# Fast and Objective MRTD measurement.

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## 1.0 Abstract

Manufacturers and Users of the Thermal Imagers have spent very much time upon the definition and measurement of the generally accepted performance curve: MRTD (Minimum Resolvable Temperature Difference). The need for a cheap and fast, objective measurement method has considerably increased since the large scale introduction of thermal imagers. This paper contains a contribution to such a method, based upon simple targets, a CCD-camera and an IBM-PC with frame-grabber unit and fast computation algorithms.

## 2.0 Introduction

Several recent publications (Williams [1], Vortman [2]) on MRTD measurements indicate the efforts, spent in different nations to obtain performance data for thermal imagers in a simple, accurate and reproducible way. This indicates, that people are not happy in using the classical method of measuring the MRTD: appearance and disappearance of 4-bar patterns in the noise on a display. This method is briefly described in Lloyd [3].

The disadvantages of the classical way to measure the MRTD curve are:

- the need for a stable collimator system
- the need for a number of 4-bar patterns
- great temperature homogeneity over the patterns
- very accurate temperature controller (better than 0.01 K)
- a number of "standard" observers
- uncontrollable answers of the observers
- different interpretation of observing 4-bars
- a very time-consuming method (several hours per curve)
- influence of status of the human observer (and his eyes)

Furthermore it appeared, that the method to measure the MRTD was not the same in different nations. Starting from the NVL method, promoted through the NATO Research Study Group 7 of Panel IV (Optics and

Infrared), demonstration tapes were distributed with agreements about when the 4-bars would be considered to disappear. Unfortunately this was not succesful, reason to start a NATO standardization group with the task to write a STANAG 4349 on MRTD measurement of thermal cameras.

In the meantime methods to calculate and model the MRTD were improved. A first attempt from the Night Vision Laboratory (Ratches [4]) apparently deviated at low spatial frequencies. Other nations started work on MRTD resulting in a comparison through RSG.7, where especially the Human Eye caused differences (Höhn [5]). Hepfer [6] made an improvement concerning the eye. Vortman's [2] model comes close to the measurements.

The measurement of the MRTD curve in an objective way was a goal for many system evaluators. Spatial resolution could relatively easy be measured by measurement of the MTF of the total system, including the display. MTF generally was obtained by the fourier transform of the line spread function (LSF), measured by means of a photo-multiplier with fiber, scanning over the display. Implementation of the noise measurement caused bigger problems however.

Edwards [7] introduces an image computer, calculating the information content in the noisy, smeared image. Williams [8] takes a CCD-camera and a computer, calculating the S/N ratio of 4-bar patterns. Cuthberson [9] does calculations of MRTD from the MTF measurements, the NETD and an observer model. His results show however some deficiencies at higher spatial frequencies. Geluk [10] measures the S/N ratio with a simple device for a 7-bar pattern in an elegant, but time-consuming way. At FEL-TNO, work started in 1987 on objective measurement methods of MRTD after poor experiences in the years before, due to the previously mentioned disadvantages of the classical MRTD measurement method. This work was sponsored by the Ministry of Defence. The realization of the hardware set-up and the software programming was carried out in the Research Group Infrared of FEL-TNO.

## 3.0 Principle of New Method

The new method, developed at FEL-TNO, consists of the following steps:

- measurement of the line spread function (LSF)
- calculation of the modulation transfer function (MTF)
- measurement of the temperature responsivity
- measurement of the noise pixel distribution

- calculation of the noise power spectrum
- calculation of the geometry (magnification, eye distance)
- calculation of the MRTD with semi-empirical formula

Following is the MRTD formula used:

$$MRTD(f) = \frac{FN_s(f) * FF_e(f)}{MTF_s(f) * MTF_e(f)} \qquad (1)$$

in which

- $MTF_s(f)$ is the system MTF, calculated from the LSF
- $MTF_e(f)$ is the MTF of the eye, approximated by:

$$MTF_e(f) = \sin^2 \left\{ \frac{\pi}{2} * \sqrt[3]{\frac{f}{f_m}} \right\} \qquad (2)$$

in which

- f is the spatial frequency in the object space (lp/mrad)
- $f_m$ is the frequency of max. eye response, transformed to the object space
- $FN_s(f)$ is the noise spectrum, calculated from the pixel distribution
- $FF_e(f)$ is the filter function, representing the eye-brain integration system:

$$FF_e(f) = \frac{1}{\sqrt{0.2 * F_r * 3.5}} * \sqrt[3]{1 + \left(\frac{f-f_m}{f_m}\right)^2} * \sqrt{\Delta f_e} \qquad (3)$$

in which $F_r$ is the frame rate and $\Delta f_e$ is the eye-noise bandwidth.

