICHECK, ALM, HSPDF(I), SUMS

20 CONTINUE

WRITE(6,25) SUMS

25 FORMAT(' ', ' Sum of signal ', 1(F10.7, 1X))

*** for signal + noise ***

C CALCULATE CUMULATIVE DISTRIBUTION (DOUBLE PRECISION)

C NOTE WHERE INPUT PDF VALUES START AND END TO SPEED UP LATER CALCULATIONS

C ISCLPN = LOCATION WHERE CUMULATIVE DISTRIBUTION IS EQUAL TO 1.0

CUM(1) = HSNPDF(1)
ISNCLP = 0
NSNBIN = 10000

DO 30 I = 2, 10000

IF(ISNCLP.EQ.0.AND.HSNBIN(I).EQ.HSNBIN(I-1)) THEN
  ISNCLP = 1
ENDIF

IF(HSNBIN(I).GT.HSNBIN(I-1)) THEN
  NSNBIN = I
  ISNCLP = 2
ENDIF

IF(ISNCLP.EQ.2.AND.HSNBIN(I).EQ.HSNBIN(I-1)) THEN
  ISNCLP = 3
  NSNBIN = I-1
ENDIF

IF(ISNCLP.EQ.1) THEN
  CUM(I) = CUM(I-1) + DBLE(HSNPDF(I))
  CUM(I-1) = 0.0
ENDIF

IF(ISNCLP.EQ.2) THEN
  CUM(I) = CUM(I-1) + DBLE(HSNPDF(I))
ENDIF

IF(ISNCLP.EQ.3) THEN
  CUM(NSNBIN) = CUM(NSNBIN) + DBLE(HSNPDF(I))
  CUM(I) = CUM(NSNBIN)
ENDIF

C WRITE(10,999) I, ISCLP, NSBIN, HSBIN(I), HSPDF(I), CUMS(I)
C999 FORMAT( ' ', 'EPDF', 3(I5, 1X), 1X, 6(E10.4, 1X))
C999 FORMAT(' ', 'EPDF', I5, 1X, 6(E10.4, 1X))

30 CONTINUE

WRITE(6,*) 'Signal + Noise - Cumulative distribution determined'
C RECALCULATE CELL PROBABILITY IN EQUAL INCREMENTS SO THAT
C STATISTICS CAN BE CORRECTLY CALCULATED

SUMSN = 0.0
IBEGSN = 1

DO 40 I = 1, 10000
C DETERMINE MEAN, LOWER LIMIT AND UPPER LIMIT FOR
C EQUAL INCREMENT CELLS

ALM = (I-0.5)/10000.
AL = ALM - (1./10000)*0.5
AU = ALM + (1./10000)*0.5

C INTERPOLATE CUMULATIVE DISTRIBUTION FOR UPPER AND LOWER LIMIT
C AND DETERMINE PROBABILITY OF CELL
C FOR SIGNAL AND NOISE PDF

IF (AL.LT.HSNBIN(I).AND.AU.LT.HSNBIN(I)) THEN
  HSNPDF(I) = 0.0
ENDIF

IF (AL.LT.HSNBIN(I).AND.AU.GE.HSNBIN(I)) THEN
  CALL RLIN2(AL, PL, IBEGSN, IBEGJ, NSNBIN)
  HSNPDF(I) = SNGL(PL)
ENDIF

IF (AL.GE.HSNBIN(I).AND.AU.LE.HSNBIN(10000)) THEN
  CALL RLIN2(AL, PL, IBEGSN, IBEGJ, NSNBIN)
  CALL RLIN2(AU, PU, IBEGSN, IBEGJ, NSNBIN)
  HSNPDF(I) = SNGL(PL - PL)
ENDIF

IF (AL.LT.HSNBIN(10000).AND.AU.GT.HSNBIN(10000)) THEN
  CALL RLIN2(AL, PL, IBEGSN, IBEGJ, NSNBIN)
  HSNPDF(I) = SNGL(CUM(10000) - PL)
ENDIF

IF (AL.GT.HSNBIN(10000).AND.AU.GT.HSNBIN(10000)) THEN
  HSNPDF(I) = 0.0
ENDIF

IF (HSNPDF(I).LT.(0.000001)) HSNPDF(I) = 0.0
SUMSN = SUMSN + HSNPDF(I)
C CALCULATE NEW STATISTICS AND ASSIGN PDF TO COMMON VARIABLES

SSX = 0.0
SSNX = 0.0
SSXX = 0.0
SSNXX = 0.0

DO 50 I = 1,10000
ALM = (I-0.5)/10000.
HSBIN(I) = ALM
HSNBIN(I) = ALM
HSPDF(I) = HSPDF(I)/SUMSN
HSNPDF(I) = HSNPDF(I)/SUMSN
SSX = SSX + DBLE(HSPDF(I))*DBLE(HSBIN(I))
SSNX = SSNX + DBLE(HSNPDF(I))*DBLE(HSNBIN(I))
SSXX = SSXX + DBLE(HSPDF(I))*DBLE(HSBIN(I))*DBLE(HSBIN(I))
SSNXX = SSNXX + DBLE(HSNPDF(I))*DBLE(HSNBIN(I))*DBLE(HSNBIN(I))

C WRITE(10,990) I,HSBIN(I),HSPDF(I),HSNBIN(I),HSNPDF(I)

C990 FORMAT(’ ’,’OPDF ’,I5,1X,4(E15.8,1X))

50 CONTINUE

SM = SNGL(SSX)
SNM = SNGL(SSNX)
SV = SNGL(SSXX - SSX*SSX)
SNV = SNGL(SSNXX - SSNX*SSNX)

CONS = SV/HSVAR
HSMEAN = SM
HSVAR = SV

CONSN = SNV/HSNVAR
HSNMEAN = SM
HSNVAR = SNV

WRITE(6,100) HSMEAN,HSVAR

100 FORMAT(’ ’,’New signal statistics (mean,variance)=' ,F6.4,1X,F8.6)
WRITE(6,110) HSNMEAN,HSNVAR

110 FORMAT(’ ’,’New s + n statistics (mean,variance)=' ,F6.4,1X,F8.6)

WRITE(9,1000) HSMEAN,HSVAR,HSNMEAN,HSNVAR

1000 FORMAT(’ ’,’Results from DlogE modification ’,X/IX,
X/IX, ’Mean Variance’,X/IX,
X/IX, ’Signal ’,F6.4,1X,F8.6,
X/IX, ’Signal and Noise ’,F6.4,1X,F8.6)

RETURN

END
SUBROUTINE PLOTXY(XH,YH,NP,LF)

Purpose: Plot XY data - can be plotted as:
- Linear-Linear - 0
- Log-Linear - 1
- Linear-Log - 2
- Log-Log - 3

Subroutines called:
DISSPLA library

Passed variables:
XH =
YH =
NP =
LF =

Commoned data:
PXY:
AMIN =
AMAX =
BMIN =
BMAX =
TITLE =
XLABEL =
YLABEL =

COMM /PXY/ AMIN, AMAX, BMIN, BMAX, TITLE, XLABEL, YLABEL

INTEGER TYPE, NMP, LF, NP, POINT
CHARACTER*20 TITLE, XLABEL, YLABEL
CHARACTER*4 AHEAD, LMES
CHARACTER*8 CDATE, CTIME
CHARACTER*6 UFLOOR, UBLDG, UPLANT, UXTEN
REAL YH(NP), XH(NP)
REAL AMIN, AMAX, BMIN, BMAX

GET DATE, TIME AND USER INFORMATION
CALL UINFO(NAME, UDEPT, UFLOOR, UBLDG, UPLANT, UXTEN, CDATE)
CALL TIME (CTIME)

IF (LF.EQ.1 .OR. LF.EQ.3) NXC = ALOG10(AMAX/AMIN) + 0.5
IF (LF.EQ.2 .OR. LF.EQ.3) NYC = ALOG10(BMAX/BMIN) + 0.5

C LET THE PLOTTING BEGIN !!!!!!
CALL NUMODE('BRIT')
CALL SIMPLX
CALL BASALF('L/CSTD')
CALL MIXALF('STAND')
CALL GRACE(0.0)
CALL HEIGHT(.20)

CALL AREA2D(7.0, 5.0)
CALL THKCRV(0.015)
CALL THKRND(0)
CALL FRAME
CALL MESSAG(TITLE, 20, 2.25, 5.5)

CALL HEIGHT(.10)
CALL MESSAG(UNAME, 20, 7.5, 7.00)
CALL MESSAG(CDATE, 8, 7.5, 6.75)
CALL MESSAG(CTIME, 8, 7.5, 6.50)

CALL HEIGHT(0.20)

CALL INTNO(POINT, 4.5, 5.5)
CALL MESSAG(EXTENDED)
CALL XNAME(XLABEL, 20)
CALL YNAME(YLABEL, 20)

IF(LF.EQ.1) THEN
   CALL AXSPLT(BMIN, BMAX, 5., YORIG, YSTP, YAXIS)
   CALL ALGPLT(AMIN, AMAX, 7., XORIG, XCYC)
   DO I = 1, NP
      IF(YH(I).LT.YORIG) YH(I) = YORIG*1.05
      IF(XH(I).LT.XORIG) XH(I) = XORIG*1.05
   CONTINUE
   ENDIF

IF(LF.EQ.2) THEN
   CALL AXSPLT(AMIN, AMAX, 7., XORIG, XSTP, XAXIS)
   CALL ALGPLT(BMIN, BMAX, 5., YORIG, YCYC)
   CALL YLOG(XORIG, XSTP, YORIG, YCYC)
   DO I = 1, NP
      IF(YH(I).LT.YORIG) YH(I) = YORIG*1.05
      IF(XH(I).LT.XORIG) XH(I) = XORIG*1.05
   CONTINUE
   ENDIF

IF(LF.EQ.3) THEN
   CALL ALGPLT(AMIN, AMAX, 7., XORIG, XCYC)
   CALL ALGPLT(BMIN, BMAX, 5., YORIG, YCYC)
   CALL LOGLOG(XORIG, XCYC, YORIG, YCYC)
   DO I = 1, NP
      IF(YH(I).LT.YORIG) YH(I) = YORIG*1.05
      IF(XH(I).LT.XORIG) XH(I) = XORIG*1.05
   CONTINUE
   ENDIF
IF (LF.EQ.1.OR.LF.EQ.2.OR.LF.EQ.3) GOTO 1003
   CALL GRAF(AMIN,'SCALE',AMAX,BMIN,'SCALE',BMAX)

1003 CONTINUE

C

   CALL CWIDTH('NORMAL')
   NM=1

C

   CALL HEIGHT(.15)
   CALL SPCMOD
   CALL HEIGHT(.2)
   CALL CURVE(XH(1),YH(1),NP,1000)
   CALL ENDPL(0)
   RETURN
END
SUBROUTINE PLTDLH(ISTAGE, LOGE, DENS)

C SUBROUTINE PLTDLH

C Purpose: Plot 61 point DlogH curve

C Subroutines called:
C PLOTXY

C Passed variables:
C ISTAGE =
C LOGE = Log exposure data
C DENS = Density data

C Commoned data:
C PXY: AMIN =
C AMAX =
C BMIN =
C BMAX =
C TITLE =
C XLABEL =
C YLABEL =

C WILLIAM R. O'SUCH
C 10/0/87

COMMON/PXY/AMIN,AMAX,BMIN,BMAX,TITLE,XLABEL,YLABEL
REAL LOGE(61),DENS(61)
CHARACTER*20 TITLE,XLABEL,YLABEL

C SET UP TITLES AND AXIS LIMITS

IF(ISTAGE.EQ.1) TITLE = 'FILM SENSITOMETRY'
IF(ISTAGE.EQ.2) TITLE = 'PAPER SENSITOMETRY'
XLABEL = 'LOG EXPOSURE'
YLABEL = 'DENSITY'
NP = 61
LF = 0
AMIN = 0.
AMAX = 4.
BMIN = 0.
BMAX = 3.

C CALL PLOTTING SUBROUTINE

CALL PLOTTXY(LOGE,DENS,NP,LF)

RETURN
END
SUBROUTINE PLTGRN(ISTAGE)

Purpose: Plot granularity data

Subroutines called:
PLOTXY

Passed variables:
ISTAGE =

Commoned data:
PXY: AMIN = AMAX = BMIN = BMAX = TITLE = XLABEL = YLABEL =

INDVAR: HSBIN = Value of signal for PDF
HSNBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWG = Frequencies for spectra
TYPE = Frequencies for spectra

WILLIAM R. O' SUCH
10/01/87

REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWG(2)
REAL HGR(10000)

INTEGER TYPE

CHARACTER*20 TITLE, XLABEL, YLABEL

SET UP AXIS LABELS

IF(ISTAGE.EQ.1) TITLE = 'FILM GRANULARITY'
IF(ISTAGE.EQ.2) TITLE = 'PAPER GRANULARITY'
XLABEL = 'LINEAR MEASURE'
YLABEL = 'RMS GRANULARITY'
NP = 10000
LF = 2
AMIN = 0.
AMAX = 1.
FILE: PLTGRN FORTRAN A1

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BMIN = 0.001
BMAX = 1.

C PLOT DATA

CALL PLOTXY(HSNBIN,HGR,NP,LF)

RETURN
END
SUBROUTINE PLTXY2(TITLE, XH, XV, YH, YV, LF, NP, NMP, POINT, IFLAG)

Purpose: Produce XY Signal and Signal Noise plots

Subroutines called:
DISPLA library

Passed variables:
TITLE =
XH =
XV =
YH =
YV =
LF =
NP =
NMP =
POINT =
IFLAG =

Commmoned data;
PVAR:  LEG =
  X =
  Y =
  AMIN =
  AMAX =
  BMIN =
  BMAX =

COMMON/PVAR/LEG,X,Y,AMIN,AMAX,BMIN,BMAX

INTEGER TYPE,IFLAG,NMP,LF,NP,POINT,IPKRAY(200)

CHARACTER*16 LEGNAM,LEG(2),X(2),Y(2)
CHARACTER*8 TITLE(2),CDATE,CTIME
CHARACTER*6 UFLOOR,UBLDG,UPLANT,uxtEN
CHARACTER*20 UNAME, UDEPT

CHARACTER*4 AHEAD,LMES

REAL YH(NP),YV(NP),XH(NP),XV(NP)
REAL AMIN,AMAX,BMIN,BMAX,AM,AN

GET DATE,TIME AND USER INFORMATION
CALL UINFO(UNAME,UDEPT,UFLOOR,UBLDG,UPLANT,uxtEN,CDATE)
CALL TIME(CTIME)

CALCULATE NUMBER OF CYCLE FOR LOG PLOTS

NXCY=3
NYCY=3
FILE: PLTXY2  FORTRAN A1  Last edited on: 2/09/88 16:39:02

IF(FLAG.EQ.0)GO TO 1000
NYC=ALOG10(BMAX/BMIN)+.5
NYCY=AMAXO(NYC,NYC)

1000 CONTINUE

C MARK POINTS EVERY NMARK VALUES

NPMARK = NP/10

C SET UP LEGEND
MAXLIN=LINESTCIPKRAY,200,16)
LEGNAM=(L)EGEND

CALL NUMODE('BRIT')
CALL SIMPLX
CALL BASALF('L/CSTD')
CALL MIXALF('STAND')
CALL GRACE(0.0)
CALL HEIGHT(.20)

CALL AREA2D(7.0,5.0)
CALL THECRV(.010)
CALL THKRND(0)

C CALL FRAME
CALL MESSAG(TITLE,16,2,25,6,0)
IF(POINT.EQ.0) CALL MESSAG('(I)NPUT (S)IGNAL ',17,2,25,5,5)
IF(POINT.EQ.1) CALL MESSAG('(C)AMERA/(F)ILM ',17,2,25,5,5)
IF(POINT.EQ.2) CALL MESSAG('(P)RINTER/(P)APER',17,2,25,5,5)
IF(POINT.EQ.99) CALL MESSAG('HUMAN (V)ISUAL (S)YSTEM',25,2,25,5,5)

CALL HEIGHT(.10)
CALL MESSAG(UNAME,20,7,5,6.75)
CALL MESSAG(CDATE,8,7,5,6.50)
CALL MESSAG(CTIME,8,7,5,6.25)

CALL Height(.20)

C CALL INTNO(POINT,4.5,5.5)
CALL CWIDTH('EXTENDED')
CALL XNAME(X,16)
CALL YNAME(Y,16)

IF(FL.EQ.1)THEN
  CALL AXSPLT(BMIN,BMAX,.YORIG,YSTP,YAXIS)
  CALL ALGPLT(AMIN,AMAX,7.,XORIG,XCYC)
  CALL XLOG(XORIG,XCYC,YORIG,YSTP)
  DO 1 I=1,NP
  IF(YH(I).LT.YORIG) YH(I)=YORIG*1.05
  IF(YV(I).LT.YORIG) YV(I)=YORIG*1.05
  IF(XH(I).LT.XORIG) XH(I)=XORIG*1.05
  IF(XV(I).LT.XORIG) XV(I)=XORIG*1.05
  1 CONTINUE
ENDIF
IF(LF.EQ.2)THEN
    CALL AXSPLT(AMIN,AMAX,7.,XORIG,XSTP,XAXIS)
    CALL ALGPLT(BMIN,BMAX,5.,YORIG,YCYC)
    CALL YLOG(XORIG,XSTP,YORIG,YCYC)
    DO 2 I=1,NP
        IF(YH(I).LT.YORIG) YH(I)=YORIG*1.05
        IF(YV(I).LT.YORIG) YV(I)=YORIG*1.05
        IF(XH(I).LT.XORIG) XH(I)=XORIG*1.05
        IF(XV(I).LT.XORIG) XV(I)=XORIG*1.05
    CONTINUE
ENDIF

IF(LF.EQ.3)THEN
    CALL ALGPLT(AMIN,AMAX,7.,XORIG,XCYC)
    CALL ALGPLT(BMIN,BMAX,5.,YORIG,YCYC)
    CALL LOGLOG(XORIG,XCYC,YORIG,YCYC)
    DO 3 I=1,NP
        IF(YH(I).LT.YORIG) YH(I)=YORIG*1.05
        IF(YV(I).LT.YORIG) YV(I)=YORIG*1.05
        IF(XH(I).LT.XORIG) XH(I)=XORIG*1.05
        IF(XV(I).LT.XORIG) XV(I)=XORIG*1.05
    CONTINUE
ENDIF

IF(LF.EQ.1.OR.LF.EQ.2.OR.LF.EQ.3)GOTO 1003
CALL GRAP(AMIN,'SCALE',AMAX,BMIN,'SCALE',BMAX)
1003 CONTINUE

CALL CWIDTH('NORMAL')
NM=1

CALL HEIGHT(.15)
CALL SPCMOD
CALL HEIGHT(.2)
CALL CURVE(XH(1),YH(1),NP,NPMARK)
CALL LINES(LEG(1),IPKRAY,NM)
IF(NMP.EQ.1)GO TO 1008

CALL HEIGHT(.15)
CALL SPCMOD
NM=NM+1
CALL HEIGHT(.2)
CALL DASH
CALL CURVE(XV(1),YV(1),NP,NPMARK)
CALL LINES(LEG(2),IPKRAY,NM)
1008 CALL RESET('DASH')
CALL SETCLR('BLACK')
CALL MYLEGN(LEGNAM,16)
CALL LEGEND(IPKRAY,NMP,6.00,3.4)
CALL ENDPL(0)
RETURN
SUBROUTINE PRTPA1

Purpose: To Modify the PDFs/SPECTRA for the effects of Printer lens MTF, paper MTF, paper granularity and paper DlogH response.

