INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/638-39

**College on Medical Physics:
Imaging and Radiation Protection**

31 August - 18 September 1992

Radiographic Sensitized Material Evaluation

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Division of Nuclear Safety
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RADIOGRAPHIC SENSITIZED MATERIALS EVALUATION

* *Test new image registration system*
  (strictly connected with progress in Radiology)

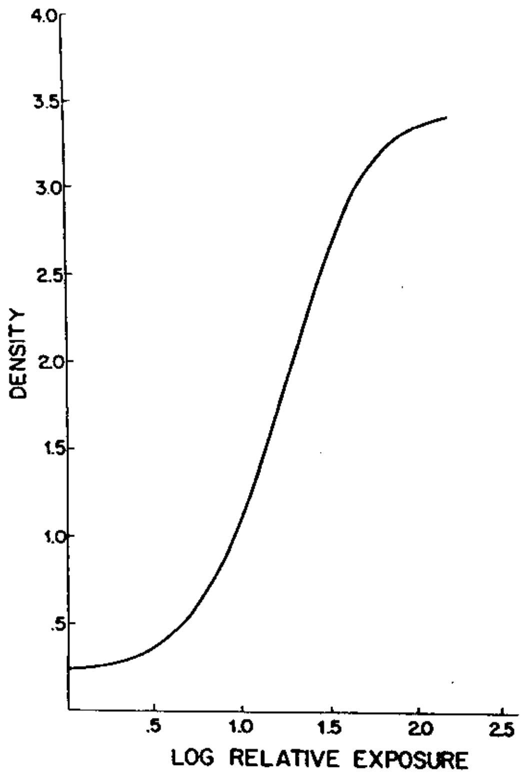
** *Purchasing criteria*

FUNDAMENTAL PHYSICAL PARAMETERS WHICH DETERMINE THE QUALITY OF A FILM -SCREEN SYSTEM

* *IMAGE QUALITY*
  - Characteristic curve
  - Spatial resolution
  - Noise

** *PATIENT DOSE* — Sensitivity

CHARACTERISTIC CURVE



CONTRAST = 1° **Derivative of characteristic curve**

GAMMA $= \dfrac{D_2 - D_1}{LogE_2 - logE_1}$

LATITUDE $= E_2 - E_1$

AVERAGE CONTRAST $= \dfrac{1.75}{LogE_4 - logE_3}$

SENSITIVITY

The reciprocal of exposure required to obtain an optical density of 1 (above the base plus fog level)

NOTE

It is commonly used the parameter SPEED instead of sensitivity:

$$\text{Sensitivity(mR)} = 128 / \text{Speed}$$

SPATIAL RESOLUTION

Spatial resolution means the capability of a receptor to reproduce small size, high contrast detail.

If the system is isoplanar and linear

↓

MTF (Modulation Transfer Function)

is the parameter most commonly used to describe the spatial resolution.
It is a monodimensional function which represents the contrast dependence on spatial frequency.

NOISE

QUANTUM NOISE
local statistical variation in the number of x-ray photons

STRUCTURAL NOISE
not uniformity size of grains of the screen and of the film

INTRINSIC NOISE
film granularity

OTHER SOURCES NOISE
manufactoring and developing process

* INCOMPLETE DESCRIPTION   standard deviation

* DETAILED ANALYSIS   Wiener spectrum

IMAGE QUALITY :

SYNTHESIS OF VARIOUS PHYSICAL CHARACTERISTICS
(non mutually independendent)

↓

SINGLE QUALITY INDEX

*** Diagnostic accuracy: measure of visual image quality**

MODEL

↙ ↘

Displayed **Perceived**

The *displayed statistical decision theory model* SNR^2_{SAD}

$$SNR^2_{S,D} = k\gamma^2 \frac{\left(\int_0^\infty O^2(u)M^2(u)u \cdot du\right)^2}{\int_0^\infty O^2(u)M^2(u)W(u)u \cdot du}$$

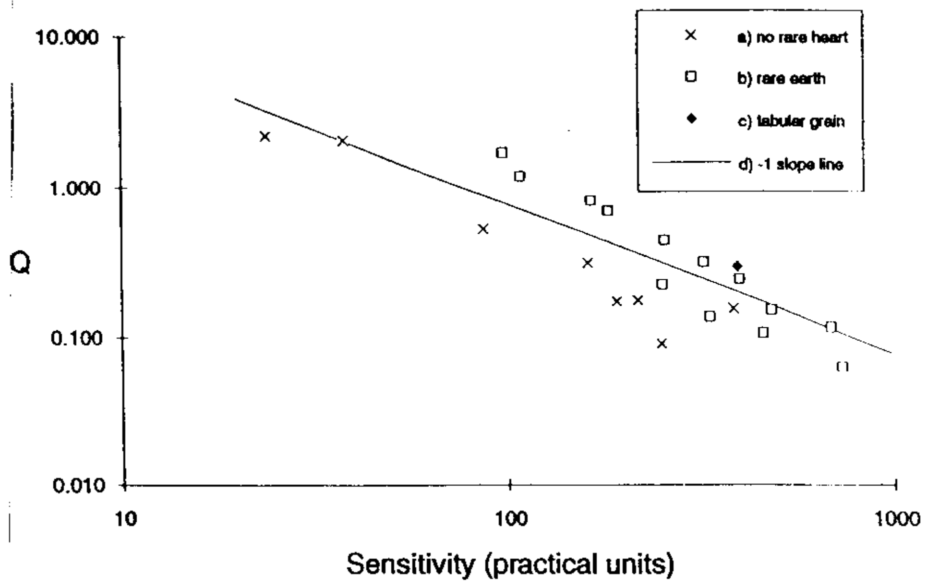
The *displayed amplitude model* $SNR^2_{A,D}$