The only targets, used in this method are: 1) a line source, oriented vertically, horizontally or tilted at any angle; 2) a circular source with a homogeneous temperature and several well calibrated degrees warmer or colder than a homogeneous background. The size of this source has to be known and adapted to the resolution and the field of view of the imager. There is no use of 4-bar patterns.

## 4.0 Set-up

The set-up of the equipment around the thermal imager under test is shown in fig. 1. The major components are the CCD-camera (Sony AVC-D5CE) and the Data Translation frame-grabber, mounted in an IBM-PC-AT computer. The image of the thermal camera is presented on a display, of which the central part is projected on the 500 x 582 CCD array. The video signal is digitized in 8 bits in a 512 x 512 frame-grabber (DT 2851). Processing of the video picture is partly done in a special processing card DT 2858, which can e.g. add, subtract, and average pictures.

The processed images can be presented on a T.V. display. The calculated function can be plotted on a standard plotter.

The targets can be located in the focal plane of a collimator, such as shown in fig. 1. The line source is a heated thin wire and the circular source is a hole in a plate in front of a regulated blackbody source. Due to the simple target set-up, it is possible to use the same measurement principle without the collimator, but with extended sources at a distance of 30-50 m. Most of the imagers can be focussed at these ranges.

Special software has been written to process the video pictures and to perform the necessary calculations. In the following chapters the measurement procedure will be described step by step. The main components of the set-up are shown in the picture of fig. 2.

## 5.0 LSF/MTF

For the line spread function LSF one has to take care of the following items during the intake procedure:

- be sure that sufficient samples of the CCD-camera are falling on the width of the line target
- be sure that the video signal remains sufficiently within the dynamic range of the thermal camera (no saturation)
- be sure that the camera is well focussed on the line; this is generally done with succes with a second line, located close to and behind the first line, tilted over an angle of 5-10$^{o}$
- be sure that the CCD-camera is properly exposed
- sufficient signal to noise ratio is obtained by averaging more frames of the thermal camera

- the geometrical relationship between object space and observer space is obtained from the circle measurement, i.e. the calibration of the spatial frequency along the horizontal axis of the MRTD curve
- alignment of the line-source with the CCD pixels is done automatically with a specially developed alignment programme
- be sure, that the thermal imager has no aliasing; if the camera has aliasing, it is recommended to put the line-source at least $5^{o}$ off the vertical axis, or to tilt the imager over more than $5^{o}$
- make a correction for the LSF (MTF) of the CCD-camera + lens.

Concerning the display of the thermal imager, there are 3 possibilities:

1) The imager has its own display monitor
2) The imager has a monitor with an eye-piece
3) The imager has no monitor; in this case the use of a high resolution standard monitor is recommended.

The CCD-camera is mounted in case 2) by means of an adaptation ring directly with its objective lens to the eye-piece. In the FEL-TNO set-up we used a Sony CCD-camera with 50 mm NIKON Lens with spacing rings. This lens has a manual diaphragm, the camera however, has automatic gain control. The CCD-camera has the possibility to be synchronized externally. This is preferred in general.

The MTF calculation is done by means of a Fast Fourier Transform algorithm which takes only a few seconds. The MTF is normalized to 1 for zero spatial frequency. The values for the lowest spatial frequencies are obtained by linear extrapolation of the MTF values of following frequencies. For high spatial frequencies, where the MTF value is below 10%, the data are replaced by the value of a parabolic curve with its extremum at the frequency axis. This curve is fitted to the MTF data between 10% and 50%. This is done to force the MTF to a zero value for a certain spatial frequency. Due to noise effects, too long the MTF keeps values of 1-5% which is impossible as several of the components of the imagers have MTF functions comparable to a sinc function.

Although the MTF for vertical lines is generally of somewhat more interest, the intake of horizontal lines is very interesting. Here the problem of aliasing arises stronger because most of the imagers have very discrete horizontal scanning lines. Tilting of the line source over $10^{\circ}$ or more is therefore recommended.

## 6.0 Noise and geometry

In this case the circular source is used, which has several degrees temperature difference with its background. The gain of the thermal imager is set at such a value that system noise is clearly visible at the display. Offset and gain are positioned in such a way that the screen luminances are well within the boundaries of the dynamic range (no saturation). The first use of the circular target is the determination of the temperature responsivity. The mean of 100 frames is taken to remove the noise. The signal level of the circular area and its surroundings is determined from the histogram of the picture. On this histogram a sum of two gaussian distributions is fitted; the centers of these distributions give the two levels. If the temperature difference of the source is known, one has obtained the temperature responsivity in terms of binary levels per degree.