Subroutines called:
ASKI LNSMT1 MTFMD1 CLEAR GAUMT1 GETDLH DLHMD2 GRAN1 GRNMD1

Passed variables: NONE

Commoned data:
COMMON/HSIGNL/HSP, HSPDF, HSVAR, HSMEAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNB var, FREQ, SWGT, TYPE
COMMON/SYSVAR/XMAG
COMMON/SAMP/HCUT, NB

REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL HMTF(100), BD(21), HDBIN(10000)
REAL PLOGH(61), PDENS(61)

INTEGER TYPE, CHANGE, SKIP

CHARACTER*30 IDENT
C OBTAIN PRINTER LENS MTF
C lens MTF is defined in image plane, so magnification
C from previous stage is used (in SYSVAR COMMON)

WRITE(6,*) '** Printer lens MTF specification'
CALL LNSMT1(HMTF,XMAG,5.6)

C WRITE OUT DATA

IDENT = 'PRINTER LENS'
CALL OUTMTF(IDENT,XMAG,HMTF)

C MODIFY INPUT SIGNAL SPECTRA/PDF AND INPUT SIGNAL+NOISE SPECTRA
C AND PDF FOR MTF. THE SPECTRA IS FILTERED BY THE MTF AND THE
C PDF VARIANCE IS SCALED TO MATCH THE INTEGRAL OF THE SPECTRA

CALL MTFMD1(HMTF,H_CUT)

C OUTPUT PDF AND SPECTRA

IDENT = 'AFTER PRINTER LENS'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C MTF is defined in print plane, so set magnification to 1.0
XMAG = 1.0

C OBTAIN PAPER MTF RESPONSE

CALL CLEAR
WRITE(6,*) '** Paper MTF specification'
CALL GAUMT1(5.,HMTF,XMAG)

C WRITE OUT DATA

IDENT = 'PAPER MTF'
CALL OUTMTF(IDENT,XMAG,HMTF)

C MODIFY SPECTRA AND PDF FOR PAPER MTF

CALL MTFMD1(HMTF,H_CUT)

C OUTPUT PDF AND SPECTRA

IDENT = 'AFTER PAPER MTF'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C OBTAIN PAPER DLOGH CHARACTERISTIC

CALL GETDLH(2,2.2,0.1,2.5,0.4,FLOGH,PDENS,EXPPT)

C OUTPUT DLOGH DATA TO A FILE
IDENT = 'PAPER DLOGH'
CALL OUTDLH(IDENT,PLOGH,PDENS,EXPPT)

C TRANSFORM PDF THROUGH DLOGH CURVE AND MODIFY SPECTRA FOR CHANGE IN
C VARIANCE
CALL DLHMD2(PLOGH,PDENS,EXPPT)

C OUTPUT PDF AND SPECTRA
IDENT = 'AFTER PAPER DLOGH'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C OBTAIN PAPER GRANULARITY INFORMATION
WRITE(6,*) 'Specification of Paper granularity'
RMAG = 1.0
CALL GRAN1(2,XMAG,RMAG,0.000,1.0,0.002)

C WRITE OUT GRANULARITY DATA
IDENT = 'PAPER GRANULARITY'
CALL OUTGRN(IDENT,XMAG)

C MODIFY PDF/SPECTRA FOR NOISE
CALL GRNM1(XMAG)

C OUTPUT PDF AND SPECTRA
IDENT = 'AFTER PAPER GRANULARITY'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

WRITE(6,*) 'Completed printer lens/paper modifications'
RETURN
END
SUBROUTINE QUITPL

PURPOSE

TO TERMINATE DISSPLA PLOT FILES. (MUST BE USED INSTEAD OF SYSTEM SUBROUTINE 'DONEPL' IF ACCESSING ZETA PLOTTER, QMS LASER PRINTER, OR HP7550 PLOTTERS.

VARIABLE DEFINITIONS

ARGUMENTS

NONE

INTERNAL

ISAVE (I*4) = FLAG FOR SAVING PLOT FILE.
LINE1 (C*22) = BUFFER FROM QUEUE.
ADDRESS (C*17) = QMS OR ZETA PLOTTER ADDRESS (QMS ZETALIST).
PRTADD (C*17) = ADDRESS OF DEFAULT PRINTER.
NEWNAM (C*8) = NEW FILENAME TO STORE PLOT DATA FILE.
OFORM (C*8) = OLD FORM MODE (USED FOR KP30 ONLY)

SUBROUTINES CALLED

ASKS KRDONE ZETA

EXECs CALLED

ZETALIST AIGETF01 QMSLIST

DEVICE/FILE DEFINITIONS

UNIT DEVICE DESCRIPTION FILENAME FILETYPE
--- ----- ----------------- --------- ---------
18 DISK QMS OUTPUT FILE $$QMS$$ $$DATA$$
19 DISK ZETA OUTPUT FILE FT19FO01
21 DISK HP-7550 OUTPUT FILE FT21FO01 SPOLHP INTERNAL
22 DISK TEKTRONIX TERMINALS

REMARKS

- IF QMS LASER PRINTER CALLED, OUTPUT HAS BEEN STORED ON FILE 18.
- IF ZETA PLOTTER WAS CALLED, OUTPUT HAS BEEN STORED ON FILE 19.
- THIS SUBROUTINE MUST BE CALLED TO SET SPOOL ADDRESS CORRECTLY,

FILE: QUITPL FORTRAN G1 Last edited on: 12/17/87 8:20:27
SUBROUTINE QUITPL

CHARACTER*80 STRING
CHARACTER*40 TAG
CHARACTER*22 LINE1
CHARACTER*17 PRTADD, ADDR
CHARACTER*8 NEWNAM, OFORM

DATA NEWNAM/' '/

C--TERMINATE DISSPLA (SYSTEM CALL CONTAINING DONEPL)
C--THE WRITE STATEMENTS ARE NECESSARY FOR TIMING USING CX TERMINALS.
WRITE (6,'')
CALL KRDONE
WRITE (6,'')
CALL CLEAR

C--CHECK TO SEE IF ZETA DATA OR QMS DATA HAS BEEN CREATED
CALL CMSFVS ('SET CMSTYPE HT',NRC)

C--DOES FILE 18 & 19 EXIST (QMS OR ZETA)
CALL CMSFVS ('STATE $$QMS$$ $DATA$$ A',NRCQ)
CALL CMSFVS ('STATE FILE FT19FOO1 A',NRCZ)

C

C--TOP OF QMS/ZETA 'IF' LOOP
C--IF RETURN CODE OF EITHER WAS ZERO, QMS OR ZETA PLOTTER WAS SELECTED
IF (NRCQ.EQ.0 .OR. NRCZ.EQ.0) THEN

C--RESET SCREEN DISPLAY TO 'ON'
CALL CMSFVS ('SET CMSTYPE RT',NRC)

C--GET ADDRESS OF CURRENT PRINTER DEVICE
CALL CMSFVS('EXECIO 2 CP (LIFO STRING TAG QU DEV PRT',NRC)
READ (5,辕A20') LINE1
FILE: QUITPL FORTRAN G1

C--IF CURRENT PRINTER HAS NOT BEEN SELECTED, SET NULL ADDRESS
   IF (LINE1(14:20).EQ. 'NOT SET') THEN
      PRTADD = '
   END IF
C
ELSE
C--OTHERWISE REMEMBER CURRENT ADDRESS OF PRINTER DEVICE
   READ (5, '(A)') PRTADD
END IF
C
C--MAIN LOOP FOR QMS AND ZETA OUTPUT ONLY
DO 70 J=1, 2
C
C--NULL PLOTTER ADDRESS, ISAVE FLAG=0 TO NOT SAVE PLOT FILE
   ADDR = '
   LINE1 = ' ISAVE = 0
C
C--SELECT ADDRESS OF QMS OR ZETA PLOTTER DESIRED
   CALL CLEAR
   IF (J.EQ.1 .AND. NRCQ.EQ. 0) THEN
      CALL CMSFVS ('EX QMSLIST', IRC)
      READ (5, '(A22)') LINE1
   ELSE IF (J.EQ.2 .AND. NRCZ.EQ. 0) THEN
      CALL CMSFVS ('EX ZETALIST', IRC)
      READ (5, '(A22)') LINE1
   ENDIF
C
C--CHECK BYTE 2, IF IT IS A '-', THIS FILE IS TO BE SAVED. ISAVE=1
C--CONVERT LINE1, BYTES 6-22 INTO A QMS OR ZETA ADDRESS
   IF (LINE1(2:2).EQ. '-') ISAVE = 1
   ADDR = LINE1(6:22)
C
C--IF NO PLOT IS DESIRED (OPTION 0), DISCARD FILE, SET NRC FLAG=-3
   IF (J.EQ.1 .AND. ADDR.EQ. 'DISCARD') THEN
      CALL CMSFVS ('ERASE $$QMS$$ $$DATA$$ A', NRC)
      NRCQ = -3
   ELSE IF (J.EQ.2 .AND. ADDR.EQ. 'DISCARD') THEN
      CALL CMSFVS ('ERASE FILE PT19FO01 A', NRC)
      NRCZ = -3
   ENDIF
C
C--CONTINUE ONLY IF DEVICE WAS SELECTED
   *GO TO 70
C
C--IF FILE IS BEING SENT TO KP30, FORM MUST BE CHANGED BACK TO STANDARD
C--IT WILL BE CHANGED BACK TO ORIGINAL FORM AFTER SENDING FILE
   STRING = 'SPOOL PRT TO RSCS'
   CALL CPFVS (STRING, NRC)
FILE: QUITPL FORTRAN G1 Last edited on: 12/17/87 8:20:27

IF(ADDRES(1:4).EQ.'KP30') THEN
  CALL CMSFVS('EXEC AIGETPO1',NRC)
  READC5,'CA8')OFORM
  STRING='SPOOL PRT TO RCS FORM STANDARD'
  CALL CPFVS(STRING,NRC)
ENDIF

C--SET TAG TO CHOSEN OUTPUT ADDRESS
STRING='TAG DEV PRT '//ADDRES
CALL CPFVS(STRING,NRC)

C--PRINT PLOT FILE WHILE SUPPRESSING LINE FEED CHARACTERS
IF(J.EQ.1) CALL CMSFVS('PRINT $$QMS$$ $DATA$$ A (CC',NRC)
ELSE IF(J.EQ.2) CALL CMSFVS('PRINT FILE PT19P001 A (LI O',NRC)
C:

C--RESET ADDRESS TO ORIGINAL PRINTER DEVICE
TAG='TAG DEV PRT '//PRTADD
CALL CPFVS(TAG,NRC)

C--IF FILE WAS SENT TO KP30, RESET FORM BACK TO ORIGINAL
IF(ADDRES(1:4).EQ.'KP30') THEN
  STRING='SPOOL PRT TO RCS FORM //OFORM
  CALL CPFVS(STRING,NRC)
ENDIF

C

C--IF FILE IS TO BE KEPT, RENAME, OTHERWISE DISCARD IT
IF(ISAVE.EQ.1) THEN
  CALL CLEAR
  IF(J.EQ.1) THEN
    PRINT*, 'In order to save this QMS LASER PLOTTER file:'
    STRING='Enter a new filename for this plot data. (filetype qi016
    * will be $QDATA$$')
  ELSE IF(J.EQ.2) THEN
    PRINT*, 'In order to save this ZETA PLOTTER file:'
    STRING='Enter a new filename for this plot data. (filetype qi016
    * will be $ZDATA$$')
  ENDIF
  PRINT*, STRING,' ',NEWNAM,8,1)
CALL CMSFVS(STRING,NRC)
C
C--CHECK TO SEE IF NEW FILE NAME EXISTS ALREADY
IF(J.EQ.1) STRING='STATE '//NEWNAM//' $QDATA$$ A'
ELSE IF(J.EQ.2) STRING='STATE '//NEWNAM//' $ZDATA$$ A'
PRINT*, STRING,' ',NEWNAM,8,1)
CALL CMSFVS(STRING,NRC)
ENDIF
FILE: QUITPL FORTRAN G1 Last edited on: 12/17/87 8:20:27

C--RESET SCREEN DISPLAY TO 'ON'
 CALL CMSFVS ('SET CMSTYPE RT',NRC)
 PRINT*, ''

C--IF RETURN CODE IS NOT ZERO, SELECT ANOTHER NAME
 IF (NEEXIST.EQ.0) THEN
 PRINT*, ''
 IF(J.EQ.1) PRINT*, NEWNAM, '$QDATA$$ A already exists.'
 IF(J.EQ.2) PRINT*, NEWNAM, '$ZDATA$$ A already exists.'
 PRINT*, 'Please select another filename.'
 PRINT*, ''
 PAUSE 'Press 'ENTER' to continue.'
 GO TO 20
 ENDIF

C--RENAME '$QMS$$ OR $DATA$$ OR FILE FT19F001 TO NEWNAM
 IF(J.EQ.1) THEN
 STRING= 'RENAME '$QMS$$ $DATA$$ A '/NEWNAM'/ '$QDATA$$ A'
 CALL CMSFVS(STRING,NRC)
 PRINT*, ''
 PRINT*, 'QMS LASER plot data has now been stored in file ',NEWNAM
 PRINT*, 'Use program 'REPQMS' to direct data to the appropriate QMS LASER plotter.'
 ELSE IF(J.EQ.2) THEN
 STRING= 'RENAME FILE FT19F001 A '/NEWNAM'/ '$ZDATA$$ A'
 CALL CMSFVS(STRING,NRC)
 PRINT*, ''
 PRINT*, 'ZETA plot data has now been stored in file ',NEWNAM
 PRINT*, '$ZDATA$$ A.'
 PRINT*, 'Use program 'REPZETA' to direct data to the appropriate ZETA plotter.'
 ENDIF
 PAUSE 'Press 'ENTER' to continue.'