$$SNR^2_{A,D} = k\gamma^2 \frac{\left(\int_0^\infty O(u)M(u)u \cdot du\right)^2}{\int_0^\infty W(u)u \cdot du}$$

$$IQ = G^2 \frac{M^2(f_0)}{V}$$

Global quality ("the technological level")

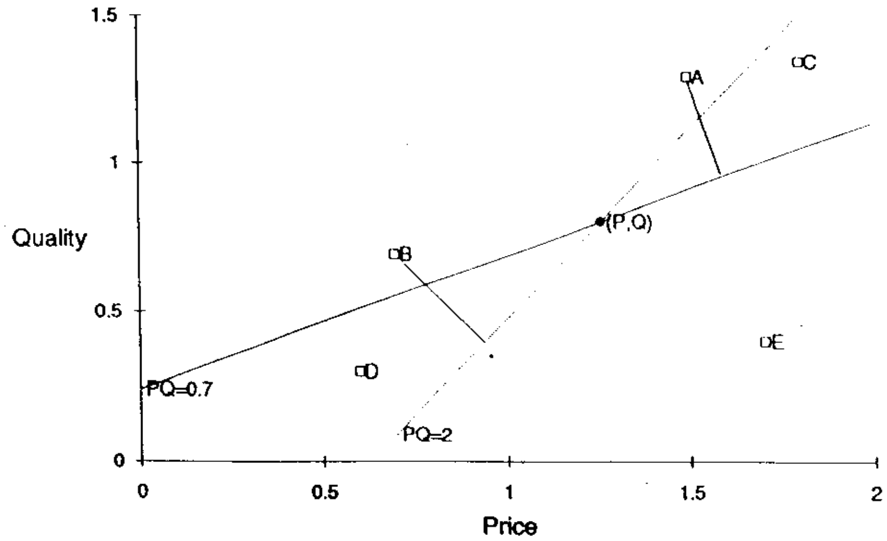
$$Q = IQ \cdot S$$



Bid specification and purchasing criteria

$$QP = \frac{\frac{\Delta Q}{Q}}{\frac{\Delta P}{P}} = \frac{P}{Q} \cdot \frac{\Delta Q}{\Delta P}$$

$$\frac{\Delta Q}{\Delta P} = QP \cdot \frac{Q}{P}$$



CHARACTERISTIC CURVE

SHAPE depends on: intrinsic propriety of the film
developing conditions

does not depends on light emission spectra of the screen

ABSOLUTE POSITION (sensitivity) depends on the radiant energy absorbed by the film

METHOD FOR OBTAINING THE CURVE

Sensitometer | **Direct x-ray exposure**

SENSITOMETER

Density	Log relative exposure	Relative exposure
.21	0.0	1.00
.22	0.1	1.26
.23	0.2	1.59
.25	0.3	2.00
.28	0.4	2.51
.31	0.5	3.16
.37	0.6	3.98
.47	0.7	5.02
.59	0.8	6.31
.75	0.9	7.95
.97	1.0	10.0
1.26	1.1	12.6
1.57	1.2	15.9
1.91	1.3	20.0
2.27	1.4	25.1
2.57	1.5	31.6
[illegible]	1.6	39.8
2.90	1.7	50.2
3.11	1.8	63.1
3.21	1.9	79.5
3.25.	2.0	100.0
3.27	2.1	125.8
3.30	2.2	158.5

ADVANTAGE
easy
quick

DISADVANTAGE
useful only to obtain the shape

(QUALITY CONTROL OF DEVELOPING PROCESS)