The second use of the circular target is the calibration of the system magnification (as mentioned at the LSF consideration). The same picture as before is thresholded on the value exactly between the previously determined levels. After that the two dimensions of the circular target (which is generally transformed to an ellipse by the imager distortion) are determined. This is done by measuring the width by searching the horizontal line with the max. number of pixels within the ellipse and calculating the other dimension. This is possible when the total area is determined by counting the total number of pixels within the area of the ellipse.

In the third and main use of the circular source two pictures are subtracted. This removes all very low frequencies and also the circular target. What remains is the noise pixel distribution, with the remark that linear noise subtraction gives a factor $\sqrt{2}$ increase in the noise voltage.

Next the mean of the power spectrum of 16 horizotnal lines of 256 points is taken for the horizontal noise spectrum. The same is done for the vertical direction. The RMS value of the pixel distributions is also calculated (NETD). By means of Parseval's relation, the power spectrum can be calibrated from the pixel distribution. After these calculations we plot as the system noise spectrum the average of the horizontal and vertical noise spectrum. Along the vertical axis is plotted the value in degree per root lp/mrad. In order to obtain the noise value in a certain spatial bandwidth one has to multiply the given value with the root of the noise bandwidth of the eye.

## 7.0 The Human Eye

Because of the spread in interpretation by different observers which gives different results, it is highly recommended to replace the real eye by a formula, which is approaching the average results. The perception capabilities of the eye has been subject of investigation for a long time. Biberman [11], gives a good overview of the information available until 1973. Overington [12] has spent tremendous effort in modelling the eye. Vortman [2] however, turns the filter functions into the MRTD direction: both the adaptive matched filter model and the synchronous integrator model are introduced. At least the discrepancies of RSG.7 are removed (ref. 5).

In this paper the eye is formalized in 3 ways:

1. A Modulation Transfer Function $MTF_e(f)$ according to formula (2) for average illumination conditions. The function goes to zero at a spatial frequency of $8*f_t$ where $f_t$ is the spatial frequency of max. response. Note that

   $f_t = \frac{f_m}{M}$ where M is system magnification. This $MTF_e$ represents

   the spatial filtering (see fig. 3).
2) The Noise Filter Function $NFF_e(f)$ representing the noise integration in the eye, which operation is somewhat frequency dependent, as shown in fig. 4.
3) Additional Noise integration, such as discussed by Lloyd [3]; which leads to a factor of

   $\sqrt{\frac{\Delta f_e}{0.2 * F_r * 3.5}}$ . For the eye-noise bandwidth we have found empirically a value of 1 lp/mrad. The value of 0.2 is the eye integration time, $F_r$ is the frame-rate and the value of 3.5 is caused by the length of the bars in the classical MRTD method. It has to be noted, that the determination of the magnification of the system until the eye has to be carried out in a proper way. One way is to measure the size of the part of the display of the thermal imager, which is viewed by the CCD-camera.

## 8.0 Results

During the project a reasonable amount of experiments have been undertaken to validate the MRTD measurements method, described in this paper. Several thermal imagers were available, one of them being the IR18 from Barr and Stroud with a 6x telescope, giving a field of view of $4^o x 6^o$. The results, obtained with this camera will be discussed in this chapter.

In the initial phase of the project we had to learn a lot of the precautions, described in the procedures in chapters 4.0, 5.0, 6.0 and 7.0. An example is the aliasing effect in a prototype imager, demonstrated in fig. 5. We took finally the tilted line to obtain reliable results. In fig. 6 two raw pictures of the circular source are shown, a) being used for the noise measurement (the second frame is not yet subtracted); b) being used for geometry and responsitivity measurement.

In fig. 7 the measured LSF of the IR18 is given, in the plot the 50% width is given: 0.43 mrad. Also the calculated $MTF_s$ of the system and the corresponding $MTF_e$ (corrected for magnification) $MTF_s$ goes down to zero at 3 lp/mrad.

In fig. 8 the noise pixel distribution is plotted; from this plot one can obtain the classical NETD value by taking the RMS value. In this case a NETD value of 0.40 K results. Also the calculated noise spectrum, $FN_s(f)$ is given.

In fig. 9 the calculated MRTD curve is plotted. The calculation was done by means of formula (1). The MRTD values, measured in the classical way are indicated in the same plot. A striking correspondence is apparent, with a view on the spread in results of the human observer.

Finally a plot is given of the MRTD measurement of a prototype thermal imager with a tilted line target (see fig. 10). Again a good agreement between the results of the classical and new method is shown.