C--IF FILE IS NOT TO BE SAVED, DISCARD IT
 ELSE IF(ISAVE.EQ.0) THEN
 IF(J.EQ.1) CALL CMSFVS('ERASE '$QMS$$ $DATA$$ A',NRC)
 IF(J.EQ.2) CALL CMSFVS('ERASE FILE FT19F001 A',NRC)
 ENDIF

C-BOTTOM OF MAIN LOOP, RETURN TO MAINLINE
 70 CONTINUE
 RETURN

C
 ENDIF

C--IF NOT A QMS OR ZETA PLOTTER
C--RESET SCREEN DISPLAY TO 'ON'
 CALL CMSFVS ('SET CMSTYPE RT',NRC)
C
 RETURN
SUBROUTINE RDMTF1(DFRQ, DMTF)

C SUBROUTINE RDMTF1

C Purpose: Read MTF datafile in CSEL format

C Subroutines called:

C SEQOP2

C Passed variables:

C NONE

C Commoned data:

C NONE

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C 10/01/87

C*******************************************************************************

CHARACTER*8 FNAME, FTYPE, RECFM
REAL DFRQ(20), DMTF(20)

100 WRITE (6, *) '*** Enter FILENAME for film MTF data to be used: '
READ (5, FMT='(A8)') FNAME

C OPEN FILE

FTYPE = 'DATA',
RECFM = '',
REWIND 20
LUNIT = 20
CALL SEQOP2 (FNAME, FTYPE, LUNIT, RECFM, NERR)
IF (NERR.NE.0) THEN
   WRITE (6, *) 'Error in reading file ERROR NUMBER ', NERR
   GO TO 100
ENDIF

C READ FILE

READ (20, 110) (DFRQ(J), DMTF(J), J=1,20)

110 FORMAT(5(2F5.3))

CLOSE (UNIT=20)

WRITE(9, 1000) FNAME, FTYPE

1000 FORMAT('O', 'MTF data read from file: ', A8, 1X, A8)

RETURN
END
SUBROUTINE RLIN(ID,X,Y,IBEGO,IBEGN,NMAX)

C***SUBROUTINE RLIN
C Purpose: Perform a linear interpolation
C Subroutines called:
C NONE
C Passed variables:
C ID =
C X =
C Y =
C IBEGO =
C IBEGN =
C NMAX =
C
C Commoned data;
C INDVAR: HSBIN = Value of signal for PDF
C HSNBIN = Values of signal with noise for S+N PDF
C FREQ = Frequencies for spectra
C SWGT = Frequencies for spectra
C TYPE = Frequencies for spectra
C CUMPRB: CUM =

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C
C**************************************************************************

COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/CUMPRB/CUM

REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)

REAL*8 CUM(10000)
REAL*8 X, Y, DX, DY, XM, RATX

INTEGER TYPE

C INTERPOLATE SIGNAL PDF
IF (ID.EQ.1) THEN
DO 100 I = IBEGO, NMAX
IF (SNGL(X).GT.HSBIN(I).AND.SNGL(X).LE.HSBIN(I+1)) GO TO 110
100 CONTINUE
C BEYOND DATA
110 IF (I.EQ. (NMAX + 1)) THEN
Y = 0.0
C WITHIN DATA
ELSE
   DX = HSBIN(I+1) - HSBIN(I)
   DY = CUM(I+1) - CUM(I)
   XM = SNGL(X) - HSBIN(I)
   RATX = XM/DX
   Y = CUM(I) + RATX*DY
   IBEGN = I - 1
ENDIF
ELSE
   RX = CUM(I) + RATX*DY
   IBEGN = I - 1
ENDIF
RETURN
END
SUBROUTINE SCENE2

Purpose: To Create the PDFs/SPECTRA for the input signal

Subroutines called:
CLEAR ASKI STSPD1 SEQOP2 PDFUNL

Passed variables:
NONE

Commoned data:
HSIGNL: HSP = Spectrum of signal
HSPDF = PDF of signal
HSVAR = Signal variance
HMSAN = Signal mean
HSANDN: HSNP = Spectrum of signal and noise
HSNPDF = PDF of signal and noise
HSNVAR = Signal and noise variance
HSNMEN = Signal and noise mean
INDVAR: HSBIN = Value of signal for PDF
HSNBIN = Values of signal with noise for S+N PDF
FREQ = Frequencies for spectra
SWGT = Frequencies for spectra
TYPE = Frequencies for spectra
SAMP: HCUT = Cutoff frequency
CB = Parameters in equation for integration
SPEC: A,B,N
INTINF: NTYPE = Type of spectrum
CUTOFF = Cutoff frequency

COMMON/HSIGNL/HSP, HSPDF, HSVAR, HMSAN
COMMON/HSANDN/HSNP, HSNPDF, HSNVAR, HSNMEN
COMMON/INDVAR/HSBIN, HSNBIN, FREQ, SWGT, TYPE
COMMON/SAMP/HCUT, CB
COMMON/SPEC/A,B,N
COMMON/INTINF/NTYPE, CUTOFF

REAL*8 DCADRE, FNC, V1, V2, AERR, RERR, ERROR
REAL HSP(100), HSPDF(10000)
REAL HSNP(100), HSNPDF(10000)
REAL HSBIN(10000), HSNBIN(10000)
REAL FREQ(100), SWGT(2)
REAL XM0(2), MEAN(2), VAR(2)
REAL*8 SUM

INTEGER TYPE, CHANGE, TPDF(2), SKIP

CHARACTER*30 IDENT

EXTERNAL FNC

DATA PI/3.14159265/

1 CALL CLEAR
WRITE(6,*) '*** Scene specification'
WRITE(6,*) ' From FUNCTION - Enter 1'
WRITE(6,*) ' From DATAFILE - Enter 2'
QUE = '==>', IAN = 1
CALL ASKI(QUE,IAN)
IF(IAN.NE.1.AND.IAN.NE.2) GO TO 1

GO TO (100,200), IAN

C INITIALIZE DEFAULTS FOR FUNCTION SPECIFICATION
C XMIN = LOWER LEVEL (BITONAL)
C XMAX = UPPER LEVEL (BITONAL)
C B AND N = PARAMETERS IN SPECTRA SPECIFICATION
C SWGT = WEIGHTING OF TWO MODES (FOR BIMODAL DSTR)
C MEAN = MEAN OF EACH MODE
C XMOD = STD DEV SPECIFICATION (STD DEV = XMOD*MEAN)
C TPDF = TYPE OF PDF (1-GAUSSIAN,2-LOGNORMAL)

100 XMIN=0.005
XMAX=0.955
B=3.0
N=3
SWGT(1)=1.0
SWGT(2)=0.0
MEAN(1)=0.500
MEAN(2)=0.750

DO 5 J=1,2
XMOD(J)=0.30
TPDF(J)=1
NB=0

5 CONTINUE

CALL CLEAR
WRITE(6,1000)B,N,XMOD(1),TPDF(1),MEAN(1)
1000 FORMAT(/24X,'INPUT SCENE INFORMATION:',
X//6X,'PARAMETER',10X,'COMMENT',20X,'DEFAULTS',
X//6X,'----------',10X,'--------',20X,'--------',
X//3X,'1. SPECTRUM',6X,'1/B**N+F**N',
X//9X,'B',12X,'HALF-POWER CY/MM',15X,F6.3,
X//9X,'N',12X,'CORRELATION',22X,I5,
X//3X,'2. VARIANCE',6X,'SIGMA/MEAN',21X,F6.3,
X//3X,'3. PDF SHAPE',7X,'1-NORMAL,2-LOGNORMAL',13X,I5,
X//3X,'4. MEAN(S)',9X,'REL EXPOSURE (0-1)',13X,F6.3)

WRITE(6,1001)
1001 FORMAT(/1X,'NOTE: INPUT SCENE AND IMAGE CHAIN ASSUMED TO BE '
X,'ISOTROPIC')
WRITE(6,*),'** Enter type of distribution?'
WRITE(6,*)'(1-unimodal 2-bimodal)'
QUE = '==='
TYPE = 1
CALL ASKI(QUE,IAN)
IF(TYPE.EQ.2.OR.TYPE.EQ.3) THEN
  WRITE(6,*), 'ENTER WEIGHTS FOR BIMODAL/BITONAL PDFS'
  READ(5,*),(SWG(J),J=1,2)
ENDIF

C UNIMODAL SPECIFICATION

IF(TYPE.EQ.1) THEN
  WRITE(6,*), '** Unimodal distribution specification'
  WRITE(6,*), 'to alter default values - enter 1, else enter 0'
  QUE = '==='
  CHANGE = 0
  CALL ASKI(QUE,CHANGE)
  IF(CHANGE.EQ.1) THEN
    WRITE(6,*), 'ENTER VALUES FOR B,N,MODUL,PDF SHAPE, MEAN'
    READ(5,*),(B.N,XMOD(1),TPDF(1),MEAN(1))
  ENDIF
ENDIF

C BIMODAL SPECIFICATION

IF(TYPE.EQ.2) THEN
  WRITE(6,*), 'BIMODAL DISTRIBUTION SPECIFICATION'
  WRITE(6,*), 'TO ALTER DEFAULT VALUES ENTER 1, ELSE ENTER 0'
  QUE = '==='
  CHANGE = 0
  CALL ASKI(QUE,CHANGE)
  IF(CHANGE.EQ.1) THEN
    WRITE(6,1007)
    1007 FORMAT(1X,'ENTER VALUES--'/
X1X,'B,N,MOD(1),MOD(2),PDF SHAPE(1),PDF SHAPE(2),MEAN(1),MEAN(2)')
    READ(5,*),(B.N,(XMOD(J),J=1,2),(TPDF(J),J=1,2),(MEAN(J),J=1,2))
  ENDIF
ENDIF

C INITIALIZE EXPOSURE VALUES FROM 0 TO 1 IN 0.0001 INCREMENTS
C INITIALIZE PDF (PROBABILITY (EXPOSURE VALUE)) = 0.0

DO 15 I=1,10000
  HSBIN(I)=0.0001*(I-0.5)
  HSPDF(I)=0.0
15 CONTINUE
CALCULATION OF INPUT PDF'S: -FORM AND WIDTH ARE ASSUMED TO BE
-10000 EQUALLY SPACED ESTIMATES IN RELATIVE EXPOSURE UNITS

UNIMODAL AND BIMODAL PDFS

SUM=0.0
TOT=SWGTL(1)+SWGTL(2)
IF(TYPE.EQ.1.OR.TYPE.EQ.2) THEN
   DO 30 J=1.TYPE
   VAR(J)=(XMOD(J)*MEAN(J)**2
   WIDTH=4.0*SQR(VAR(J))
   IF(WIDTH.LT.(0.001)) THEN
      L=INT(MEAN(J)*10000.+1
      HSPDF(L)=SWGTL(J)/TOT
      SUM=SUM+HSPDF(L)
   GO TO 30
   ENDIF
30 CONTINUE
IF(TYPE.EQ.1) THEN
   TMEAN=AL0GCMEAN(J)**2/SQRT(VAR(J))
   VAR(J)=AL0GC+VAR(J)/MEAN(J)**2
   MEAN(J)=TMEAN
ENDIF

DO 20 I=1,10000
IF(TPDF(J).EQ.1) THEN
   NORMAL DISTRIBUTION
   TEMP=0.0
   FAC=(HSBIN(I)-MEAN(J)**2/(2*VAR(J))
   IF(FAC.LT.150.0) TEMP=EXP(-FAC)*SWGTL(J)/TOT
   TEMP=TEMP/SQRT(2.*PI*VAR(J))
   HSPDF(I)=TEMP+HSPDF(I)
   IF (HSPDF(I).LT.(0.000001)) HSPDF(I) = 0.0
   SUM=SUM+HSPDF(I)
ELSE
   LOG-NORMAL DISTRIBUTION
   TEMP=0.0
   FAC=(AL0G(HSBIN(I))**2/(2*VAR(J))
   IF(FAC.LT.150.0) TEMP=EXP(-FAC)/HSBIN(I)/TOT
   TEMP=TEMP/SQRT(2.*PI*VAR(J))
   HSPDF(I)=TEMP+HSPDF(I)
   IF (HSPDF(I).LT.(0.000001)) HSPDF(I) = 0.0
   SUM=SUM+HSPDF(I)
ENDIF
20 CONTINUE
30 CONTINUE
ENDIF

RESCALE PDF SO INTEGRAL = UNITY

SET SIGNAL AND NOISE PDF EQUAL TO SIGNAL ONLY PDF
DO 60 I=1,10000
HSPDF(I)=HSPDF(I)/SUM
HSNPDF(I)=HSPDF(I)
HSNBIN(I)=HSBIN(I)
60 CONTINUE

C RECALCULATE MEAN AND VARIANCE AND DISPLAY TO USER
CALL STSPD1(HSBIN,HSPDF,AM,AV)
WRITE(6,70) AM,AV
70 FORMAT('0', 'Scene statistics (mean, variance)', F6.4, 1X, F6.4)
PAUSE

C REASSIGN MEANS AND VARIANCE
HSMEAN = AM
HSNMEAN = AM
HSVAR = AV
HSNVAR = AV

C CALCULATION OF INPUT SPECTRA: -SHAPE AND MODULATION ARE ASSUMED
C -CUTOFF FREQUENCY IS 20 CYCLES/MM
C -100 VALUES CALCULATED FROM 0 TO 20 CYCLES/MM
C -INPUT NOISE IS ZERO

C V1 LOWEST FREQUENCY
C V2 HIGHEST FREQUENCY

V1=0.0
V2=20.0

C SPECIFY "CUTOFF" FREQUENCY FOR IMAGE
C HCU = HORIZONTAL CUTOFF

HCU=SNGL(V2)
CUTOFF = HCU

AERR=0.0
RERR=0.001

HSNVAR=HSVAR

C SCALE SPECTRA SO THE INTEGRAL OF THE SPECTRA = VARIANCE

C CALCULATE INTEGRAL OF FUNCTION
XINT=SNGL(DCADRE(FNC,V1,V2,AERR,RERR,ERROR,IER))

C DETERMINE SCALING OF SPECTRA TO MAKE PDF VARIANCE = INTEGRAL
A = (2.*PI*HSVAR)/(2.*XINT)

C SCALE SPECTRA

DO 10 I=1,100
FREQ(I)=0.2*(I-0.5)
HSP(I)=A/(E**N+FREQ(I)**N)
HSNP(I)=HSP(I)
10 CONTINUE

GO TO 999

C READ IMAGE PDF FROM FILE

200 WRITE(6,*) 'READING FILE ....'

C INITIALIZE PDF

DO 205 I = 1,10000
HSPDF(I) = 0.0
HSBIN(I) = 0.0
205 CONTINUE

C OBTAIN FILENAME

210 WRITE(6,*) 'ENTER FILENAME FOR DATAFILE'
READ(5,FMT='(A8)') FNAME
FTYPE = 'HIST'
RECFM = '
LUNIT = 12
CALL SEQOP2 (FNAME,FTYPE,LUNIT,RECFM,NERR)
IF (NERR.NE.0) THEN
WRITE(6,*) 'ERROR IN OPENING FILE ',NERR
GO TO 210
ENDIF

C MOVE DOWN FILE TO HISTOGRAM DATA (BUILDING 69 FORMAT)

DO 220 I = 1,8
READ(12,215)JUNK
215 FORMAT(A1)
220 CONTINUE

C READ IN DATA FROM FILE

C A2 = 1000*RELATIVE LOGE
C R = FREQUENCY OF RED PIXELS
C R = FREQUENCY OF GREEN PIXELS
C R = FREQUENCY OF BLUE PIXELS

SUM = 0.
DO 230 I = 1,10000
READ(12,*,END=240) A1,A2,R,G,B
EXPOS = 10.**((A2/1000.) - 2.25)
IF (EXPOS.GT.(1.0)) GO TO 230
IREAD = I
HSBINCIREAD) = EXPOS
HSPDF(IREAD) = G
SUM = SUM + HSPDF(IREAD)
230 CONTINUE
240 CONTINUE
CLOSE (UNIT=12)
C NORMALIZE PDF SO SUM IS EQUAL TO 1.0
C SET SIGNAL AND NOISE PDF TO BE EQUAL TO SIGNAL ONLY PDF
DO 250 I = 1,10000
IF (I.GT.IREAD) HSBIN(I) = HSBIN(IREAD)
HSPDF(I) = HSPDF(I) / SUM
HSNBIN(I) = HSBIN(I)
HSNPDF(I) = HSPDF(I)
250 CONTINUE
HSNVAR = 1.0
HSVAR = 1.0
HSMEAN = 1.0
HSNMEAN = 1.0
C CORRECT SPACING OF HSBIN TO BE EQUAL INCREMENTS
CALL PDFUNL(CONS,CONSN)
C OBTAIN MEAN AND VARIANCE
CALL STSPD1(HSBIN,HSPDF,AM,AV)
CALL CLEAR
WRITE(6,70) AM,AV
PAUSE
C REASSIGN MEANS AND VARIANCE
HSMEAN = AM
HSNMEAN = AM
HSVAR = AV
HSNVAR = AV
C CALCULATION OF INPUT SPECTRA: -SHAPE AND MODULATION ARE ASSUMED
-CUTOFF FREQUENCY IS 20 CYCLES/MM
-100 VALUES CALCULATED FROM 0 TO 20 CYCLES/MM
-INPUT NOISE IS ZERO
C V1 LOWEST FREQUENCY
C V2 HIGHEST FREQUENCY

V1=0.0
V2=20.0
B=1.
N=2

C SPECIFY "CUTOFF" FREQUENCY FOR IMAGE
C HCUT = HORIZONTAL CUTOFF

HCUT=SNGL(V2)

C INITIALIZE CUTOFF FREQUENCY FOR INTEGRATION
CUTOFF = HCUT
AERR=0.0
RERR=0.001
HSNVAR=HSVAR

C SCALE SPECTRA SO THE INTEGRAL OF THE SPECTRA = VARIANCE
XINT=SNGL(DCADRE(FNC,V1,V2,AERR,RERR,ERROR,IEM))
A=HSVAR/(XINT*2.0)

DO 260 I=1,100
FREQ(I)=0.2*(I-0.5)
HSP(I)=A/(B**N+FREQ(I)**N)
HSNPCI=HSP(I)
260 CONTINUE

999 CONTINUE

C OUTPUT SCENE DATA TO A FILE
IDENT = 'AFTER INPUT SCENE SPEC'
CALL OUTPDF(IDENT)
CALL OUTSPT(IDENT)