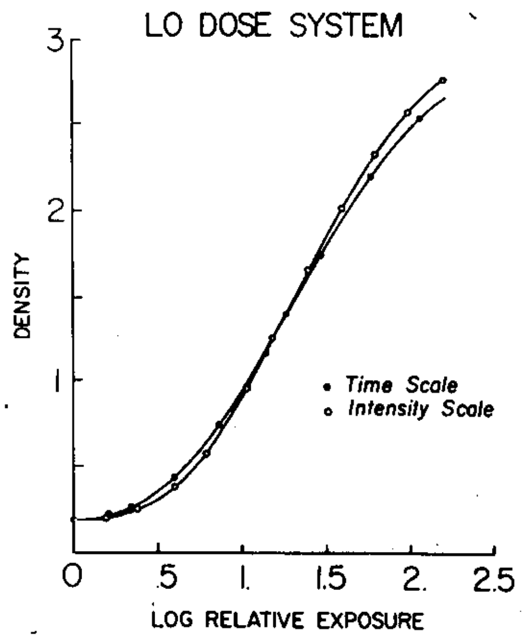
DIRECT X-RAY EXPOSURE

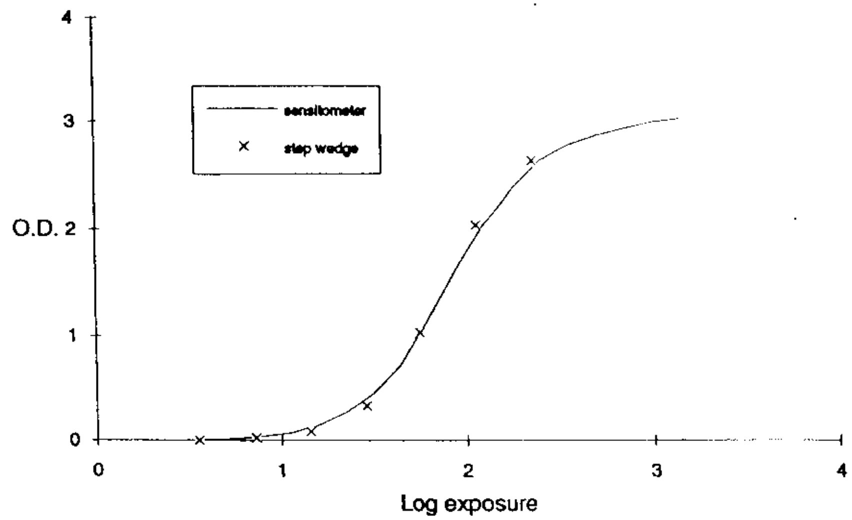
TIMING SCALE

INTENSITY SCALE: - metal step wedge

- bootstrap technique

- recording system placed at various distance from the source

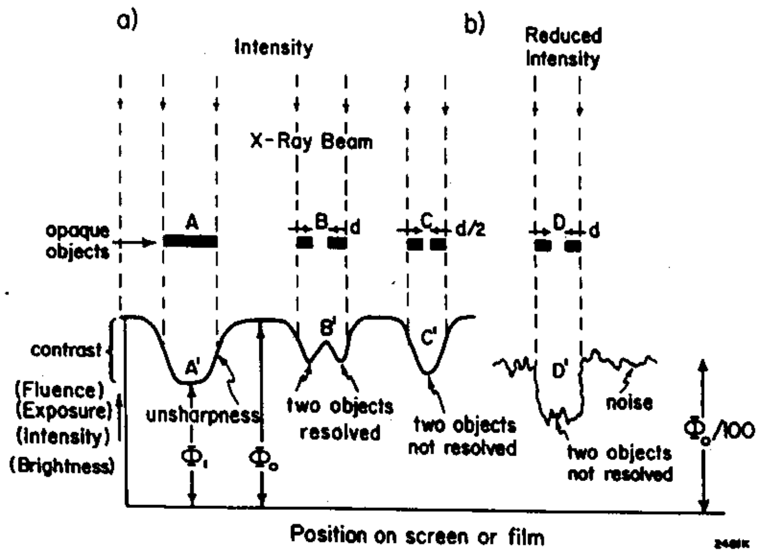




SPATIAL RESOLUTION

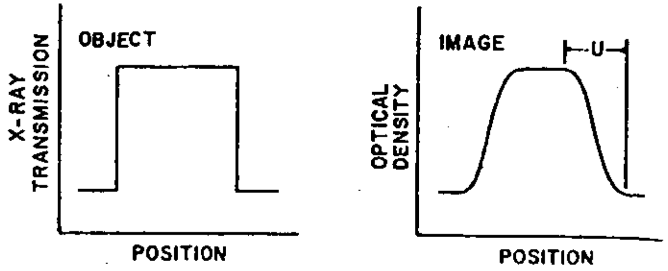
RESOLVING POWER

The ability of a photographic material to mantain in the developed image the separate identity of parallel bars when their relative displacement is small



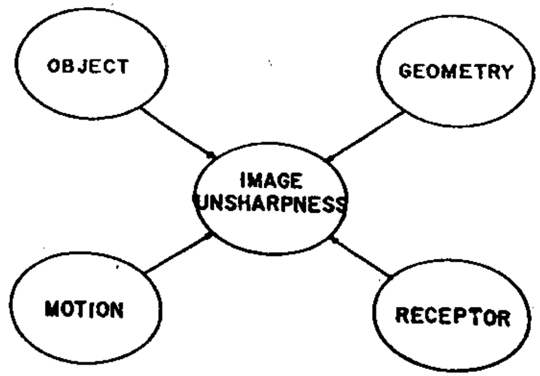
UNSHARPNESS

ONE OBJECT WITH SHARP EDGES PRODUCES AN IMAGE WITH BLURRED EDGE



FACTORS AFFECTING UNSHARPNESS :