## 9.0 Conclusions

The new method, described in this paper, to measure the MRTD of a thermal imager, has proved to have eliminated most of the disadvantages of the classical method; the new method has the following features:

- the MRTD is obtained in an objective way
- The MRTD can be measured in the field
- the method is fast (± 15 min.) compared to the classical method
- the method is cheap, because
    * the targets are simple
    * no expensive collimator system is necessary
    * the temperature stability can be relatively low
    * there is no need for expensive observers
    * the method is fast

It is recommended to look for possibilities to reach an international agreement about an MRTD measurement, such as described in this paper. Manufacturers of thermal imagers, users and advisers like the various government-agencies as FEL-TNO, should agree upon a standard method.

## 10.0 Acknowledgements

At first we want to acknowledge the Netherlands Ministry of Defence for sponsoring this project. Secondly we thank our colleagues at RSRE (Malvern) and FfO (Tübingen) for their helpful discussions. Finally we thank our colleagues at FEL-TNO who carried out the MRTD measurements according to the classical method.

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## 12.0 Appendix with figures

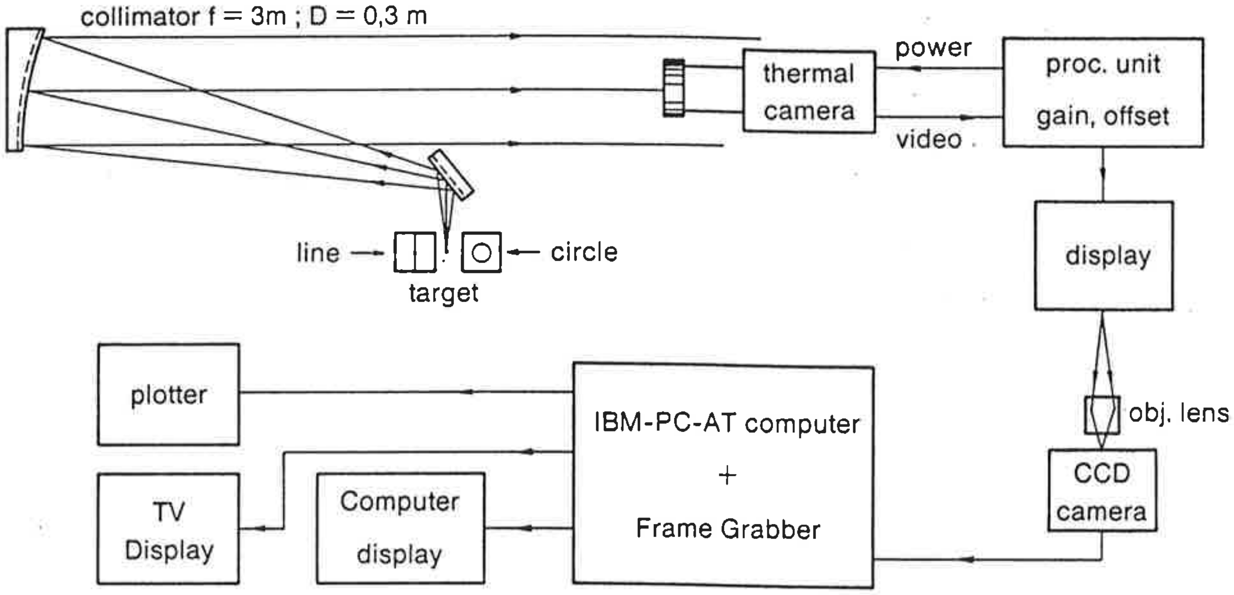


Figure 1: Block Diagram of MRTD Set-Up

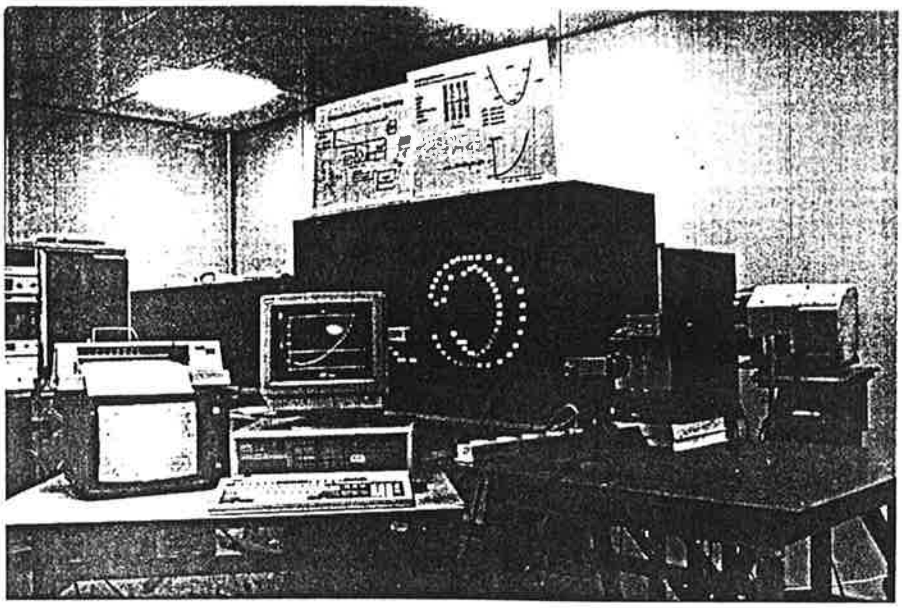

Figure 2: Picture of MRTD measurement set-up at FEL-TNO view of collimator, thermal imager, CCD-camera and A-computer