C STORE SCENE SPECIFICATION AND STATISTICS IN FILE
WRITE(9,1011)B,N,XMOD(1),TPDF(1),MEAN(1)
WRITE(9,70) AM,AV

1011 FORMAT('0',/4X,'Scene Information (Unimodal)',:,
X//5X,'Parameter',10X,'Comment',20X,'Value',,
X/5X,'-------',10X,'-------',20X,'------',
X//3X,'1. Spectrum',6X,'1/B**N+F**N',,
X/9X,'B',12X,'Half-Power CY/MM',15X,F6.3,
X/9X,'N',12X,'Correlation',,22X,I5,
X//3X,'2. Variance',8X,'Sigma/Mean',21X,F6.3,
X/3X,'3. PDF Shape',7X,'1-Normal,2-Lognormal',13X,I5,
X//3X,'4. Mean ',9X,'Rel Exposure (0-1)',13X,F6.3)
RETURN
END
SUBROUTINE SNP2(XMAG,HVAR)

C***
C
C Purpose: To modify the signal + Noise spectrum for the additional
C variance. Noise can be either
C 1. Bandlimited white noise
C 2. Exponential
C 3. Triangular
C
C Subroutines called:
C CLEAR ASKI
C
C Passed variables:
C XMAG = Magnification to the next stage
C HVAR = Additional variance due to noise
C
C Commoned data;
C HSANDN: HSNP = Spectrum of signal and noise
C HSNPDF = PDF of signal and noise
C HSNVAR = Signal and noise variance
C HSNMEN = Signal and noise mean
C INDVAR: HSBIN = Value of signal for PDF
C HSNBIN = Values of signal with noise for S+N PDF
C FREQ = Frequencies for spectra
C SWGT = Frequencies for spectra
C TYPE = Frequencies for spectra
C INTINF: NTYPE = Type of spectrum
C CUTOFF = Cutoff frequency
C
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C***

COMMON/HSANDN/HSNP,HSNPDF,HSNVAR,HSNMEN
COMMON/INDVAR/HSBIN,HSNBin,FREQ,SWGT,TYPE
COMMON/INTINF/NTYPE,CUTOFF

REAL HSNP(100),HSNPDF(10000)
REAL HSBIN(10000),HSNBin(10000)
REAL HN(100),FREQ(100),SWGT(2)

CHARACTER*80 QUE

DATA PI/3.141592654/

DO 5 I = 1,100
5 HN(I) = 0.0

C OBTAIN TYPE OF NOISE

CALL CLEAR
**FILE:** SNP2  FORTRAN  A1  Last edited on: 4/08/88  7:53:47

```
10  WRITE(6,100)
100  FORMAT( ' Enter type of noise:',
1 1X,/ 
1 1X, 1. Bandlimited White Noise',
1 1X, 2. Triangular shaped Noise',
1 1X, 3. Exponential Noise')
   QUE = '===',
   IDEF = 2
   CALL ASKI(QUE,IDEF)
   IF(IDEF.LT.1.OR. IDEF.GT.3) GO TO 10

   WRITE(6,*)' Enter frequency cutoff for unity magnification'
   QUE = '===',
   FCUT = 50.
   CALL ASKRI(QUE,FCUT)

   IF(IDEF.EQ.1) THEN
      DO 200 I = 1,100
         IF((FREQ(I)*XMAG).LE.FCUT) HN(I) = (HVAR*2.*PI)/(2.*FCUT/XMAG)
      CONTINUE
      WRITE(9,1002) FCUT
      1002  FORMAT( ' Bandlimited White Noise , Cutoff at ',F6.2)
      ELSE IF(IDEF.EQ.2) THEN
         CONS = XMAG*((HVAR*2.*PI)/FCUT)
         DO 300 I = 1,100
            IF((FREQ(I)*XMAG).LE.FCUT) HN(I) = CONS -(CONS/(FCUT/XMAG))*FREQ(I)
         CONTINUE
         WRITE(9,1003) FCUT
         1003  FORMAT( ' Triangular Shaped Noise , Cutoff at ',F6.2)
      ELSE IF(IDEF.EQ.3) THEN
         CONS1 = 4.605*XMAG/FCUT
         CONS2 = CONS1*(HVAR*2.*PI)/2.
         DO 400 I = 1,100
            IF((FREQ(I)*XMAG).LE.FCUT) HN(I) = CONS2*EXP(-1.*CONS1*FREQ(I))
         CONTINUE
         WRITE(9,1004) FCUT
         1004  FORMAT( ' Exponentially Shaped Noise , Cutoff at ',F6.2)
      ENDIF
      MODIFY SIGNAL & NOISE SPECTRA BY ADDING ADDITIONAL NOISE SPECTRUM
      DO 500 I=1,100
         HSNP(I) = HSNP(I) + HN(I)
      C WRITE(10,*)'SNP ',FREQ(I),HN(I), HSNP(I)
500  CONTINUE
```
WRITE(6,*) 'Spectrum modified'

NTYPE = IDEF
IF(NTYPE.NE.3.AND.FCUT.LT.(CUTOFF/XMAG)) CUTOFF = FCUT/XMAG

RETURN
END
SUBROUTINE SNPDF3(IFLAG,HNV,IERR)

Purpose: To modify the Signal and Noise PDF/Spectrum for the
addition of noise

Subroutines called:
MDNORD

Passed variables:
IFLAG  =  Type of noise (gaussian in linear or density)
HNV    =  Additional variance in signal with noise
IERR   =  Error flag

Commoned data;
HSIGNL:  HSP     =  Spectrum of signal
         HSPDF   =  PDF of signal
         HSVAR   =  Signal variance
         HSMEAN  =  Signal mean
HSANDN:  HSNP    =  Spectrum of signal and noise
         HSNPDF  =  PDF of signal and noise
         HSNVAR  =  Signal and noise variance
         HSNMEN  =  Signal and noise mean
INDVAR:  HSBIN   =  Value of signal for PDF
         HSNBIN  =  Values of signal with noise for S+N PDF
         FREQ    =  Frequencies for spectra
         SWGT    =  Frequencies for spectra
         TYPE    =  Frequencies for spectra
GRANUL:  HGR     =  Granularity data

COMMON/HSIGNL/HSP,HSPDF,HSVAR,HSMEAN
COMMON/HSANDN/HSNP,HSNPDF,HSNVAR,HSNEM
COMMON/INDVAR/HSBIN,HSNBIN,FREQ,SWGT,TYPE
COMMON/GRANUL/HGR

REAL  HSP(100),HSPDF(10000)
REAL  HSNP(100),HSNPDF(10000)
REAL  HSBIN(10000),HSNBIN(10000)
REAL  FREQ(100),SWGT(2)
REAL  HGR(10000)
REAL  HDTEMP(15000)
REAL*8 HPTEMP(10000)
REAL*8 ZBIN,ZPROB,ARGL,ARGU,LV,UV,PCELL,HSUM
REAL*8 HTMP1,HTMP2
REAL*8 SUMC

INTEGER OUTT,OUT,OLOW,OHIG,IN
DETERMINE THE CONDITIONAL NOISE PDF'S FOR ALL POSSIBLE ARGUMENTS, I.E., PROB(Z-SN/SN) WHERE SN IS A DISCRETE INPUT VALUE, Z IS A DISCRETE OUTPUT VALUE, AND Z-SN IS THE NOISE. BECAUSE Z VALUES CAN SPAN THE FULL DYNAMIC RANGE AND THE NOISE CAN BE SMALL CAUSING PROB(Z-SN/SN) TO APPROACH A DELTA FUNCTION, 1000 OUTPUT BINS WILL BE USED. THEY WILL BE LINEARLY SPACED FROM 0-100 IN RELATIVE EXPOSURE UNITS. AFTER INTEGRATION THE RESULTS WILL BE SUMMED IN GROUPS OF TEN TO PRODUCE 100 OUTPUT BINS. TO CONVERT THE CONTINUOUS PDF'S TO DISCRETE PDF'S CONTINUOUS VALUES AT THE CENTER OF EACH BIN ARE MULTIPLIED BY THE BIN WIDTH.

DETERMINE THE LIMITS OF NON-ZERO INPUT PROBABILITIES TO IMPROVE THE PERFORMANCE OF THE CALCULATION OF THE CONDITIONAL PDF FUNCTIONS

IERR = 0
IFL = 0
DO 10 K=1,15000
HDTEMP(K) = (K - 0.5)/10000.
IF (K.GE.1.AND.K.LE.10000) THEN
WRITE(10,*)'OLDPDF ',K,HSNIN(K),HSNPDF(K)
HDTEMP(K) = 0.0
IF (HSNPDF(K).LT.(0.000001).AND.IFL.EQ.0) INL = K
IF (IFL.EQ.0.AND.HSNPDF(K).GE.(0.000001)) IFL = 1
IF (IFL.EQ.1) INH = K
IF (HSNPDF(K).LT.(0.000001).AND.IFL.EQ.1) THEN
INH = K
IFL = 2
ENDIF
IF (HSNPDF(K).GE.(0.000001).AND.IFL.EQ.2) THEN
INH = K
IFL = 1
ENDIF
ENDIF
10 CONTINUE
IF (INH.EQ.0) INH = 10000
WRITE(6,*) 'Limits of non-zero input PDF ',INL,INH
WRITE(9,*) 'Limits of non-zero input PDF ',INL,INH
IF(IFLAG.EQ.0) THEN
C NOISE ADDITION IS GAUSSIAN IN LINEAR METRIC
C
C Perform calculation of output pdf for each input cell
C \( p(out) = \text{integral} \ (p(out/in) \cdot p(in)) \ d(input) \)

\[ HSUM = 0.0 \]

DO 30 IN = INL,INH

C SPEED UP LOOP

IF (HSNPDF(IN).LE.(0.0)) GO TO 20

C TO SPEED UP CALCULATION DETERMINE THE LOWEST AND HIGHEST LIMIT
C OF THE OUTPUT VALUES AND CALCULATE ONLY OVER THAT REGION

TLOW = HSNBIN(IN) - 3.8*HGR(IN)

OLOW = INT(TLOW * 10000.)

IF (OLOW.LT.1) IERR = 1

OLOW = MAX(OLOW,1)

THIG = HSNBIN(IN) + 3.8*HGR(IN)

OHIG = INT(THIG * 10000.)

OHIG = MIN(OHIG,15000)

IF (OHIG.GT.15000) IERR = 2

SUMC = 0.0

C PERFORM CALCULATION OVER CONDITIONAL PDF

C CALCULATE CONDITIONAL PDF \( p(out/in) \) BASED ON A GAUSSIAN

C INTEGRATE GAUSSIAN DISTRIBUTION IN LINEAR VALUE

C DETERMINE CONDITIONAL PDF

C DETERMINE JOINT PROBABILITY \( p(out/in) \cdot p(in) \)

C STORE JOINT PROBABILITY IN OUTPUT ARRAY AND EACH LOOP WILL

C SUM OVER ALL INPUT VALUES

DO 20 OUT = OLOW,OHIG

OUTT = OUT

IF (OUTT.GT.10000) OUTT = 10000

ZBIN = DBLE(HDTEMP(OUT))

ZPROB = 0.0

C FIND OUTPUT PROBABILITY \( p(out/in) \)

IF ((ZBIN-0.00005).GE.(0.0)) THEN

ARGL = ((ZBIN - 0.00005) - DBLE(HSNBIN(IN)))/DBLE(HGR(IN))

CALL MDNORDCARGU.LV)

ARGU = ((ZBIN + 0.00005) - DBLE(HSNBIN(IN)))/DBLE(HGR(IN))

CALL MDNORDCARGU.UV)

ZPROB = UV-LV

ENDIF

C CALCULATE \( p(out,in) = p(out/in) \cdot p(in) \)

PCELL = DBLE(HSNPDF(IN))*ZPROB

C WRITE(10,*) 'SNPDF L ',IN,OUT,ZPROB,HSNPDF(IN)
FILE: SNPDF3 FORTRAN A1 Last edited on: 10/15/87 13:16:11

IF (PCELL.LT.(1.D-10)) GO TO 20
C
SUM OVER INPUT CELLS FOR EACH LOOP OF IN
SUM OVER P(out,IN) OVER IN = P(out)
HSUM = HSUM + PCELL
HPTEMP(outt) = HPTEMP(outt) + PCELL
SUMC = SUMC + ZPROB

20 CONTINUE

IF (FLOAT(IN/250).EQ.(FLOAT(IN)/250.)) WRITE(6,45) IN,INH,HSUM
45 FORMAT(' ', 'Input cell ', I8,'/',I8,' Sum of P(out,IN ) ',F10.5)
30 CONTINUE

ELSE
C
NOISE NORMAL IN DENSITY (I.E. -LOG10(LINEAR METRIC))
C
Perform calculation of output pdf for each input cell
p(out) = integral (p(out/in) * p(in)) d(input)
HSUM = 0.0
DO 50 IN = INL,INH
C
SPEED UP LOOP
IF (HSNPDF(IN).LE.(0.0)) GO TO 40
C
TO SPEED UP CALCULATION DETERMINE THE LOWEST AND HIGHEST LIMIT
C
OF THE OUTPUT VALUES AND CALCULATE ONLY OVER THAT REGION
C
TLOW = 10.**(-1.*(-1.*LOG10(HSNBIN(IN)) + 3.8*HGR(IN)))
OLOW = INT(TLOW * 10000.) - 1
IF (OLOW.LT.1) IERR = 1
OLOW = MAX0(OLOW,1)
THIG = 10.**(-1.*(-1.*LOG10(HSNBIN(IN)) - 3.8*HGR(IN)))
OHIG = INT(THIG * 10000.) + 1
IF (OHIG.GT.15000) IERR = 2
OHIG = MIN0(OHIG,15000)
SUMC = 0.0

C
PERFORM CALCULATION OVER CONDITIONAL PDF
C
CALCULATE CONDITIONAL PDF P(out/in) BASED ON A GAUSSIAN
C
DISTRIBUTION IN DENSITY
C
INTEGRATE GAUSSIAN DISTRIBUTION OVER RANGE OF OUTPUT VALUES
C
DETERMINE CONDITIONAL PROBABILITY
C
DETERMINE JOINT PROBABILITY P(out/in)*P(IN)
C
STORE JOIN PROBABILITY IN OUTPUT ARRAY AND EACH LOOP WILL
C
SUM OVER ALL INPUT VALUES
FILE: SNPDF3 FORTRAN A1  Last edited on: 10/15/87 13:16:11

DO 40 OUT = OLOW,OHIG
  OUTT = OUT
  IF (OUT.GT.10000) OUTT = 10000
  ZBIN = DBLE(HDTEMP(OUT))
  ZPROB = 0.0
  IF ((ZBIN-0.00005).GE.(0.0)) THEN
    ARGL = (-1.*DLOG10(ZBIN+0.00005) -
             DBLE(-1.*LOG10(HSNBIN(IN))))/DBLE(HGR(IN))
    CALL MDNORD(ARGL,LV)
    ARGU = (-1.*DLOG10(ZBIN-0.00005) -
             DBLE(-1.*LOG10(HSNBIN(IN))))/DBLE(HGR(IN))
    CALL MDNORD(ARGU,UV)
    ZPROB = UV-LV
  ENDIF
  PCELL = DBLE(HSNPDF(IN))*ZPROB
  IF (PCELL.LT.(1.D-10)) GO TO 40
C 40 CONTINUE
  HSUM = HSUM + PCELL
  HPTEMP(OUTT) = HPTEMP(OUTT) + PCELL
  SUMC = SUMC + ZPROB
C  WRITE(10,*)IN,OLow,OHig,OUT,HPTEMP(OUT)
  IF (FLOAT(IN/250).EQ.(FLOAT(IN)/250.)) WRITE(6,45) IN,INH,HSUM
C 50 CONTINUE
C ENDIF
C  WRITE(6,60) HSUM
  IF (X/1X,'Sum of Joint Probability ',F10.5)
C C RENORMALIZE AND FIND NEW MEANS AND VARIANCES
C
  HTMP1=0.0
  HTMP2=0.0
  DO 100 I=1,10000
    HSNPDF(I) = SNGL(HPTemp(I)/HSUM)
    HSNBINC(I) = HDTEMP(I)
    WRITE(10,*)'NEW PDF ',I,HSNBINC(I),HSNPDF(I)
    HTMP1 = DBLE(HSNPDF(I))*DBLE(HSNBIN(I)) + HTMP1
    HTMP2 = DBLE(HSNPDF(I))*DBLE(HSNBIN(I))*DBLE(HSNBIN(I)) + HTMP2
C 100 CONTINUE
C CALCULATE ADDITIONAL NOISE VARIANCE BY
C S+N VARIANCE OUT - S+N VARIANCE IN
C

HNVN = SNGL(HTMP2 - (HTMP1*HTMP1))
HNV = HNVN - HSNVAR
WRITE(6,105) HNV
105 FORMAT(' ', 'Additional Variance = ', F8.6)
IF(HNV.LE.0.0) HNV = 0.0
HSNMEM = SNGL(HTMP1)
VAROLD = HSNVAR
HSNVAR = HNV + HSNVAR
WRITE(6,110) HSMEAN, HSNVAR
110 FORMAT(' ', 'S stats (mean, variance) ', F6.3, 1X, F8.6)
WRITE(6, 120) HSNMEM, HSNVAR
120 FORMAT(' ', 'S+N stats (mean, variance) ', F6.3, 1X, F8.6)
WRITE(9, 1000) HSMEAN, HSNVAR, HSNMEM, HSNVAR
1000 FORMAT(' ', /1X, 'Results from addition of noise ',
          X/1X, 'Mean',
          X/1X, 'Variance',
          X/1X, 'Signal',
          X/1X, 'Signal and Noise',
          F6.3, 1X, F8.6,
          F6.3, 1X, F8.6)
WRITE(6,*') 'Completed Modification of S + N PDF'
PAUSE
RETURN
END
SUBROUTINE SPTPLT(TITLE,LF,POINT)