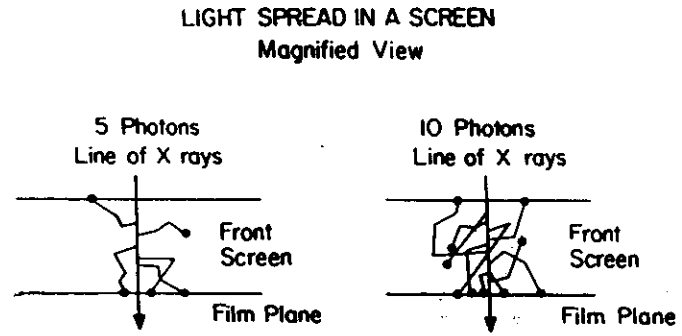
- *SIZE OF THE FOCAL SPOT*
- *MOTION OF THE OBJECT DURING EXPOSURE*
- *GEOMETRIC BLURRING*
- *BLURRING IN THE SCREEN-FILM COMBINATION*

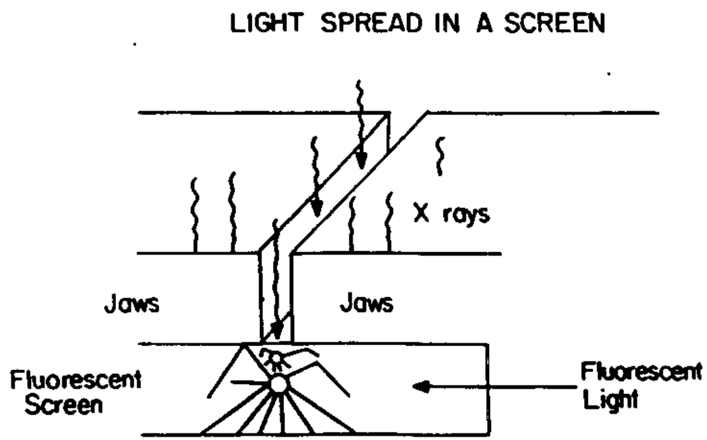


BLURRING IN THE SCREEN-FILM COMBINATION

LIGHT SPREAD

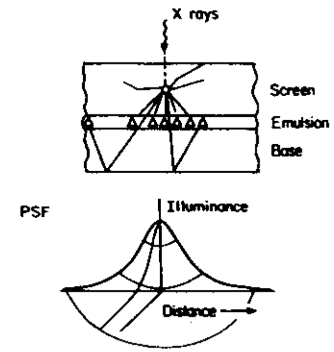
When a screen-film combination is exposed to a narrow line of X rays , the resultant fluorescent light diffuses through the screen and "defocusses" the image





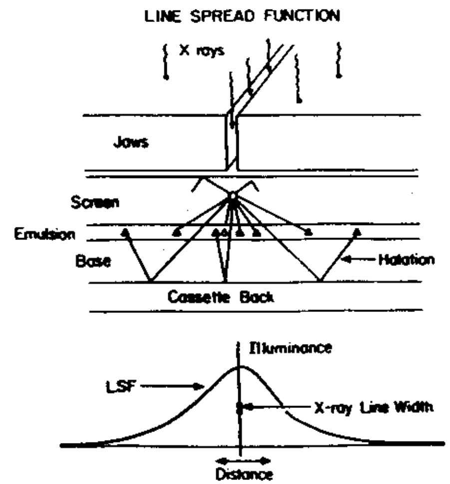
POINT SPREAD FUNCTION (PSF)

Illuminance versus distance function for the light wich spreads from a point of X rays absorbed in the screen



LINE SPREAD FUNCTION (LSF)

The spatial distribution of illuminance in the film plane transverse to the X ray line

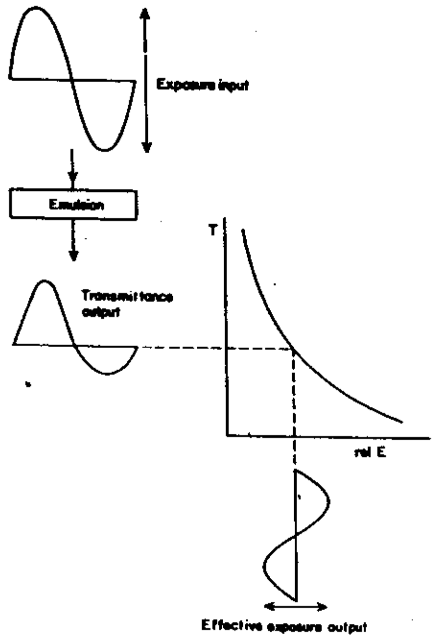


MODULATION TRANSFER FUNCTION (MTF)

'ODULATION TRANSFER FACTOR

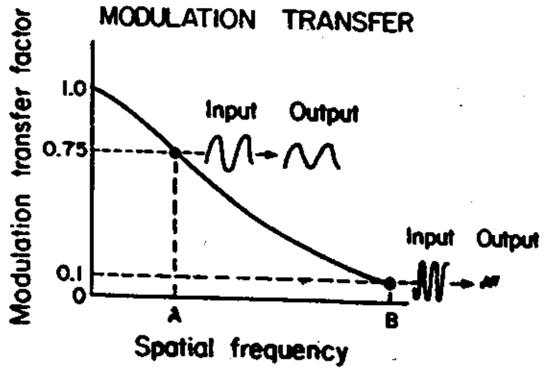
'he ratio of the effective
xposure modulation to the
ıput exposure modulation

$$'T = \frac{\text{Modulation of Output Signal}}{\text{Modulation of Input Signal}} = \frac{M}{M'}$$