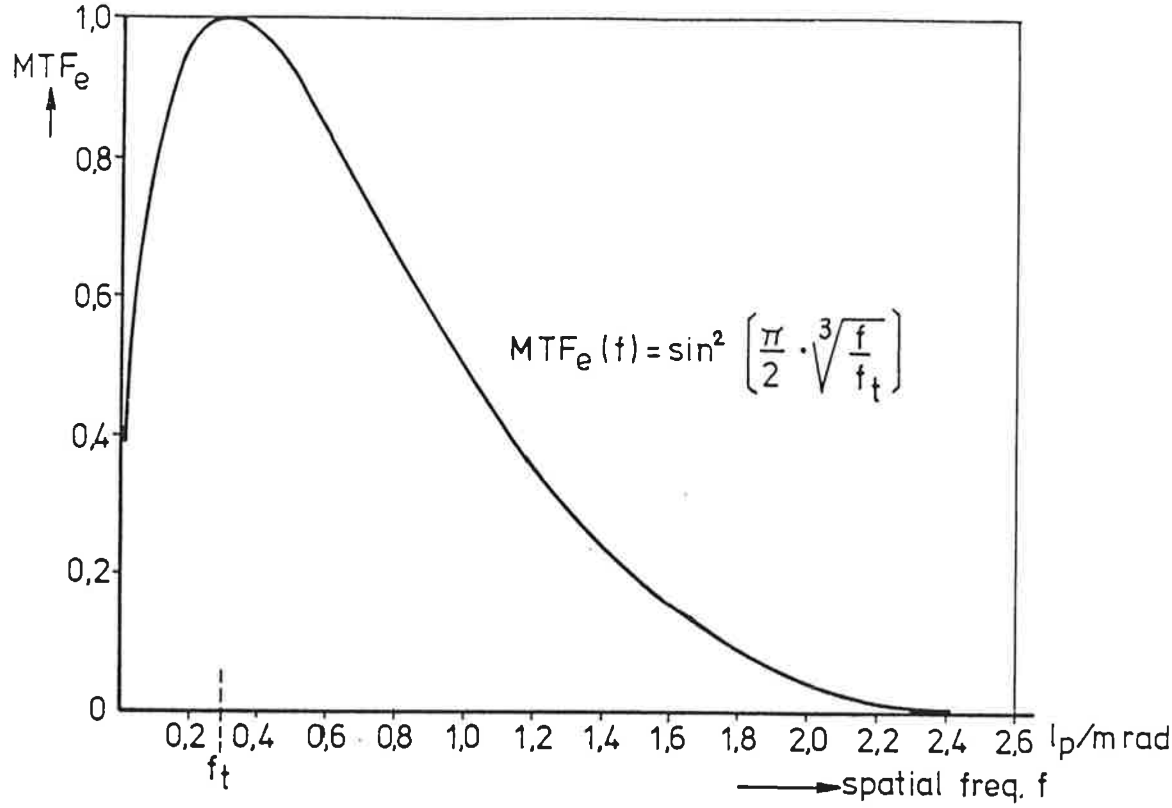


Figure 3: Modulation Transfer Function of the human eye $MTF_e(f)$

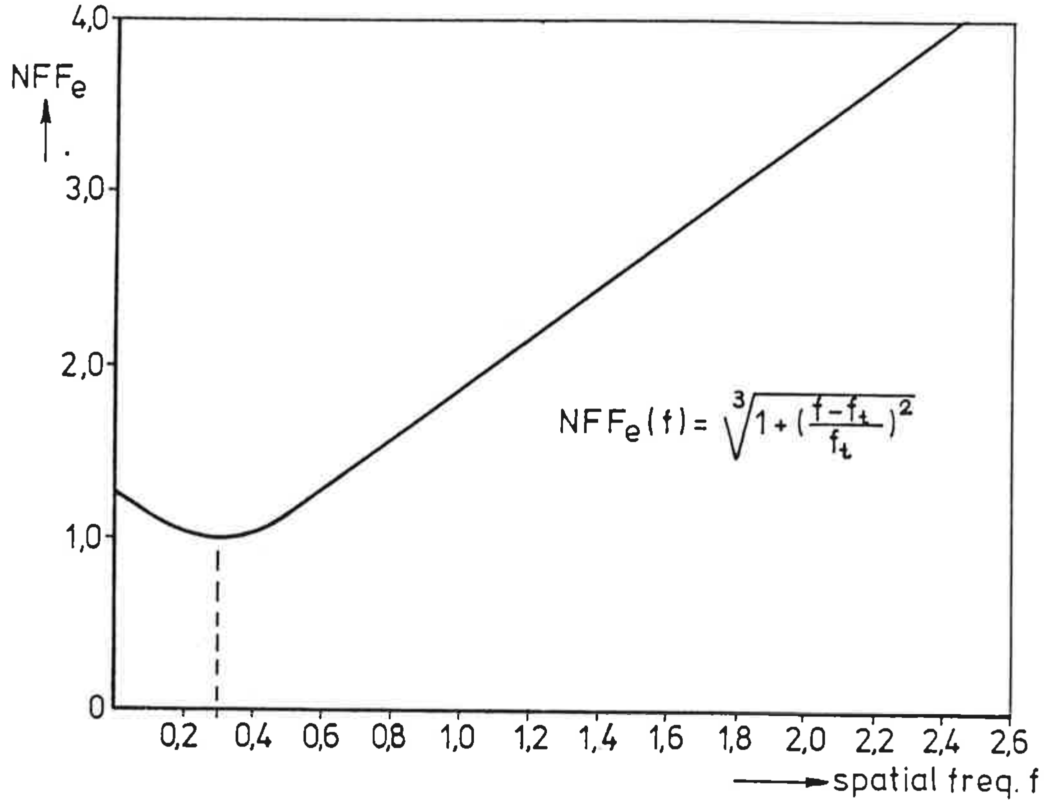


Figure 4: Noise Filter Function of the human eye $NFF_e(f)$