C***SUBROUTINE SPTPLT***

C Purpose: Produce plot of spectra

C Subroutines called:
C PLTXY2

C Passed variables:
C TITLE = Title for output
C LF =
C POINT =

C Commoned data;
C HSIGNL: HSP = Spectrum of signal
C HSPDF = PDF of signal
C HSVAR = Signal variance
C HSMEAN = Signal mean
C HSANDN: HSNP = Spectrum of signal and noise
C HSNPDF = PDF of signal and noise
C HSNVAR = Signal and noise variance
C HSNMEN = Signal and noise mean
C INDVAR: HSBIN = Value of signal for PDF
C HSNBIN = Values of signal with noise for S+N PDF
C FREQ = Frequencies for spectra
C SWGT = Frequencies for spectra
C TYPE = Frequencies for spectra
C PVAR: LEG =
C X =
C Y =
C AMIN =
C AMAX =
C BMIN =
C BMAX =

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10/01/87

COMMON/HSIGNL/HSP,HSPDF,HSVGAR,HSMEAN
COMMON/HSANDN/HSNP,HSNPDF,HSNVAR,HSNMEAN
COMMON/INDVAR/HSBIN,HSNBIN,FREQ,SWGT,TYPE
COMMON/PVAR/LEG,X,Y,AMIN,AMAX,BMIN,BMAX

REAL HSP(100),HSPDF(10000)
REAL HSNP(100),HSNPDF(10000)
REAL HSBIN(10000),HSNBN(10000)
REAL YS(100),YSN(100),AMIN,AMAX,BMIN,BMAX,IS(100)
REAL FREQ(100)

INTEGER LF,NP,TYPE,POINT

CHARACTER*16 LEG(2),X(2),Y(2)
CHARACTER*8 TITLE(2)

WRITE(6,*) 'Creating Plot of Image Spectrum -- Please wait'

AMIN=0.0
AMAX=9.50
BMIN=0.00001
BMAX=0.01

DO 3 I = -4,4
TEST = 10.**I
IF (BMAX.LT.TEST) GO TO 4
CONTINUE
3
4 BMAX = TEST
NP=100

DO 10 I=1,NP
XS(I)=FREQ(I)
YS(I)=HSP(I)
YSN(I)=HSNP(I)

C BMIN=AMIN1(BMIN,HSP(I))
C BMAX=AMAX1(BMAX,HSP(I))
10 CONTINUE

C IF(BMIN.EQ.0.0) BMN=BMAX*1.E-5
X(1) ='(P)REQUENCY C/MM'
Y(1) ='(P)OWER (S)PECT.'
LEG(1)= 'SIGNAL $
LEG(2)= 'SIGNAL + NOISE '$

C PLOT SPECTRA
CALL PLTXY2(TITLE,XS,XS,YS,YSN,LF,NP,2,POINT,1)

RETURN
END
SUBROUTINE STSPD1(BIN, PDF, AM, AV)

C** SUBROUTINE STSPD1
C
C Purpose : Calculate statistics (means and variances)
C
C Subroutines called:
C NONE
C
C Passed variables:
C BIN = Value
C PDF = Probability of the value
C AM = Mean
C AV = Variance
C
C Commoned data:
C NONE
C WILLIAM R. O'SUCH
C 10/01/87
C
REAL BIN(10000), PDF(10000)
REAL*8 MEAN, VAR

C CALCULATE MEAN
MEAN = 0.0
DO 10 I = 1, 10000
X = DBLE(BIN(I))
PX = DBLE(PDF(I))
MEAN = MEAN + PX*X
10 CONTINUE

C CALCULATE VARIANCE
VAR = 0.0
DO 20 I = 1, 10000
X = DBLE(BIN(I))
PX = DBLE(PDF(I))
VAR = VAR + (X - MEAN)*(X - MEAN)*PX
20 CONTINUE

AM = SNGL(MEAN)
AV = SNGL(VAR)

RETURN
END
SUBROUTINE TRUN1(BIN, PDF, MEAN, VAR, ELOW, EHIGH)

Purpose: To clip signal and signal & Noise PDFs. Packing
Clipped values in the lowest and highest bins available
Calculate news statistics and noise power spectra.

Main Program: IQCN1
Subroutines called: TRUN1
Passed variables:
ELOW =
EHIGH =
BIN = Value
PDF = Probability of Value
MEAN = Mean
VAR = Variance

Commoned data:
NONE
WILLIAM R. O'SUCH
07/31/87

REAL BIN(10000), PDF(10000), MEAN
XL=0.0
XXL=0.0
XSUML=0.0
XH=0.0
XXH=0.0
XSUMH=0.0
HW=(BIN(2)-BIN(1))/2.
DO 10 I=1,10000
IF(BIN(I)+HW.LT.ELOW) THEN
XL=XL+PDF(I)*BIN(I)
XXL=XXL+PDF(I)*BIN(I)**2
XSUML=XSUML+PDF(I)
PDF(I)=0.0
ELSE
YL=XSUML*BIN(I)
YYL=XSUML*BIN(I)**2
PDF(I)=XSUML+PDF(I)
GO TO 20
ENDIF
10 CONTINUE
20 DO 30 I=10000,1,-1
IF(BIN(I)-HW.GT.EHIGH) THEN
XH=XH+PDF(I)*BIN(I)
XXH=XXH+PDF(I)*BIN(I)**2
XXH=XXH+PDF(I)
PDF(I)=0.0
ELSE
YH=XSUMH*BIN(I)
YYH=XSUMH*BIN(I)**2
PDF(I)=XSUMH+PDF(I)
GO TO 40
ENDIF
30 CONTINUE
C CALCULATE NEW MEANS AND VARIANCES
C
40 XMOD1=YYL+YYH-XXL-XXH
XMOD2=YL+YH-XL-XH
VAR=VAR+MEAN**2+XMOD1-(MEAN+XMOD2)**2
MEAN=MEAN+XMOD2
RETURN
END
APPENDIX C

LISTING OF POSSIBLE VARIATIONS

Below is a list of the parameters that one can vary within IQCN1.

**Input image**

- Mean
- Variance
- Spectrum Shape
- Measured spectrum from a file

**Camera lens/film stage**

Magnification from Camera/film stage to printer lens/paper stage

Camera lens Modulation Transfer Function

- Input can come from either:
  - File
  - Diffraction limited equation

**Film**

Modulation Transfer Function

- Input can come from either:
  - File
  - Gaussian function

Density-log Exposure Function

- Input can come from either:
  - File
  - Straight Line function with gamma, min. density and max. density
  - ArcTan Function

Granularity

- Input can come from either:
  - File
  - Function

Power Spectrum

- Shape can be either:
  - Band limited white noise
  - Exponential
  - Triangular
**Printer lens/Paper stage**

Printer lens modulation transfer function
- Input can come from either:
  - File
  - Diffraction Limited equation

**Paper**

- Modulation Transfer Function
  - Input can come from either:
    - File
    - Gaussian function
- Density-log Exposure Function
  - Input can come from either:
    - File
    - Straight Line function with gamma, min. density and max. density
    - ArcTan Function

**Granularity**

- Input can come from either:
  - File
  - Function

**Power Spectrum**

- Shape can be either:
  - Band limited white noise
  - Exponential
  - Triangular

**Human Visual System**

- Surround Illuminance
- Viewing Distance

Page C-2
APPENDIX D

EXAMPLE SESSION

The following output shows an example interactive session. The following is a description of each response:

1. Command to start program - IQCN1.

2. Specify FILENAME (FILETYPE assumed to be LISTING) for output listing. In this case VARIATION 1 is chosen.

3. Specify plotting device. In this case a QMS Laser printer is chosen.

4. Specify for number of components (i.e. stages). Up to 10 stages can be chosen. In this case, a color negative system has two components - film and paper.

5. Specify the sequence of components. In this case - 1,2 - indicates that a film then a paper stage will be used.

6. Specification for plotting of each stage. In this case - 1,1 - indicates that both the film and paper stage results will be plotted.

7. Specification for the type of plotting of PDFs and SPECTRA. In this case - 0,2 - indicates that a Linear-Linear plot is used for PDFs and a Logarithmic-Linear plot is used for the SPECTRA.

8. Specify title for output and plots.

9. Specify scene (i.e. input signal). A 1 indicates that the scene is from a function, while a 2 indicates that the data comes from a datafile. A description of the defaults is shown.

10. Specify a bimodal or unimodal type distribution. A unimodal distribution (i.e. default of 1) was chosen.

11. Specify whether to change default values that were listed earlier.

12. Resultant scene statistics (mean and variance).

13. Specify scaling for PDFs. Either full scale (0-1) or centered around mean (+/- 0.2).

14. Specify magnification to next stage. In this case, the default value of 3.88 x was chosen.

15. Specify camera lens MTF. Either from a datafile or a diffraction limited equation. In this case the function was chosen.

16. Specify f-number for diffraction limited equation. In this case, the default of f-8.0 was chosen.
17. Results from modification of PDFs/Spectra for the lens MTF. Variances before and after modification are listed.

18. Specify film MTF. Either from a datafile or a gaussian function. In this case, a datafile was chosen.

19. Specify FILENAME for film MTF. FILETYPE is assumed to be DATA. FILM was chosen.

20. Results from modification of PDF for film MTF. Variance before and after modification is shown.

21. Specify if Density-log Exposure curve is from a file, straight line function or arc-tangent function. In this case, a datafile was chosen.

22. Specify FILENAME for DlogE data. FILM2 was specified.

23. Specify FILETYPE for DlogE data. IQFILM was specified.

24. Specify where on the log Exposure axis will the mean of the previous stage be centered. In this case the default (i.e. 1.4) was not chosen and a new value of 1.8 is chosen.

25. Results from transfer of input PDF through DlogE curve. New statistics are listed.

26. Specify if film granularity data is from a file or a function. A file was chosen.

27. Specify FILENAME for granularity data. FILM2 was chosen.

28. Specify FILETYPE for granularity data. IQFILM was chosen.

29. Results from modification of signal and noise PDF. Progress of calculation is shown. Resultant statistics are shown.

30. Specify shape of noise. Either bandlimited white noise, triangularly shaped noise or exponentially shaped noise. Exponential noise was chosen.

31. Specify frequency where noise power is 1% of unity power. 100 cycles/mm was chosen.

32. Resultant information content and other metrics.

33. Specify scaling for PDF plots. In this case the plot will be centered around the mean (+/- 0.2).

34. Specify printer lens MTF from either a datafile or diffraction limited equation. In this case the function was chosen.

35. Specify f-number for diffraction limited equation. In this case, the default of f-5.6 was chosen.
36. Results from modification of PDFs for the lens MTF. Variances before and after modification are listed.

37. Specify if paper MTF is from either a datafile or a gaussian function. In this case, a datafile was chosen.

38. Specify FILENAME for paper MTF. FILETYPE is assumed to be DATA. PAPER1 was chosen.

39. Results from modification of PDFs for paper MTF. Variances before and after modification are shown.

40. Specify if Density-log Exposure curve is from a file, straight line function or arc-tangent function. In this case, a datafile was chosen.

41. Specify FILENAME for DlogE data. PAPER was specified.

42. Specify FILETYPE for DlogE data. IQPAPER was specified.

43. Specify where on the log Exposure axis will the mean of the previous stage be centered. In this case the default was not chosen and a new value of 0.85 was chosen.

44. Results from transfer of PDFs through DlogE curve. New statistics are listed.

45. Specify if paper granularity data is from a file or a function. A file was chosen.

46. The file PAPER IQPAPER is entered.

47. Results from modification of signal and noise PDF. Progress of calculations are shown. Resultant statistics are shown.

48. Specify shape of noise. Either bandlimited white noise, triangularly shaped noise or exponentially shaped noise. Bandlimited white noise was chosen.

49. Specify cutoff frequency. 20 cycles/mm was chosen.

50. Resultant information content and other metrics.

51. Specify scaling for PDF plots. In this case the plot will be centered around the mean (+/- 0.2).

52. Specify if soft or hard copy. The default of hard copy was chosen.

53. Specify surround illuminance. The default of 6 ft-lamberts was chosen.

54. Specify viewing distance. The default of 355 mm was chosen.
55. Results from modification of data for the neural, sampling and optical MTF effects of human visual system.

56. Results from modification of data for the noise effects of the human visual system. Progress of calculations are shown. Resultant statistics are displayed.

57. Specify shape of noise. Either bandlimited white noise, triangularly shaped noise or exponentially shaped noise. Bandlimited white noise was chosen.

58. Specify cutoff frequency. 20 cycles/mm was chosen.

59. Resultant information content and other metrics.

60. Specify scaling of PDFs.

61. Specify location where plots will be sent.

62. Exit program
Trace of IQCN1:

**1.**
```bash
iqcn1
```
**2.**
```bash
ENTER NAME OF LISTING FILE FOR OUTPUT
```
**3.**
```bash
var1
```
**4.**
```bash
GO IQCN1 (mod. 4-B-86)
```

Attempting load.

**DMSLIO7401 EXECUTION BEGINS...**

**ENTER OUTPUT DEVICE CODE**
- **0** → TERMINATE PROCESS
- **1** → IBM 3279 Terminal
- **2** → ZETA Plotter (3rd floor)
- **3** → QMS Laser Printer (1st floor)
- **4** → VT240 Emulation (7171 Protocol Converter)
- **5** → Tektronix 4105 emulator (7171 Converter)

**List of possible components:**

1. lens-film
2. lens-paper

**Enter number of components:**

? 2

**Enter sequence of components (i.e. 1,2)**

? 1,2

**For each component, specify if you would like a plot - (1 - yes , 0 - no)**

? 1,1

**Specify type of plot for PDF,SPECTRA:**

- Linear-Linear = 0
- Linear-Logarithmic = 1
- Logarithmic-Linear = 2
- Logarithmic-Logarithmic = 3

? 0,2

**Enter 16 character title**

VARIATION 1
** Scene specification
From FUNCTION - Enter 1
From DATAFILE - Enter 2

---

1 (DEFAULT)

** INPUT SCENE INFORMATION:

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>COMMENT</th>
<th>DEFAULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SPECTRUM</td>
<td>1/Be<em>N</em>Fe*N</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>HALF-POWER CY/MM</td>
<td>3.000</td>
</tr>
<tr>
<td>N</td>
<td>CORRELATION</td>
<td>3</td>
</tr>
<tr>
<td>2. VARIANCE</td>
<td>SIGMA/MEAN</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF SHAPE</td>
<td>1-NORMAL, 2-LOGNORMAL</td>
<td>1</td>
</tr>
<tr>
<td>4. MEAN(S)</td>
<td>REL EXPOSURE (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

NOTE: INPUT SCENE AND IMAGE CHAIN ASSUMED TO BE ISOTROPIC

** Enter type of distribution?
(1-unimodal 2-bimodal)

---

1 (DEFAULT)

** Unimodal distribution specification

To alter default values - enter 1, else enter 0

---

0 (DEFAULT)

** Scene statistics (mean, variance) 0.5000 0.0223

IFY001A PAUSE

Creating plot of PDF — Please wait

** Scale plot from 0 to 1 (1) or Best Fit (2)

1 (DEFAULT)

** Enter range around mean

0.399999976 (DEFAULT)

Creating Plot of Image Spectrum — Please wait
Component
1
Entering camera/film section
IFY001A PAUSE
** Enter Magnification to next stage
DEFAULT: Magnification = 3.88
CHANGE? 1-yes 0-no
->
0 (DEFAULT)
** Camera Lens MTF Specification
** Lens MTF specification
  From a FILE - 1
  From a FUNCTION - 2
->
2 (DEFAULT)
Diffraction limited lens - Default is F- 8.00
** Change? 1-YES 0-NO
->
0 (DEFAULT)
MTFMD1: Modifying PDFs for MTF
Before modification:
Signal Variance = 0.02227 Signal + Noise Variance = 0.02227
After modification:
Signal Variance = 0.01985 Signal + Noise Variance = 0.01985
IFY001A PAUSE
** Film MTF specification
  from a FILE - 1
  from a FUNCTION - 2
->
2 (DEFAULT)

1
** Enter FILENAME for film MTF data to be used:
film
MTFMD1: Modifying PDFs for MTF
Before modification:
Signal Variance = 0.01985 Signal + Noise Variance = 0.01985
After modification:
Signal Variance = 0.01694 Signal + Noise Variance = 0.01694
IFY001A PAUSE
**Density - Log Exposure specification**
- from a FILE - 1
- from a FUNCTION (STRAIGHT LINE) - 2
- from a FUNCTION (ARC TAN ) - 3