\n MTF specifies at each spatial
requency the fraction of input
nodulation which will be imaged

$$'MTF(f) = \frac{M(f)}{M(0)}$$



MEASUREMENT OF RESOLVING POWER

SPATIAL DOMAIN

PSF
LSF

DISADVANTAGES

. Practical difficulties in the measurement

. Function not mathematically additive or multiplicative

FREQUENCY DOMAIN

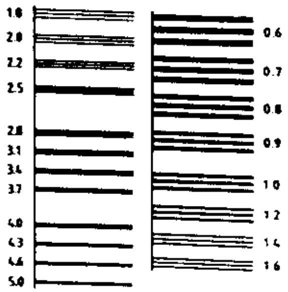
MTF

ADVANTAGES

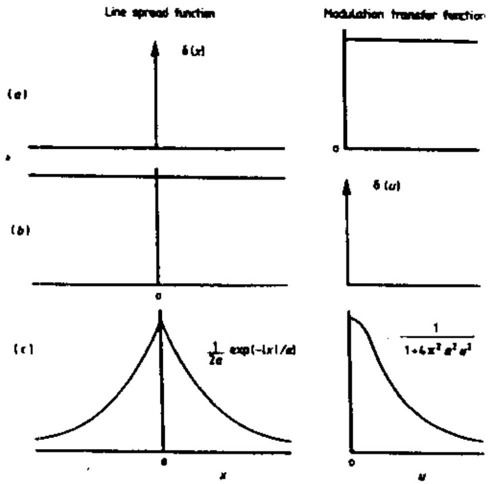
. Provide a complete picture of the resolution.
Rapresent the ratio of output amplitude to the input amplitude when a sinusoidal signal of varying frequency is passed through a given transfer system

MEASUREMENT OF MTF

DIRECT MEASUREMENT OF PERIODIC PATTERN TEST OBJECT



FOURIER TRANSFORM OF THE MEASURED LSF



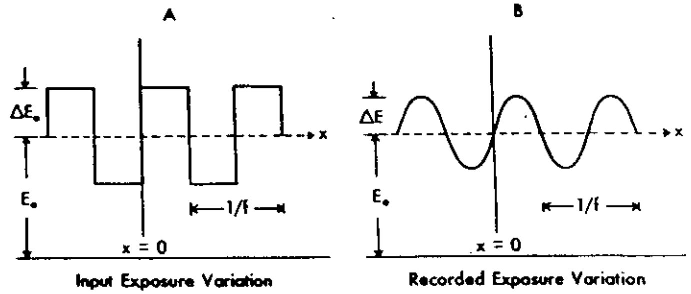
USE OF BAR PATTERN TEST OBJECT

Difficulties to obtain a test object which gives sinusoidal input exposure variation

SQARE-WAVE RESPONSE FUNCTION (SWRF)