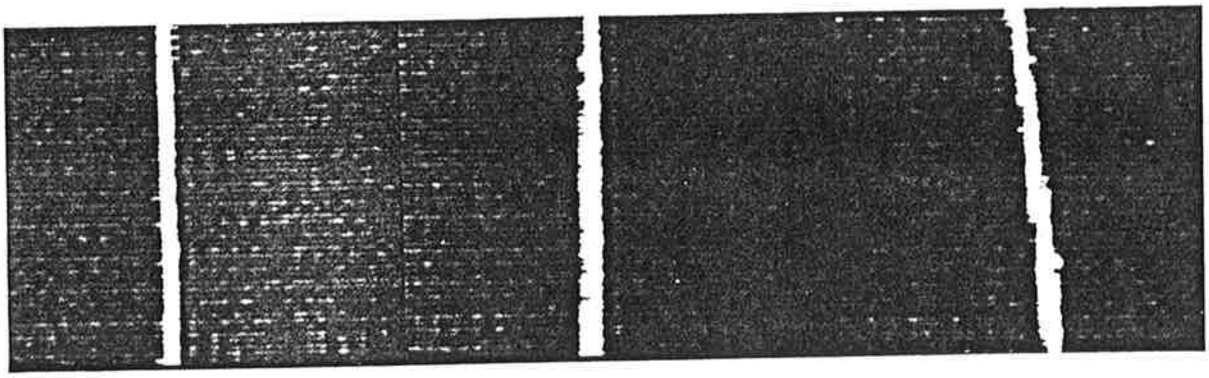

Figure 5: Three possible images of line target in Thermal Imager with aliasing
a) sample just on the line
b) 2 samples on the line
c) line tilted
Picture taken after CCD-camera