---

**2 (DEFAULT)**

1

**Enter Filename for datafile**
 filament2

**Enter Filetype for datafile**
 iqfilm

**At what LogE value should the mean be placed**
- **Default:** 1.40
- **Change?** 1-yes 0-no

---

**0 (DEFAULT)**

1

**Enter new exposure point (LogE)**

? 1.8

**Signal - Cumulative distribution determined**
- Sum of signal 0.9997596
- Signal + Noise - Cumulative distribution determined
  - Sum of signal + noise prob 0.9997596

**New signal statistics (mean, variance)=** 0.0541 0.000157
**New s + n statistics (mean, variance)=** 0.0541 0.000157

**Finished Modification due to DlogE curve**

IFY001A PAUSE

**Film granularity specification**

**Granularity specification**
- from a FILE - 1
- from a FUNCTION - 2

---

**2 (DEFAULT)**

1

**Enter Filename for datafile**
 filament2

**Enter Filetype for datafile**
 iqfilm

**Limits of non-zero input PDF**

<table>
<thead>
<tr>
<th>Input cell</th>
<th>500/1930</th>
<th>Sum of P(out,in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750/1930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000/1930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1250/1930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500/1930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1750/1930</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Completed Output Probability Calculations**

**Sum of Joint Probability** 0.99986
**Additional Variance** = 0.000041
**S stats (mean, variance)** 0.054 0.000157
**S + N stats (mean, variance)** 0.054 0.000198

**Completed Modification of S + N PDF**

IFY001A PAUSE
** Enter type of noise:
   1. Bandlimited White Noise
   2. Triangular shaped Noise
   3. Exponential Noise

=>
   2 (DEFAULT)

** Enter frequency cutoff for unity magnification

=>
   50.0000000 (DEFAULT)

Spectrum modified
Completed Camera/Film Calculations

VARIATION 1  04/08/88  09:45:34
Stage 1  Output of CAMERA LENS AND FILM

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>177.30</td>
</tr>
<tr>
<td>IFY001A PAUSE</td>
<td>Creating plot of PDF — Please wait</td>
</tr>
<tr>
<td>** Scale plot from 0 to 1 (1) or Best Fit (2)</td>
<td>1 (DEFAULT)</td>
</tr>
<tr>
<td>** Enter range around mean</td>
<td>0.399999976 (DEFAULT)</td>
</tr>
<tr>
<td>Creating Plot of Image Spectrum — Please wait</td>
<td></td>
</tr>
</tbody>
</table>
Component 2
Entering printer/paper section
IFY001A PAUSE
** Printer lens MTF specification
** Lens MTF specification
   From a FILE - 1
   From a FUNCTION - 2
>>> 2 (DEFAULT)

Diffraction limited lens - Default is F = 5.60
** Change? 1-YES 0-NO
>>> 0 (DEFAULT)

MTFMD1: Modifying PDFs for MTF
Before modification:
Signal Variance = 0.00016 Signal + Noise Variance = 0.00020
After modification:
Signal Variance = 0.00015 Signal + Noise Variance = 0.00018
IFY001A PAUSE
** Paper MTF specification
   from a FILE - 1
   from a FUNCTION - 2
>>> 2 (DEFAULT)

1
** Enter FILENAME for film MTF data to be used:
   paper1

MTFMD1: Modifying PDFs for MTF
Before modification:
Signal Variance = 0.00015 Signal + Noise Variance = 0.00018
After modification:
Signal Variance = 0.00010 Signal + Noise Variance = 0.00011
IFY001A PAUSE
** Density - Log Exposure specification
   from a FILE - 1
   from a FUNCTION (STRAIGHT LINE) - 2
   from a FUNCTION (ARC TAN ) - 3
>>> 2 (DEFAULT)

1
** Enter Filename for datafile
   paper
   ** Enter Filetype for datafile
   iqpaper
   ** At what LogE value should the mean be placed
   ** Default: 0.40
   ** Change? 1-yes 0-no
>>> 0 (DEFAULT)

1
** Enter new exposure point (LogE)
? .85

#44#
Signal ** Cumulative distribution determined
 Sum of signal 0.9995862
Signal + Noise - Cumulative distribution determined
 Sum of signal + noise prob 0.9993989
New signal statistics (mean, variance) = 0.1729 0.003856
New s + n statistics (mean, variance) = 0.1756 0.004815
Finished Modification due to DlogE curve
IFY001A PAUSE

Specification of Paper granularity
** Granularity specification
 from a FILE - 1
 from a FUNCTION - 2
=>

#45#
2 (DEFAULT)

#46#
** Enter Filename for datafile
paper

#47#
** Enter Filetype for datafile
ipaper

Limits of non-zero input PDF 40 4325
Input cell 250/ 4325 Sum of P(out,in) 0.00647
Input cell 500/ 4325 Sum of P(out,in) 0.02788
Input cell 750/ 4325 Sum of P(out,in) 0.07266
Input cell 1000/ 4325 Sum of P(out,in) 0.14288
Input cell 1250/ 4325 Sum of P(out,in) 0.24343
Input cell 1500/ 4325 Sum of P(out,in) 0.36650
Input cell 1750/ 4325 Sum of P(out,in) 0.51077
Input cell 2000/ 4325 Sum of P(out,in) 0.64712
Input cell 2250/ 4325 Sum of P(out,in) 0.76532
Input cell 2500/ 4325 Sum of P(out,in) 0.85569
Input cell 2750/ 4325 Sum of P(out,in) 0.91643
Input cell 3000/ 4325 Sum of P(out,in) 0.95411
Input cell 3250/ 4325 Sum of P(out,in) 0.97973
Input cell 3500/ 4325 Sum of P(out,in) 0.99280
Input cell 3750/ 4325 Sum of P(out,in) 0.99716
Input cell 4000/ 4325 Sum of P(out,in) 0.99912
Input cell 4250/ 4325 Sum of P(out,in) 0.99979

Completed Output Probability Calculations
Sum of Joint Probability 0.99988
Additional Variance = 0.00011
S stats (mean, variance) 0.173 0.003856
S + N stats (mean, variance) 0.176 0.004826
Completed Modification of S + N PDF
IFY001A PAUSE
** Enter type of noise:
   1. Bandlimited White Noise
   2. Triangular shaped Noise
   3. Exponential Noise

---
2 (DEFAULT)

** Enter frequency cutoff for unity magnification

---
50.000000 (DEFAULT)

---
Spectrum modified
Completed printer lens/paper modifications

---
VARIATION 1 04/08/88 09:49:13
Stage 2 Output of PRINTER LENS AND PAP
METRIC VALUE

---
Info Content 136.78
IFY001A PAUSE
Creating plot of PDF — Please wait
** Scale plot from 0 to 1 (1) or Best Fit (2)
   1 (DEFAULT)

---
2
** Enter range around mean
0.39999976 (DEFAULT)
Creating Plot of Image Spectrum — Please wait
• Human Visual System Specification
• Soft copy or hard copy application? SOFT-1, HARD-0
  --> 0 (DEFAULT)

• Enter surround illuminance in footlamberts
  --> 6.00000000 (DEFAULT)

Default viewing distance: 0.355 meters

• Change viewing distances? enter -1, else -0
  --> 0 (DEFAULT)

Modify PDF/SPECTRA for Optical MTF Effects of HVS
MTFWD1: Modifying PDFs for MTF
Before modification:
  Signal Variance = 0.00386 Signal + Noise Variance = 0.00483
After modification:
  Signal Variance = 0.00232 Signal + Noise Variance = 0.00284
IFY001A PAUSE

Modify PDF/SPECTRA for Sampling MTF Effects of HVS
MTFWD1: Modifying PDFs for MTF
Before modification:
  Signal Variance = 0.00232 Signal + Noise Variance = 0.00284
After modification:
  Signal Variance = 0.00206 Signal + Noise Variance = 0.00252
IFY001A PAUSE
Modify PDF/SPECTRA for Neural MTF Effects of HVS

MTFMOD1: Modifying PDFs for MTF

Before modification:
Signal Variance = 0.00206 Signal + Noise Variance = 0.00252

After modification:
Signal Variance = 0.00129 Signal + Noise Variance = 0.00157

IFY001A PAUSE

Modify PDF/SPECTRA for noise effects of HVS

Limit of non-zero input PDF

<table>
<thead>
<tr>
<th>Input cell</th>
<th>4291</th>
<th>Sum of P(out, in)</th>
<th>4291</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>4291</td>
<td>0.00648</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>4291</td>
<td>0.02793</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>4291</td>
<td>0.07214</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>4291</td>
<td>0.14301</td>
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</tr>
<tr>
<td>1250</td>
<td>4291</td>
<td>0.24357</td>
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<tr>
<td>1500</td>
<td>4291</td>
<td>0.36663</td>
<td></td>
</tr>
<tr>
<td>1750</td>
<td>4291</td>
<td>0.51076</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>4291</td>
<td>0.64693</td>
<td></td>
</tr>
<tr>
<td>2250</td>
<td>4291</td>
<td>0.76497</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>4291</td>
<td>0.85531</td>
<td></td>
</tr>
<tr>
<td>2750</td>
<td>4291</td>
<td>0.91608</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>4291</td>
<td>0.95405</td>
<td></td>
</tr>
<tr>
<td>3250</td>
<td>4291</td>
<td>0.97945</td>
<td></td>
</tr>
<tr>
<td>3500</td>
<td>4291</td>
<td>0.99185</td>
<td></td>
</tr>
<tr>
<td>3750</td>
<td>4291</td>
<td>0.99707</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>4291</td>
<td>0.99907</td>
<td></td>
</tr>
<tr>
<td>4250</td>
<td>4291</td>
<td>0.99976</td>
<td></td>
</tr>
</tbody>
</table>

Completed Output Probability Calculations

Sum of Joint Probability 0.99981
Additional Variance 0.000009
S stats (mean, variance) 0.173 0.001290
S + N stats (mean, variance) 0.176 0.001581

Completed Modification of S + N PDF

IFY001A PAUSE

** Enter type of noise:
  1. Bandlimited White Noise
  2. Triangular shaped Noise
  3. Exponential Noise

2 (DEFAULT)

** Enter frequency cutoff for unity magnification

50.000000 (DEFAULT)

Spectrum modified
VARIATION 1  04/08/88  09:50:53
Stage 99  Output of HUMAN VISUAL SYSTEM
METRIC       VALUE

Info Content  46.15
IFY001A PAUSE

STAGE 7 (HVS): VIEWING DISTANCE (METERS) = 0.355
Creating plot of PDF — Please wait
** Scale plot from 0 to 1 (1) or Best Fit (2) **
1  (DEFAULT)
2 ** Enter range around mean **
0.399999976 (DEFAULT)  .
Creating Plot of Image Spectrum — Please wait

Select a QMS LASER plotter for output. If your selection is entered as
a negative number (ex: "-1"), plot file will also be saved allowing
subsequent copies thru the use of the FORTRAN program "REPQMS".

Please select one of the following options for your QMS output:
0 = Bit Bucket  (No plot desired, discard plot file)
1 or -1 = B59 1st floor lobby (P01C6)
2 or -2 = B59 5th floor R-507 (P02BF)
3A or -3A = B59 3rd floor Open Shop, R-382 (P0FF)
3B or -3B = B59 3rd floor R-313f (P0205)
6 or -6 = B82b 6th floor hallway (P10JE)
81D or -81D = B91 4th floor, room 453 (P07FC)
3a

PRT FILE 6867 TO RCS CS COPY 001 NOHOLD
DMTAXM101I FILE 6867 (6867) ENQUEUED ON LINK P0FF
TO CONTINUE ENTER-Y, ELSE-N
n
R;
The following shows the output as stored in the listing file. Below is an explanation of each numbered item.

1. Description of input scene and resultant statistics.
2. Magnification to next stage.
7. Specification of noise shape with cutoff frequency.
8. Resultant information content metric and other metrics.
10. Specification for paper MTF and resultant effect on the statistics.
14. Resultant information content metric and other metrics.
15. Specification of hardcopy and adaptation level.
17. Results from optical, neural and sampling MTF effects.
18. Results from noise addition.
20. Resultant information content metric and other metrics.
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 1

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F*F</strong>N</td>
<td>3.000</td>
</tr>
<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal,2-Lognormal</td>
<td>1</td>
</tr>
<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean,variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000</td>
</tr>
</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000</td>
</tr>
</tbody>
</table>

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0541</td>
</tr>
</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero Input PDF

331 1930

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.054</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.054</td>
</tr>
</tbody>
</table>

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 1

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>177.30</td>
</tr>
</tbody>
</table>
PRINTER–PAPER SECTION

Lens MTF – Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0545</td>
</tr>
</tbody>
</table>

MTF data read from file: PAPER1 DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0545</td>
</tr>
</tbody>
</table>

Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
</tr>
</tbody>
</table>

Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.173</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.176</td>
</tr>
</tbody>
</table>

Bandlimited White Noise, Cutoff at 20.00

VARIATION 1

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>136.78</td>
</tr>
</tbody>
</table>
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
<td>0.002319</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
<td>0.002837</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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<td>0.002060</td>
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<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
<td>0.002515</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
<td>0.001290</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
<td>0.001572</td>
</tr>
</tbody>
</table>

Limits of non-zero input PDF 40 4291

<table>
<thead>
<tr>
<th>Results from addition of noise</th>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.173</td>
<td>0.001290</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.176</td>
<td>0.001581</td>
</tr>
</tbody>
</table>

Bandlimited White Noise, Cutoff at 20.00

VARIATION 1 04/08/88 09:50:53

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>46.15</td>
</tr>
</tbody>
</table>
The following figures shows the output plots from the program. Below is a brief explanation of each plot. In all plots the dotted red line represents the signal with noise, while the blue solid line represents the signal only.

Input Signal
* Cumulative probability functions
* Noise power spectra

Film
* Film sensitometry (i.e. Density - log exposure curve)
* Film granularity. RMS granularity versus transmittance (i.e. linear measure)
* Resultant cumulative probability functions
* Resultant noise power spectra.

Paper
* Paper sensitometry (i.e. Density - log exposure curve)
* Paper granularity. RMS granularity versus transmittance (i.e. linear measure)
* Resultant cumulative probability functions
* Resultant noise power spectra.

Human Visual System
* Resultant cumulative probability functions
* Resultant noise power spectra.

Page D-6
variation 1
Input Signal

Legend
■ = signal
○ = signal + noise
variation 1
Input Signal

Legend
- = signal
- = signal + noise
variation 1
Camera/Film

Legend
□ = signal
○ = signal + noise
variation 1
Camera/Film

Legend
- = signal
- - = signal + noise
variation 1

Printer/Paper

Legend

- = signal
- = signal + noise
variation 1

Printer/Paper

Legend

- = signal
- = signal + noise
variation 1

Human Visual System

Legend
- = signal
- = signal + noise
variation 1

Human Visual System

Legend
- = signal
○ = signal + noise
APPENDIX E
RESULTS FROM TEST VARIATIONS - PLOTS

Each plot is labeled with the variation number described in table 1.
variation 1
Input Signal

Legend
- signal
- signal + noise
variation 1

Input Signal

Legend

\( \square \) = signal
\( \circ \) = signal + noise

Frequency c/mm
variation 1
Camera/Film

Legend
☐ = signal
○ = signal + noise
Legend

- = signal
- = signal + noise

Camera/Film variation 1

Frequency c/mm

Power Spect.
variation 1
Printer/Paper

Legend
- □ = signal
- ○ = signal + noise
variation 1

Printer/Paper

Legend
• = signal
○ = signal + noise
variation 1

Human Visual System

Legend
- = signal
- - = signal + noise
variation 1
Human Visual System

Legend
- = signal
- = signal + noise
variation 2
Input Signal

Legend
- = signal
\(\circ\) = signal + noise
variation 2
Input Signal

Legend

□ = signal
○ = signal + noise

Frequency c/mm
variation 2
Camera/Film

Legend

- = signal
- = signal + noise
variation 2
Camera/Film

Legend
□ = signal
○ = signal + noise
variation 2

Printer/Paper

Legend
- = signal
- = signal + noise

Power Spect.
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}

Frequency c/mm
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
variation 3

Input Signal

Legend
- signal
- signal + noise
variation 3
Camera/Film

Legend
- = signal
- = signal + noise
Legend
- = signal
- = signal + noise

Printer/Paper

Variation 3
variation 3
Printer/Paper

Legend
- = signal
- - = signal + noise
variation 3
Human Visual System

Legend
\(\square = \text{signal}\)
\(\circ = \text{signal + noise}\)
variation 4

Input Signal

Legend

- signal
- signal + noise
variation 4

Input Signal

Legend
- = signal
- signal + noise

Power Spect. vs. Frequency c/mm

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$

0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Legend

□ = signal
○ = signal + noise

Camera/Film variation 4

Power Spectr. vs. Frequency c/mm
variation 4

Printer/Paper

Legend
- = signal
- = signal + noise
variation 4

Human Visual System

Legend
- = signal
- = signal + noise
variation 4
Human Visual System

Legend
- = signal
○ = signal + noise
variation 5
Input Signal

Legend
\( \square = \text{signal} \)
\( \circ = \text{signal + noise} \)
variation 5
Camera/Film

Legend
\( \square \) = signal
\( \circ \) = signal + noise
variation 5
Camera/Film

Legend
□ = signal
○ = signal + noise

Power Spect.
$10^{-1}$ $10^{-2}$ $10^{-3}$

Frequency c/mm
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
variation 5
Printer/Paper

Legend
□ = signal
○ = signal + noise

Cumul. Prob.