Modulation Transfer Factor of a square-wave response

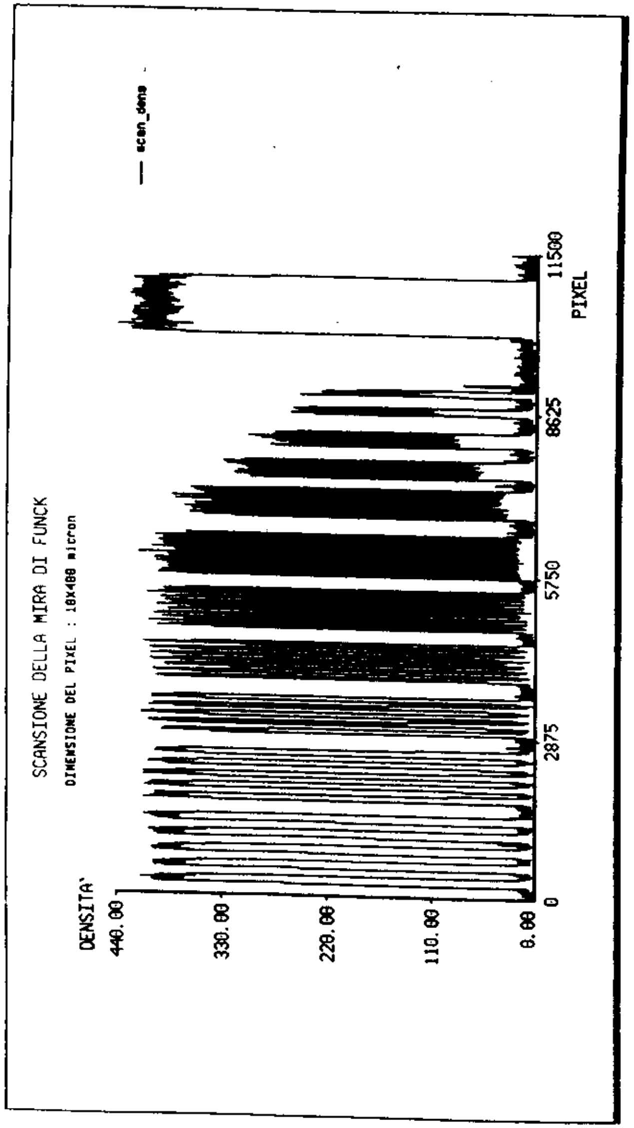
$$S(f) = dE(f) / dEo$$



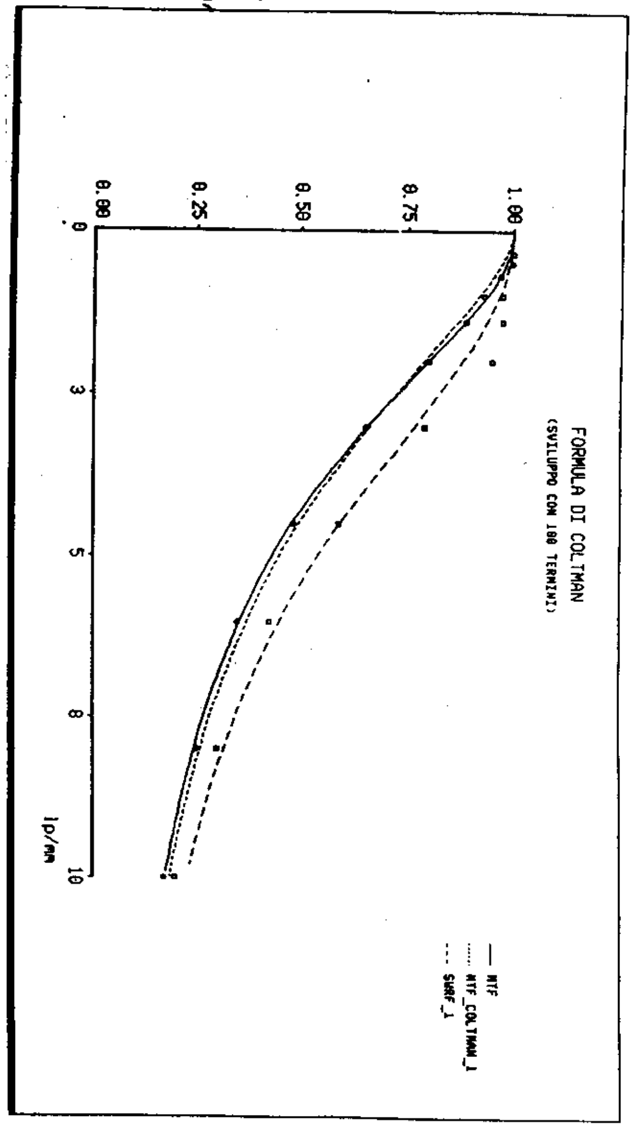
COLTMAN EQUATION

Gives the mathematical ralationships between the SWRF and MTF

$$MTF(f) = \frac{\pi}{4}\left[S(f) + \frac{S(3\cdot f)}{3} - \frac{S(5\cdot f)}{5} + \frac{S(7\cdot f)}{7} + \frac{S(11\cdot f)}{11} - \frac{S(13\cdot f)}{13} - \frac{S(15\cdot f)}{15} - \frac{S(17\cdot f)}{17} + \frac{S(19\cdot f)}{19} \ldots\right].$$



SCANSIONE DELLA MIRA DI FUNCK
DIMENSIONE DEL PIXEL : 10X400 micron
scan_dens
DENSITA'
440.00
330.00
220.00
110.00
0.00
0
2875
5750
8625
11500
PIXEL



FORMULA DI COLTMAN
(SVILUPPO CON 100 TERMINI)
1.00
0.75
0.50
0.25
0.00
0
3
5
8
10
lp/mm
MTF
MTF_COLTMAN_1
SURF_1

FOURIER TRANSFORM OF THE LSF

$$MTF(u) = \int_0^\infty LSF(x) \cos 2\pi ux \, dx \Big/ \int_0^\infty LSF(x) \, dx$$