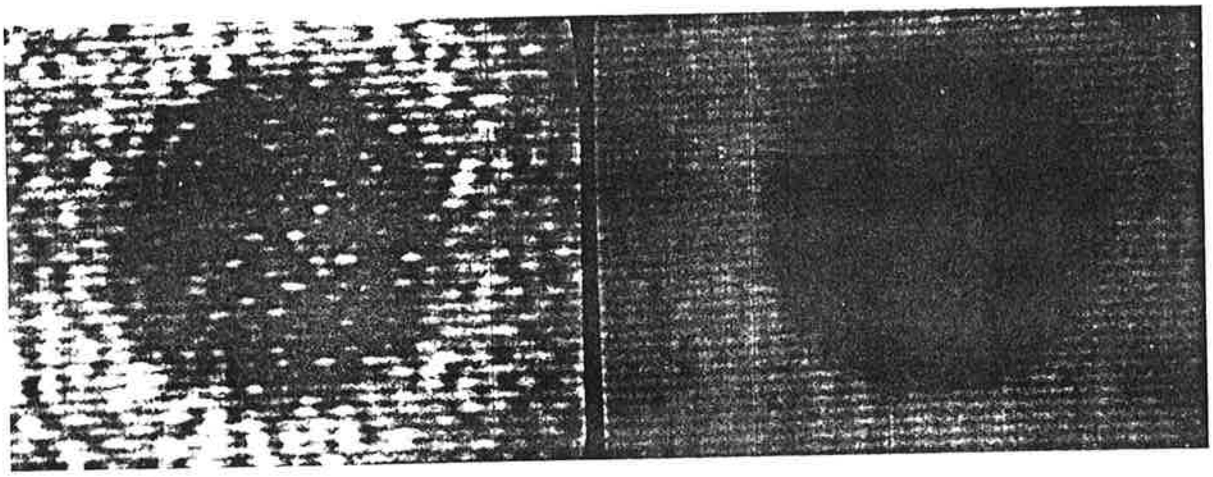

Figure 6: Typical image of circular source
a) 1 frame
b) 100 frames averaged
picture taken with CCD-camera

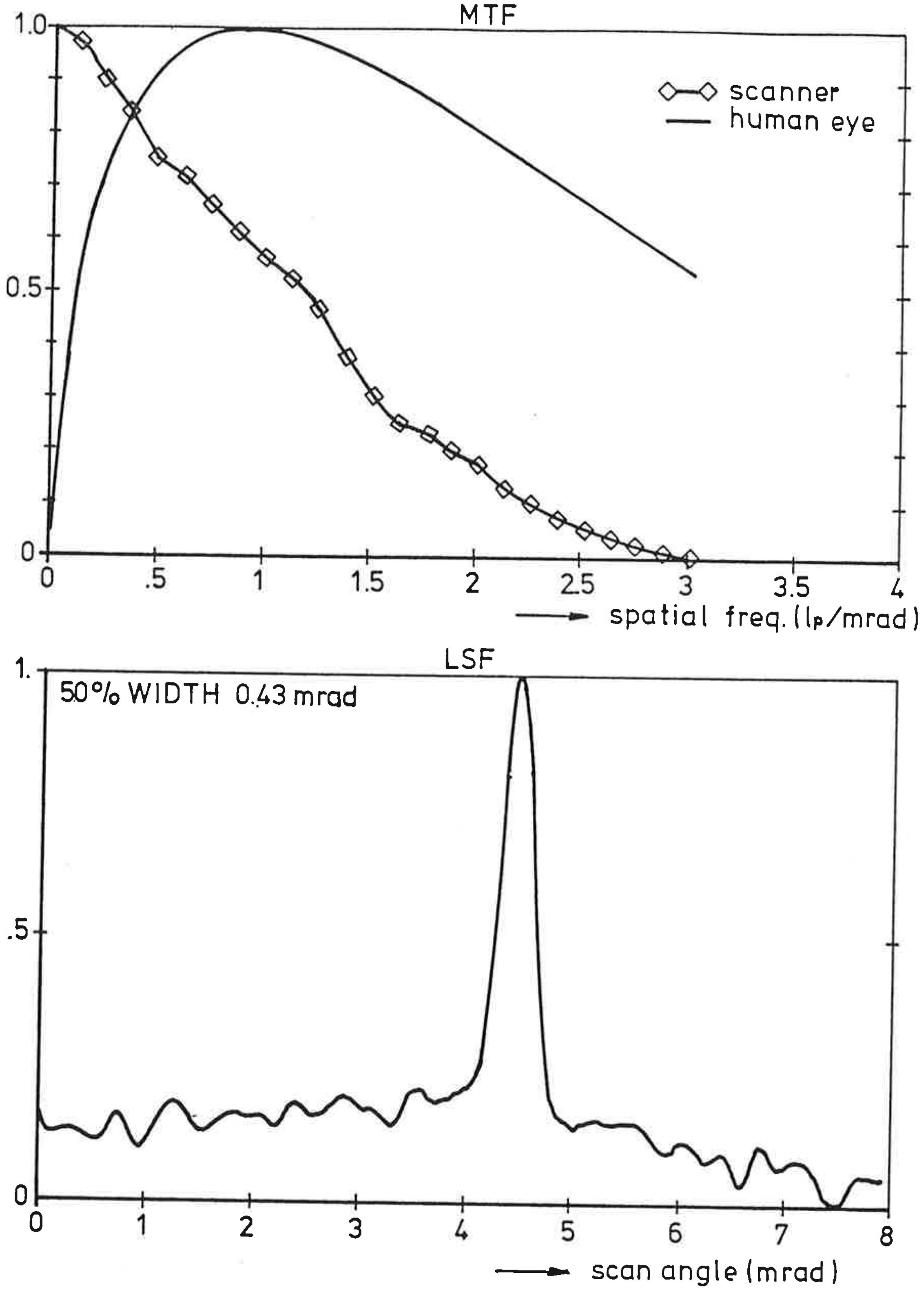


Figure 7: LSF measurement from line target (IR18 camera)
Calculated $MTF_s$ and $MTF_e$