Linear Value

-0.05 0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40
variation 5
Printer/Paper

Legend
□ = signal
○ = signal + noise
variation 5
Human Visual System

Legend
- = signal
- = signal + noise
variation 5

Human Visual System

Legend

■ = signal
○ = signal + noise
variation 6
Input Signal

Legend
- = signal
- = signal + noise
variation 6
Camera/Film

Legend
- signal
- signal + noise
variation 6.
Camera/Film

Legend
\[ \Box = \text{signal} \]
\[ \circ = \text{signal + noise} \]
variation 6
Printer/Paper

Legend
- = signal
- - = signal + noise
variation 6

Printer/Paper

Legend

\(\square\) = signal
\(\circ\) = signal + noise
variation 6
Human Visual System

Legend
\(\square\) = signal
\(\circ\) = signal + noise
variation 7

Input Signal

Legend
- = signal
- = signal + noise
variation 7
Camera/Film

Legend
- = signal
- = signal + noise
variation 7
Camera/Film

Legend
\(\square\) = signal
\(\circ\) = signal + noise
variation 7
Printed Paper

Legend
\(\square\) = signal
\(\circ\) = signal + noise
variation 7
Printer/Paper

Legend
- = signal
- = signal + noise
variation 7

Human Visual System

Legend

\(\square\) = signal
\(\circ\) = signal + noise
variation 8
Input Signal

Legend
- = signal
- = signal + noise
variation 8
Input Signal

Legend
□ = signal
○ = signal + noise

Cumul. Prob.

0.0 0.2 0.4 0.6 0.8 1.0

Linear Value

0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
variation 8
Camera/Film

Legend
\(\square\) = signal
\(\circ\) = signal + noise
variation 8
Camera/Film

Legend
■ = signal
○ = signal + noise
variation 8
Printer/Paper

Legend
☐ = signal
○ = signal + noise
variation 8
Printer/Paper

Legend
□ = signal
○ = signal + noise
variation 8

Human Visual System

Legend
- = signal
- = signal + noise
variation 9
Input Signal

Legend
- = signal
○ = signal + noise
variation 9
Camera/Film

Legend

= signal
= signal + noise

Power Spect. $10^{-3}$

Frequency $c/mm$
variation 9

Human Visual System

Legend
- = signal
○ = signal + noise
variation 10
Input Signal

Legend
- = signal
- = signal + noise
variation 10

Input Signal

Legend
- = signal
○ = signal + noise
variation 10
Camera/Film

Legend
- = signal
- = signal + noise
variation 10

Camera/Film

Legend

□ = signal
○ = signal + noise
variation 10
Printer/Paper

Legend
- = signal
- = signal + noise
variation 10

Printer/Paper

Legend
- = signal
- = signal + noise
variation 11
Input Signal

Legend
\square = signal
\circ = signal + noise
variation 11
Camera/Film

Legend
□ = signal
○ = signal + noise
variation 11
Camera/Film

Legend

□ = signal
○ = signal + noise
variation 11
Printer/Paper

Legend
- = signal
- = signal + noise

Cumul. Prob.
0.0 0.2 0.4 0.6 0.8 1.0
Linear Value
0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85
variation 11
Printer/Paper

Legend
- = signal
- - = signal + noise

Power Spect. vs Frequency c/mm

-4 -3 -2 -1

0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0

04/11/88
13:15:16
variation 11

Human Visual System

Legend
\( \square = \text{signal} \)
\( \circ = \text{signal + noise} \)
variation 11

Human Visual System

Legend
- = signal
- = signal + noise
variation 12
Input Signal

Legend
- = signal
- = signal + noise
variation 12
Input Signal

Legend
- = signal
- = signal + noise
variation 12
Camera/Film

Legend
- = signal
- = signal + noise
variation 12
Camera/Film

Legend
△ = signal
○ = signal + noise
variation 12
Printer/Paper

Legend
• = signal
○ = signal + noise
variation 12

Human Visual System

Legend

□ = signal
○ = signal + noise
Variation 12

Human Visual System

Legend

- = signal
- = signal + noise

Power Spect.

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$

Frequency c/mm

0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
variation 13
Input Signal

Legend
- = signal
- = signal + noise
variation 13
Input Signal

Legend
= signal
= signal + noise

Power Spect.
\[10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1}\]

Frequency c/mm
\[0.0 \quad 2.0 \quad 4.0 \quad 6.0 \quad 8.0 \quad 10.0 \quad 12.0 \quad 14.0\]
variation 13

Camera/Film

Legend
- $\Box =$ signal
- $\bigcirc =$ signal + noise
variation 13
Camera/Film

Legend
\(\square = \text{signal}\)
\(\circ = \text{signal} + \text{noise}\)
variation 13
Printer/Paper

Legend
• = signal
• = signal + noise
variation 13
Printer/Paper

Legend
- = signal
- = signal + noise

Power Spect.  \( 10^{-5} \)  \( 10^{-4} \)  \( 10^{-3} \)  \( 10^{-2} \)  \( 10^{-1} \)

Frequency c/mm
variation 13
Human Visual System

Legend
- = signal
- = signal + noise
variation 13

Human Visual System

Legend

- = signal
- = signal + noise

Power Spect.

Frequency c/mm
variation 14
Input Signal

Legend
- = signal
- = signal + noise

Cumul. Prob.

Linear Value
variation 14

Input Signal

Legend
• = signal
○ = signal + noise
variation 14
Camera/Film

Legend
- = signal
- = signal + noise
variation 14
Camera/Film

Legend
- = signal
- = signal + noise
variation 14
Printer/Paper

Legend
- = signal
- = signal + noise
variation 14

Printer/Paper

Legend
- = signal
○ = signal + noise
Human Visual System

Legend

= signal
= signal + noise

Cumul. Prob.

Linear Value
variation 14

Human Visual System

Legend
- = signal
= signal + noise

Power Spect.

Frequency c/mm
APPENDIX F
RESULTS FROM TEST VARIATIONS - LISTING

Each listing is labeled with the variation number described in table 1.

Page F-1
Title for this run: VARIATION 1

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td>3.000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Correlation</td>
<td></td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
<td>1</td>
</tr>
<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF—Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000</td>
<td>0.019854</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000</td>
<td>0.019854</td>
</tr>
</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000</td>
<td>0.016938</td>
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<tr>
<td>Signal and Noise</td>
<td>0.5000</td>
<td>0.016938</td>
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</tbody>
</table>

Read DlogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DlogE modification

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<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
<td>0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0541</td>
<td>0.000157</td>
</tr>
</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 331 1930

Results from addition of noise

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.054</td>
<td>0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.054</td>
<td>0.000198</td>
</tr>
</tbody>
</table>

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 1 04/11/88 16:14:56

METRIC VALUE

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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<tbody>
<tr>
<td>Info Content</td>
<td>177.30</td>
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</table>
Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
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</tbody>
</table>

MTF data read from file: PAPER1 DATA

Results from MTF effects

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<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0545</td>
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</tbody>
</table>

Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification

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<th>Mean</th>
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<tr>
<td>Signal</td>
<td>0.1729</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
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</tbody>
</table>

Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
<td>0.176</td>
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</table>

Bandlimited White Noise, Cutoff at 20.00

<table>
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<tr>
<th>VARIATION</th>
<th>VALUE</th>
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<tr>
<td>1</td>
<td>04/11/88 16:17:36</td>
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<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>136.78</td>
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</table>
HUMAN VISUAL SYSTEM SECTION

HardCopy – Adapted to 6.00 Foot-Lamberts
For Viewing Distance of 0.355 meters

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
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</table>

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
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</table>

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1729</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1756</td>
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</tbody>
</table>

Limits of non-zero input PDF 40 4291

Results from addition of noise

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<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.173</td>
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<tr>
<td>Signal and Noise</td>
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</table>

Bandlimited White Noise, Cutoff at 20.00

VARIATION 1

<table>
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<tr>
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<th>VALUE</th>
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<tbody>
<tr>
<td>Info Content</td>
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Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 2

Scene Information (Unimodal):

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<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>Spectrum B</td>
<td>1/B<strong>N+F</strong>N</td>
<td>3.000</td>
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<tr>
<td></td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>2</td>
</tr>
<tr>
<td>Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>PDF Shape</td>
<td>1-Normal,2-Lognormal</td>
<td>1</td>
</tr>
<tr>
<td>Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF – Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.018732</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000 0.018732</td>
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</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<td>0.5000 0.014564</td>
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<tr>
<td>Signal and Noise</td>
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</tbody>
</table>

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0537 0.000121</td>
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<tr>
<td>Signal and Noise</td>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF

Results from addition of noise

<table>
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<tr>
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<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.054 0.000121</td>
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<td>Signal and Noise</td>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 2 04/08/88 16:11:21

METRIC VALUE

Info Content 259.88
Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

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<thead>
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<th>Variance</th>
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MTF data read from file: PAPER1 DATA

Results from MTF effects

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<th>Mean</th>
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</thead>
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<tr>
<td>Signal and Noise</td>
<td>0.0540</td>
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Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DlogE modification

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<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1694</td>
<td>0.003099</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1721</td>
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</tr>
</tbody>
</table>

Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF

<table>
<thead>
<tr>
<th></th>
<th>51</th>
<th>4080</th>
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</table>

Results from addition of noise

<table>
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<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.169</td>
<td>0.003099</td>
</tr>
<tr>
<td>Signal and Noise</td>
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</tr>
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</table>

Bandlimited White Noise, Cutoff at 20.00

VARIATION 2

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
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</thead>
<tbody>
<tr>
<td>Info Content</td>
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</tbody>
</table>
HUMAN VISUAL SYSTEM SECTION

HardCopy – Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
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</tbody>
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Results from MTF effects

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<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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<tr>
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<td>0.1721</td>
<td>0.002072</td>
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Results from MTF effects

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<tr>
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<td>0.001022</td>
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<tr>
<td>Signal and Noise</td>
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Limits of non-zero input PDF

| 52 | 4047 |

Results from addition of noise

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<td>Signal and Noise</td>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 2

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04/08/88 16:15:59
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<tr>
<td>B</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>0.700</td>
</tr>
<tr>
<td>2. Variance</td>
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<td>0.500</td>
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<td>4. Mean</td>
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Scene statistics (mean, variance): 0.500, 0.0651
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF—Diffraction Limited at 8.0

Results from MTF effects

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<tr>
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<tbody>
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<td>Signal and Noise</td>
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Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

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<th>Variance</th>
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<tbody>
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<tr>
<td>Signal and Noise</td>
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Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

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<tbody>
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<td>Signal and Noise</td>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF

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<table>
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<tr>
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<tbody>
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Results from addition of noise

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<td>Signal</td>
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<tr>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 3

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<tbody>
<tr>
<td>Info Content</td>
<td>326.42</td>
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04/08/88 16:22:08
 Gunnery / Observation / Control

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CT CT

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VARIATION 3

METRIC

04/08/88 16:26:52

VALUE

261.43
HUMAN VISUAL SYSTEM SECTION

HardCopy – Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

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<thead>
<tr>
<th>Results from MTF effects</th>
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<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.2170</td>
<td>0.0008210</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.2192</td>
<td>0.000838</td>
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<table>
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<th>Variance</th>
</tr>
</thead>
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<td>Signal and Noise</td>
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<td>Signal and Noise</td>
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Limits of non-zero input PDF 33 5639

<table>
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<th>Variance</th>
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</thead>
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Bandlimited White Noise, Cutoff at 20.00

<table>
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<th>VARIATION 3</th>
<th>04/08/88 16:28:34</th>
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<td>VALUE</td>
</tr>
<tr>
<td>Info Content</td>
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Title for this run: VARIATION 4

Scene Information (Unimodal):

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<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+P</strong>N</td>
<td>3.000</td>
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<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>2</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.700</td>
</tr>
<tr>
<td>3. PDF Shape</td>
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<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
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</tr>
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Scene statistics (mean,variance) 0.5000 0.0631
**CAMERA–FILM SECTION**

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF – Diffraction Limited at 8.0

**Results from MTF effects**

<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>Signal and Noise</td>
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</table>

**Film MTF Specification**

MTF data read from file: FILM DATA

**Results from MTF effects**

<table>
<thead>
<tr>
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<th>Mean</th>
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<td>Signal and Noise</td>
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Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.88

**Results from DLogE modification**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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<td>0.000589</td>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 339 1656

**Results from addition of noise**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
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</tr>
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<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
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Exponentially Shaped Noise, Cutoff at 100.00

<table>
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<tr>
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<tr>
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VARIATION 4 04/08/88 16:34:16
Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
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<td>0.000551</td>
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<td>Signal and Noise</td>
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<td>0.000610</td>
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MTF data read from file: PAPER1 DATA

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
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<th>Variance</th>
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<tr>
<td>Signal and Noise</td>
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Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DlogE modification

<table>
<thead>
<tr>
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<th>Mean</th>
<th>Variance</th>
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<tbody>
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Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF

|            | 44 | 5187 |

Results from addition of noise

<table>
<thead>
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<tbody>
<tr>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 4

<table>
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<tr>
<td>Info Content</td>
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</table>
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 5

Scene Information (Unimodal):

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<thead>
<tr>
<th>Parameter</th>
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<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>B</td>
<td>1/B<strong>N+F</strong>N</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Half-Power CY/MM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correlation</td>
</tr>
<tr>
<td>2. Variance</td>
<td></td>
<td>Sigma/Mean</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td></td>
<td>1-Normal,2-Lognormal</td>
</tr>
<tr>
<td>4. Mean</td>
<td></td>
<td>Rel Exposure (0-1)</td>
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Scene statistics (mean,variance) 0.5000 0.0223
CAMERA—FILM SECTION

Magnification to next stage: 7.50

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects

<table>
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<tr>
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<tbody>
<tr>
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Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
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<tbody>
<tr>
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<tr>
<td>Signal and Noise</td>
<td>0.5000 0.012823</td>
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Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

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<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
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<td>Signal and Noise</td>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 346 1419

Results from addition of noise

<table>
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<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.053 0.000099</td>
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<tr>
<td>Signal and Noise</td>
<td>0.054 0.000137</td>
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</tbody>
</table>

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 5 METRIC VALUE

<table>
<thead>
<tr>
<th>Info Content</th>
<th>76.54</th>
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04/08/88 16:48:23
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0534</td>
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<tr>
<td>Signal and Noise</td>
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MTF data read from file: PAPER1 DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.0534</td>
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<tr>
<td>Signal and Noise</td>
<td>0.0537</td>
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</table>

Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1690</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1727</td>
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Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF 64 4271

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.169</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.173</td>
</tr>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 5

<table>
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<tr>
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<th>VALUE</th>
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</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>04/08/88 16:52:17</td>
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</tbody>
</table>

62.88
**HUMAN VISUAL SYSTEM SECTION**

**HardCopy - Adapted to** 6.00 Foot-Lamberts

*For Viewing Distance of 0.355 meters*

<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1690</td>
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<tr>
<td>Signal and Noise</td>
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<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Signal and Noise</td>
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<table>
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<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.1690</td>
<td>0.001128</td>
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<tr>
<td>Signal and Noise</td>
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<td>0.001529</td>
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*Limits of non-zero input PDF* 66 4234

<table>
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<tr>
<th>Results from addition of noise</th>
<th>Mean</th>
<th>Variance</th>
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<td>0.001128</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.173</td>
<td>0.001537</td>
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**Bandlimited White Noise, Cutoff at 20.00**

**VARIATION 5 VALUE** 04/08/88 16:53:41

<table>
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<tbody>
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Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 6

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td>3.000</td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
<td>1</td>
</tr>
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<td>4. Mean</td>
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</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAME RA—FIL M SE CTION

Magnification to next stage: 3.80

Camera Lens MTF Specification

Lens MTF—Diffraction Limited at 8.0

Results from MTF effects
Mean Variance
Signal 0.5000 0.019854
Signal and Noise 0.5000 0.019854

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects
Mean Variance
Signal 0.5000 0.016938
Signal and Noise 0.5000 0.016938

Read DLogE data from file: FILM IQFIL M

Exposure Point is at 1.80

Results from DLogE modification
Mean Variance
Signal 0.0541 0.000157
Signal and Noise 0.0541 0.000157

Granularity data from file: FILM IQFIL M

Limits of non-zero input PDF 331 1930

Results from addition of noise
Mean Variance
Signal 0.054 0.000157
Signal and Noise 0.055 0.000330

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 6 04/11/88 08:12:44

METRIC VALUE

Info Content 62.28
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
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<tr>
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<tr>
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<td>Signal and Noise</td>
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MTF data read from file: PAPER1 DATA

Results from MTF effects

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Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification

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<td>Signal and Noise</td>
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Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF 35 5415

Results from addition of noise

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<tr>
<td>Signal and Noise</td>
<td>0.183 0.007291</td>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 6 04/11/88 08:18:40

METRIC VALUE

| Info Content | 49.85 |
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts
For Viewing Distance of 0.355 meters

Results from MTF effects

<table>
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<tbody>
<tr>
<td>Signal</td>
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</tr>
<tr>
<td>Signal and Noise</td>
<td>0.1830</td>
</tr>
</tbody>
</table>

Results from MTF effects

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<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
<td>0.1830</td>
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Results from MTF effects

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<th>Variance</th>
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<tr>
<td>Signal</td>
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Limits of non-zero input PDF

34 5183

Results from addition of noise

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<tr>
<td>Signal and Noise</td>
<td>0.183</td>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 6