COMPUTATIONAL METHODS

THE SAMPLING THEOREM

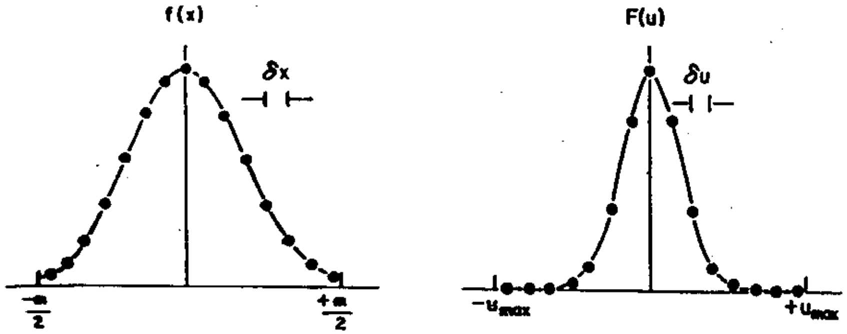
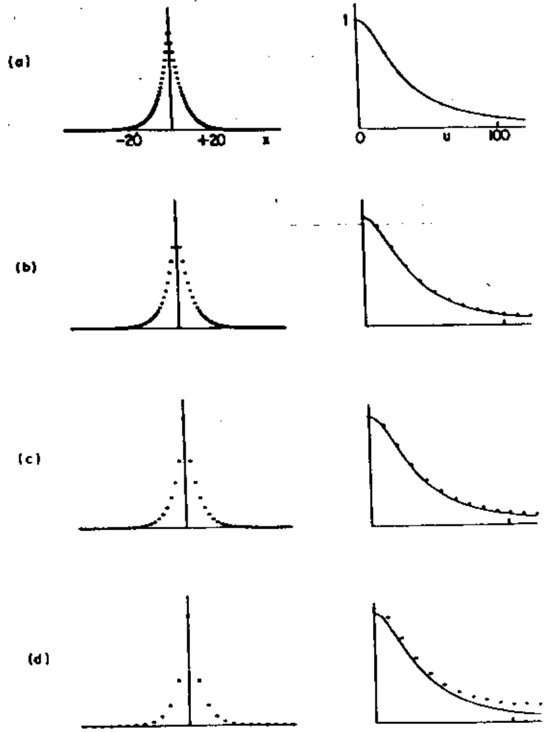


Illustration of the sampling theorem. If $f(x)$ is defined within the range m, then $F(u)$ is fully described by points $\delta u = \frac{1}{m}$ apart. Conversely, if the range of interest of $F(u)$ is $2u_{max}$, then $f(x)$ may be sampled at intervals not greater than $\delta x = \frac{1}{2u_{max}}$.

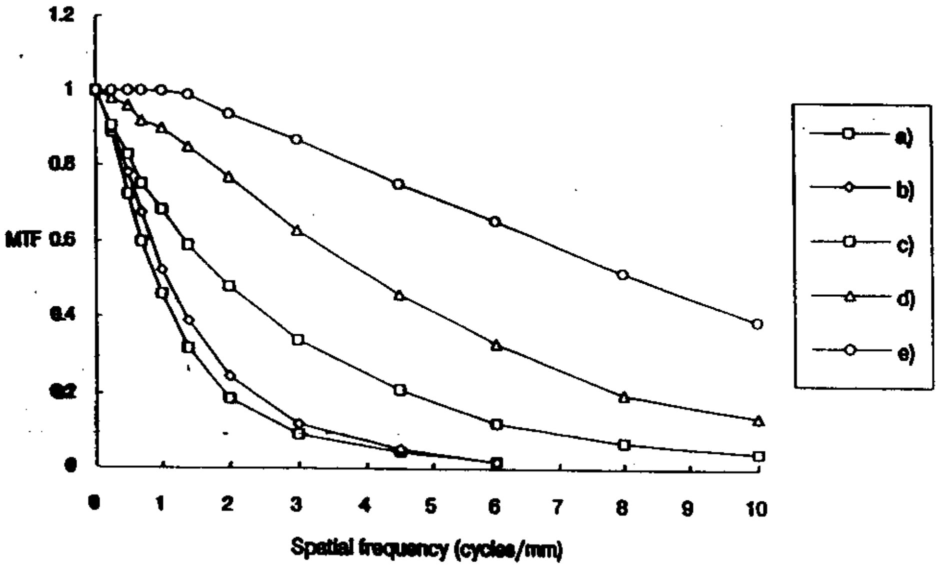
THE EFFECT OF SAMPLING ON COMPUTED MTF



Practical suggestion :

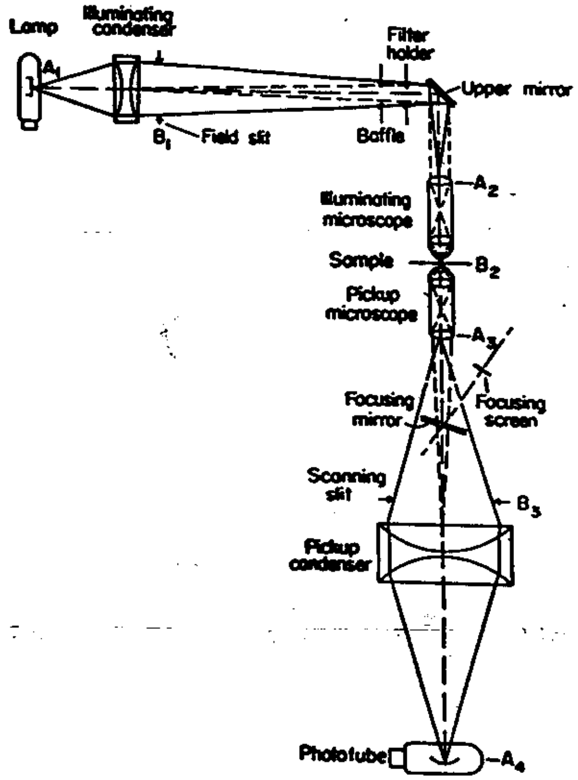
MTF Error < 0.5% ——▶ Sampling interval < 25% of the FWHM of the LSF

QUANTITATIVE VALUES (lp/mm)

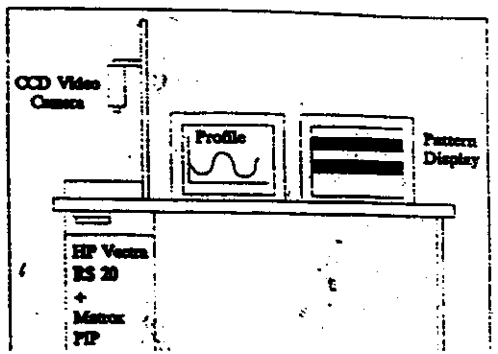


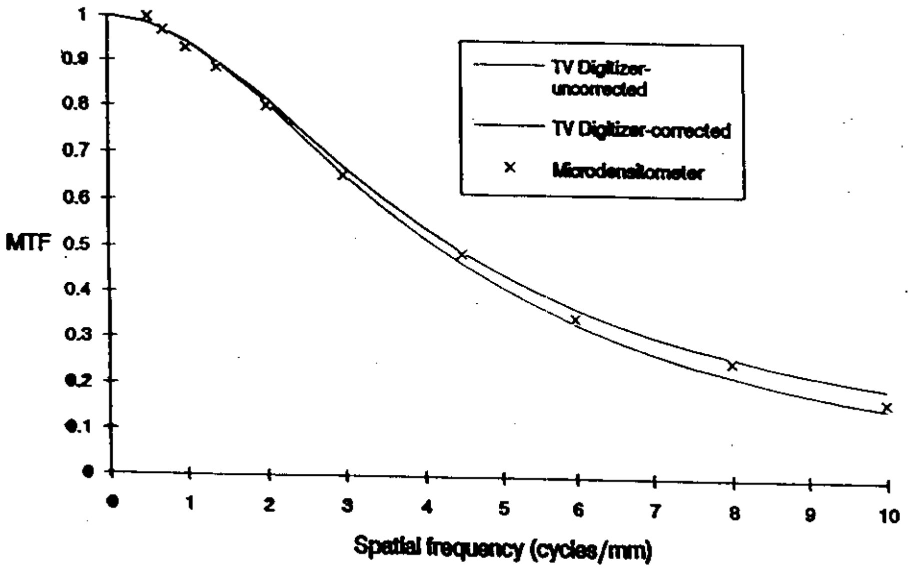
INSTRUMENTATION

MICRODENSITOMETER



TV-CAMERA DIGITIZER





NOISE

The noisy apperence (RADIOGRAPHIC MOTTLE) of a uniformly exposed X-Ray film is due to the spatial variation of the film density

A number of studies have demonstrated that the density D_A as measured with an aperture of area A should follow a Gaussian distribution

MEASURE OF RADIOGRAPHIC NOISE

AUTOCORRELTION FUNCTION

WIENER SPECTRUM

AUTOCORRELATION FUNCTION

FIRST ORDER STATISTICS

$$\bar{D} = \frac{1}{A}\iint_A D(x,y)\,dxdy \qquad \sigma^2 = \frac{1}{A}\iint [D(x,y) - \bar{D}]^2\,dxdy$$

While $\bar{D}$ and σ fully describe the statistical character of the noise, they do not tell us whether there is any correlation between density measured at different points

HIGHER ORDER STATISTICS

AUTOCORRELATION FUNCTION

$$C(\zeta,\eta) = \frac{1}{A}\iint_A \Delta D(x,y)\,\Delta D(x + \zeta,\, y + \eta)\,dxdy$$

It follows that

$$C(O,O) = \sigma^2$$

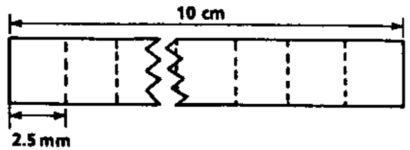
the scale value of the autocorrelation function is simply equal to the variance

WIENER SPECTRUM

$$\phi(fx,fy) = \frac{1}{A}\left[\iint_A \Delta D(x,y)\,e^{-2\pi i(xf_x + yf_y)}\,dxdy\right]^2 \qquad (6)$$

the Wiener spectrum is the Fourier transform squared of the density fluctuations. While determining φ(fx,fy), an ensemble average should be taken in addition to the space average indicated in Equation

MEASUREMENT



Slit Width 5 μ   Spacing 10 μ

No. of Data Points Collected per Segment 250

↓

Fourier Transform 250 Data Points from Each Segment

↓

Determine Wiener Spectrum

↓

Average 40 Wiener Spectra

WIENER SPECTRUM

$$\phi(fx,fy) = \frac{1}{A}\left[\int\!\!\int_A \Delta D(x,y)\, e^{-2\pi i(xf_x + yf_y)}\, dxdy\right]^2 \qquad (6)$$

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MEASUREMENT