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04/11/88 08:23:03
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 7

Scene Information (Unimodal):

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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B*N+F*N</td>
<td>3.000</td>
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<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
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<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
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Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage : 3.88

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.019854</td>
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<tr>
<td>Signal and Noise</td>
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Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

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<tr>
<th>Mean</th>
<th>Variance</th>
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<td>Signal</td>
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Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 0.60

Results from DlogE modification

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<tr>
<td>Signal and Noise</td>
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</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 2180 3021

Results from addition of noise

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<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
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<td>Signal and Noise</td>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 7

<table>
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### PRINT PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

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<td>Signal and Noise</td>
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MTF data read from file: PAPER1  DATA

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<th>Variance</th>
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<tr>
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Read DLogE data from file: PAPER  IOPAPER

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Granularity data from file: PAPER  IOPAPER

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Results from addition of noise

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Bandlimited White Noise, Cutoff at 20.00

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<tr>
<td>04/11/88</td>
<td>08:35:17</td>
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</table>
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
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Results from MTF effects

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Results from MTF effects

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Limits of non-zero input PDF 490 3341

Results from addition of noise

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Bandlimited White Noise, Cutoff at 20.00

VARIATION 7 04/11/88 08:38:50

METRIC VALUE

| Info Content | 6.95 |
Model to Estimate Information Content for a two stage
Photographic System

William R. O'Such

Title for this run: VARIATION B

Scene Information (Unimodal):

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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td></td>
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<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td>3.000</td>
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<td>N</td>
<td>Correlation</td>
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<tr>
<td>2. Variance</td>
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<td>3. PDF Shape</td>
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<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
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Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF – Diffraction Limited at 8.0

Results from MTF effects

<table>
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<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
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<td>Signal and Noise</td>
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Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
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<th>Mean</th>
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<tr>
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Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.20

Results from DlogE modification

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<tr>
<td>Signal and Noise</td>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 871 2940

Results from addition of noise

<table>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 8 04/11/88 08:47:33

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PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

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MTF data read from file: PAPER DATA

Results from MTF effects

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<td>Signal and Noise</td>
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Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification

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<td>Signal and Noise</td>
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Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF 113 4398

Results from addition of noise

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<th>Variance</th>
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<tr>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 8

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04/11/88 08:50:29
### HUMAN VISUAL SYSTEM SECTION

**HardCopy - Adapted to** 6.00 Foot-Lamberts

**For Viewing Distance of** 0.355 meters

#### Results from MTF effects

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<tr>
<th></th>
<th>Mean</th>
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<tbody>
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#### Results from MTF effects

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#### Results from MTF effects

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**Limits of non-zero input PDF**

|        | 115 | 4362 |

#### Results from addition of noise

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**Bandlimited White Noise, Cutoff at 20.00**

**VARIATION 8**

|        | 04/11/88 | 08:52:14 |

**METRIC**

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Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 9

Scene Information (Unimodal):

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<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td>3.000</td>
</tr>
<tr>
<td></td>
<td>Half-Power CY/MM</td>
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<tr>
<td>B</td>
<td>N</td>
<td>3</td>
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<tr>
<td></td>
<td>Correlation</td>
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<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
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<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
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<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA—FILM SECTION

Magnification to next stage : 3.88

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
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<tbody>
<tr>
<td>Signal</td>
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Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

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<td>0.5000</td>
<td>0.016938</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000</td>
<td>0.016938</td>
</tr>
</tbody>
</table>

Read DlogE data from file: FILM2 IQFILM

Exposure Point is at 2.40

Results from DlogE modification

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0201</td>
<td>0.000024</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0201</td>
<td>0.000024</td>
</tr>
</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 120 825

Results from addition of noise

<table>
<thead>
<tr>
<th>Effect</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.020</td>
<td>0.000024</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.020</td>
<td>0.000030</td>
</tr>
</tbody>
</table>

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 9
04/11/88 08:56:20

METRIC  VALUE
Info Content  193.00
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects
Mean Variance
Signal 0.0201 0.000023
Signal and Noise 0.0202 0.000027

MTF data read from file: PAPER1 DATA

Results from MTF effects
Mean Variance
Signal 0.0201 0.000015
Signal and Noise 0.0202 0.000017

Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification
Mean Variance
Signal 0.1739 0.004239
Signal and Noise 0.1768 0.005327

Granularity data from file: PAPER IQPAPER 35 4475

Limits of non-zero input PDF

Results from addition of noise
Mean Variance
Signal 0.174 0.004239
Signal and Noise 0.177 0.005339

Bandlimited White Noise, Cutoff at 20.00

VARIATION 9 04/11/88 08:58:44

METRIC VALUE
Info Content 141.74
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

Results from MTF effects
Mean Variance
Signal 0.1739 0.002549
Signal and Noise 0.1768 0.003146

Results from MTF effects
Mean Variance
Signal 0.1739 0.002264
Signal and Noise 0.1768 0.002790

Results from MTF effects
Mean Variance
Signal 0.1739 0.001418
Signal and Noise 0.1768 0.001744

Limits of non-zero input PDF
36 4444

Results from addition of noise
Mean Variance
Signal 0.174 0.001418
Signal and Noise 0.177 0.001753

Bandlimited White Noise, Cutoff at 20.00

VARIATION 9 04/11/88 08:59:56
METRIC VALUE
Info Content 46.39
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 10

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
<td>1</td>
</tr>
<tr>
<td>Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage : 3.88

Camera Lens MTF Specification

Lens MTF – Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.019854</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000 0.019854</td>
</tr>
</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.016938</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000 0.016938</td>
</tr>
</tbody>
</table>

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.0541 0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0541 0.000157</td>
</tr>
</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.054 0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.054 0.000198</td>
</tr>
</tbody>
</table>

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 10

METRIC VALUE

| Info Content | 177.30 |

04/11/88 11:57:10
**PRINTER-PAPER SECTION**

**Lens MTF - Diffraction Limited at 5.6**

**Results from MTF effects**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
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</tr>
</tbody>
</table>

MTF data read from file: PAPER2 DATA

**Results from MTF effects**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tr>
<td>Signal</td>
<td>0.0541</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0545</td>
</tr>
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</table>

Read DLogE data from file: PAPER IQPAPER

**Exposure Point is at 0.85**

**Results from DlogE modification**

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<td>Signal</td>
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<tr>
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Granularity data from file: PAPER IQPAPER

**Limits of non-zero input PDF**

| 37 | 4680 |

**Results from addition of noise**

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<th>Mean</th>
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<td>Signal and Noise</td>
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Bandlimited White Noise. Cutoff at 20.00

**VARIATION 10**

**METRIC**

| 04/11/88 | 12:03:28 |

**Value**

| Info Content | 143.58 |
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

Results from MTF effects
Mean Variance
Signal 0.1751 0.002485
Signal and Noise 0.1785 0.003069

Results from MTF effects
Mean Variance
Signal 0.1751 0.002175
Signal and Noise 0.1785 0.002678

Results from MTF effects
Mean Variance
Signal 0.1751 0.001371
Signal and Noise 0.1785 0.001685

Limits of non-zero input PDF
37 4635

Results from addition of noise
Mean Variance
Signal 0.175 0.001371
Signal and Noise 0.178 0.001694

Bandlimited White Noise, Cutoff at 20.00

VARIATION 10
METRIC VALUE

Info Content 48.93
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 11

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B+N+N</td>
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<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td>3</td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td></td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
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<tr>
<td>3. PDF Shape</td>
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<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
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</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF – Diffraction Limited at 8.0

Results from MTF effects
Mean Variance
Signal 0.5000 0.019854
Signal and Noise 0.5000 0.019854

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects
Mean Variance
Signal 0.5000 0.016938
Signal and Noise 0.5000 0.016938

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification
Mean Variance
Signal 0.0541 0.000157
Signal and Noise 0.0541 0.000157

Granularity data from file: FILM2 IQFILM
Limits of non-zero input PDF 331 1930

Results from addition of noise
Mean Variance
Signal 0.054 0.000157
Signal and Noise 0.054 0.000198

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 11
METRIC VALUE
04/11/88 13:08:55

Info Content 177.30
PRINTER–PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
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<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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MTF data read from file: PAPER

Results from MTF effects

<table>
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<tr>
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<th>Variance</th>
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<tr>
<td>Signal</td>
<td>0.0541</td>
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<td>Signal and Noise</td>
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Read DLogE data from file: PAPER

Exposure Point is at 0.55

Results from DLogE modification

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Granularity data from file: PAPER

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<th>Mean</th>
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<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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Limits of non-zero input PDF

| 451  | 7696 |

Results from addition of noise

<table>
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<tr>
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<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<tr>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 11

<table>
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<th>Time</th>
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<tbody>
<tr>
<td>04/11/88</td>
<td>13:14:54</td>
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METRIC VALUE

| Info Content | 161.37 |
HUMAN VISUAL SYSTEM SECTION

Hard Copy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.6013</td>
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<tr>
<td>Signal and Noise</td>
<td>0.6010</td>
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</table>

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.6013</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.6010</td>
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</table>

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
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</tr>
<tr>
<td>Signal and Noise</td>
<td>0.6010</td>
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Limits of non-zero input PDF

| 469 | 7817 |

Results from addition of noise

<table>
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<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.601</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.601</td>
</tr>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 11 04/11/88 13:19:09

METRIC   VALUE

Info Content 54.45
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 12

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/Bl<strong>N</strong>F<strong>N</strong></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td>3.000</td>
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<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
<td>1</td>
</tr>
<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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</tr>
<tr>
<td>Signal and Noise</td>
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<td>0.019854</td>
</tr>
</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
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<tr>
<td>Signal and Noise</td>
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<td>0.016938</td>
</tr>
</tbody>
</table>

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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<td>0.000157</td>
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</tbody>
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Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF 331 1930

Results from addition of noise

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
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<td>0.000157</td>
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<tr>
<td>Signal and Noise</td>
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<td>0.000198</td>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 12

<table>
<thead>
<tr>
<th>METRIC</th>
<th>VALUE</th>
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</thead>
<tbody>
<tr>
<td>Info Content</td>
<td>177.30</td>
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</table>

04/11/88 13:26:09
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects
Mean  Variance
Signal  0.0541  0.000148
Signal and Noise  0.0545  0.000183

MTF data read from file: PAPER1  DATA

Results from MTF effects
Mean  Variance
Signal  0.0541  0.000099
Signal and Noise  0.0545  0.000114

Read DLogE data from file: PAPER  IQPAPER

Exposure Point is at 1.15

Results from DLogE modification
Mean  Variance
Signal  0.0208  0.000085
Signal and Noise  0.0215  0.000118

Granularity data from file: PAPER  IQPAPER

Limits of non-zero input PDF
27  879

Results from addition of noise
Mean  Variance
Signal  0.021  0.000085
Signal and Noise  0.021  0.000118

Bandlimited White Noise, Cutoff at 20.00

VARIATION 12  04/11/88  13:27:08

METRIC       VALUE
Info Content  110.19
HUMAN VISUAL SYSTEM SECTION

HardCopy – Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.355 meters

<table>
<thead>
<tr>
<th>Results from MTF effects</th>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
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<td>Signal and Noise</td>
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<th>Variance</th>
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</thead>
<tbody>
<tr>
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Limits of non-zero input PDF | 25 | 867

<table>
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<th>Mean</th>
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<tr>
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Bandlimited White Noise, Cutoff at 20.00

<table>
<thead>
<tr>
<th>VARIATION 12</th>
<th>METRIC</th>
<th>VALUE</th>
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<tbody>
<tr>
<td></td>
<td>Info Content</td>
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</table>
Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 13

Scene Information (Unimodal):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Spectrum B</td>
<td>Half-Power CY/MM</td>
<td>3.000</td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
<td>0.300</td>
</tr>
<tr>
<td>3. PDF Shape</td>
<td>1-Normal, 2-Lognormal</td>
<td>1</td>
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<tr>
<td>4. Mean</td>
<td>Rel Exposure (0-1)</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Scene statistics (mean, variance) 0.5000 0.0223
CAMERA–FILM SECTION
Magnification to next stage:  3.88
Camera Lens MTF Specification
Lens MTF – Diffraction Limited at 8.0
Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.019854</td>
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<tr>
<td>Signal and Noise</td>
<td>0.5000 0.019854</td>
</tr>
</tbody>
</table>

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.5000 0.018938</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.5000 0.018938</td>
</tr>
</tbody>
</table>

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.0541 0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
<td>0.0541 0.000157</td>
</tr>
</tbody>
</table>

Granularity data from file: FILM2 IQFILM

Limits of non-zero input PDF: 331 1930

Results from addition of noise

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.054 0.000157</td>
</tr>
<tr>
<td>Signal and Noise</td>
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Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 13
METRIC 04/11/88 14:54:20
VALUE

Info Content 177.30
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects
   Mean    Variance
Signal   0.0541  0.000148
Signal and Noise  0.0545  0.000183

MTF data read from file: PAPER1 DATA

Results from MTF effects
   Mean    Variance
Signal   0.0541  0.000099
Signal and Noise  0.0545  0.000114

Read DLogE data from file: PAPER IQPAPER

Exposure Point is at 0.85

Results from DLogE modification
   Mean    Variance
Signal   0.1729  0.003856
Signal and Noise  0.1756  0.004815

Granularity data from file: PAPER IQPAPER

Limits of non-zero input PDF

Results from addition of noise
   Mean    Variance
Signal   0.173  0.003856
Signal and Noise  0.176  0.004826

Bandlimited White Noise, Cutoff at 20.00

VARIATION 13  04/11/88  15:00:47
METRIC VALUE

Info Content  136.78
HUMAN VISUAL SYSTEM SECTION

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 0.100 meters

Results from MTF effects

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<tr>
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<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
<td>0.1756</td>
<td>0.004274</td>
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Results from MTF effects

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<td>Signal and Noise</td>
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Results from MTF effects

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</thead>
<tbody>
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Limits of non-zero input PDF

40 4291

Results from addition of noise

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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Bandlimited White Noise, Cutoff at 71.00

VARIATION 13 04/11/88 15:04:02

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<tbody>
<tr>
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Model to Estimate Information Content for a two stage Photographic System

William R. O'Such

Title for this run: VARIATION 14

Scene Information (Unimodal):

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<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Value</th>
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<tbody>
<tr>
<td>1. Spectrum</td>
<td>1/B<strong>N+F</strong>N</td>
<td>3.000</td>
</tr>
<tr>
<td>B</td>
<td>Half-Power CY/MM</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Correlation</td>
<td>3</td>
</tr>
<tr>
<td>2. Variance</td>
<td>Sigma/Mean</td>
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<tr>
<td>3. PDF Shape</td>
<td>1-Normal,2-Lognormal</td>
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<td>4. Mean</td>
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Scene statistics (mean,variance) 0.5000 0.0223
CAMERA—FILM SECTION

Magnification to next stage: 3.88

Camera Lens MTF Specification

Lens MTF - Diffraction Limited at 8.0

Results from MTF effects
Mean Variance
Signal 0.5000 0.019854
Signal and Noise 0.5000 0.019854

Film MTF Specification

MTF data read from file: FILM DATA

Results from MTF effects
Mean Variance
Signal 0.5000 0.016938
Signal and Noise 0.5000 0.016938

Read DLogE data from file: FILM2 IQFILM

Exposure Point is at 1.80

Results from DLogE modification
Mean Variance
Signal 0.0541 0.000157
Signal and Noise 0.0541 0.000157

Granularity data from file: FILM2 IQFILM
Limits of non-zero input PDF

Results from addition of noise
Mean Variance
Signal 0.054 0.000157
Signal and Noise 0.054 0.000198

Exponentially Shaped Noise, Cutoff at 100.00

VARIATION 14 04/11/88 15:59:47
METRIC VALUE
Info Content 177.30
PRINTER-PAPER SECTION

Lens MTF - Diffraction Limited at 5.6

Results from MTF effects

<table>
<thead>
<tr>
<th>Mean</th>
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<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
<td>0.0545 0.000183</td>
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MTF data read from file: PAPER1  DATA

Results from MTF effects

<table>
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<tr>
<th>Mean</th>
<th>Variance</th>
</tr>
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<tr>
<td>Signal</td>
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<tr>
<td>Signal and Noise</td>
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</table>

Read DLogE data from file: PAPER  IQPAPER

Exposure Point is at 0.85

Results from DlogE modification

<table>
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<tr>
<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
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Granularity data from file: PAPER  IQPAPER

Limits of non-zero input PDF

| 40 | 4325 |

Results from addition of noise

<table>
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<tr>
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<tbody>
<tr>
<td>Signal</td>
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Bandlimited White Noise, Cutoff at 20.00

VARIATION 14

| 04/11/88 | 16:03:27 |

METRIC  VALUE

| Info Content | 136.78 |
**HUMAN VISUAL SYSTEM SECTION**

HardCopy - Adapted to 6.00 Foot-Lamberts

For Viewing Distance of 1.000 meters

Results from MTF effects

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<tr>
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Results from MTF effects

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Results from MTF effects

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Limits of non-zero input PDF 40 4291

Results from addition of noise

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<th>Mean</th>
<th>Variance</th>
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<tbody>
<tr>
<td>Signal</td>
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<td>Signal and Noise</td>
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Bandlimited White Noise, Cutoff at 7.10

**VARIATION 14**

<table>
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<tr>
<th>METRIC</th>
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04/11/88 16:05:28