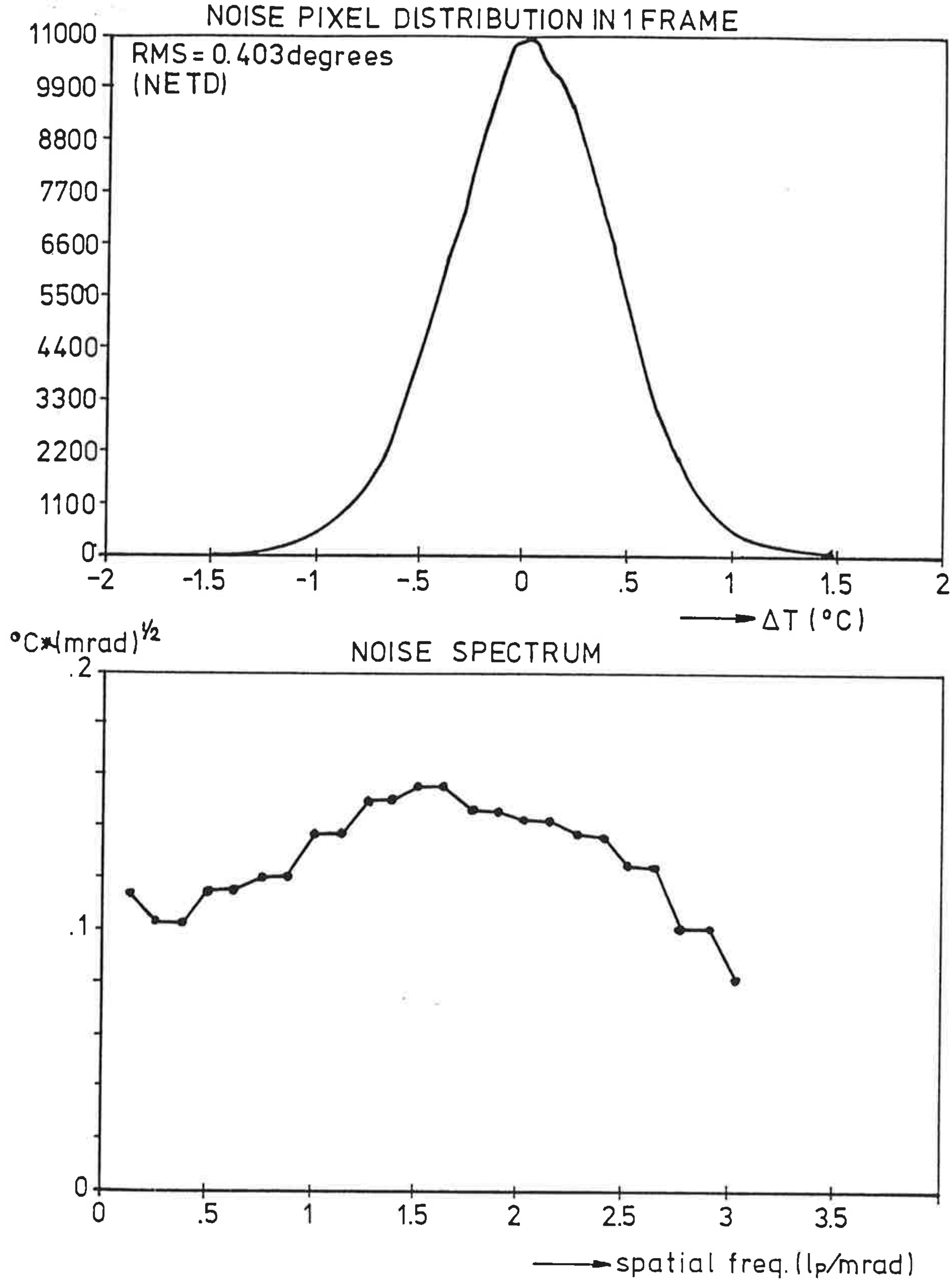


Figure 8: Noise Pixel Distribution and Noise Spectrum $FN_s$ for IR18 camera

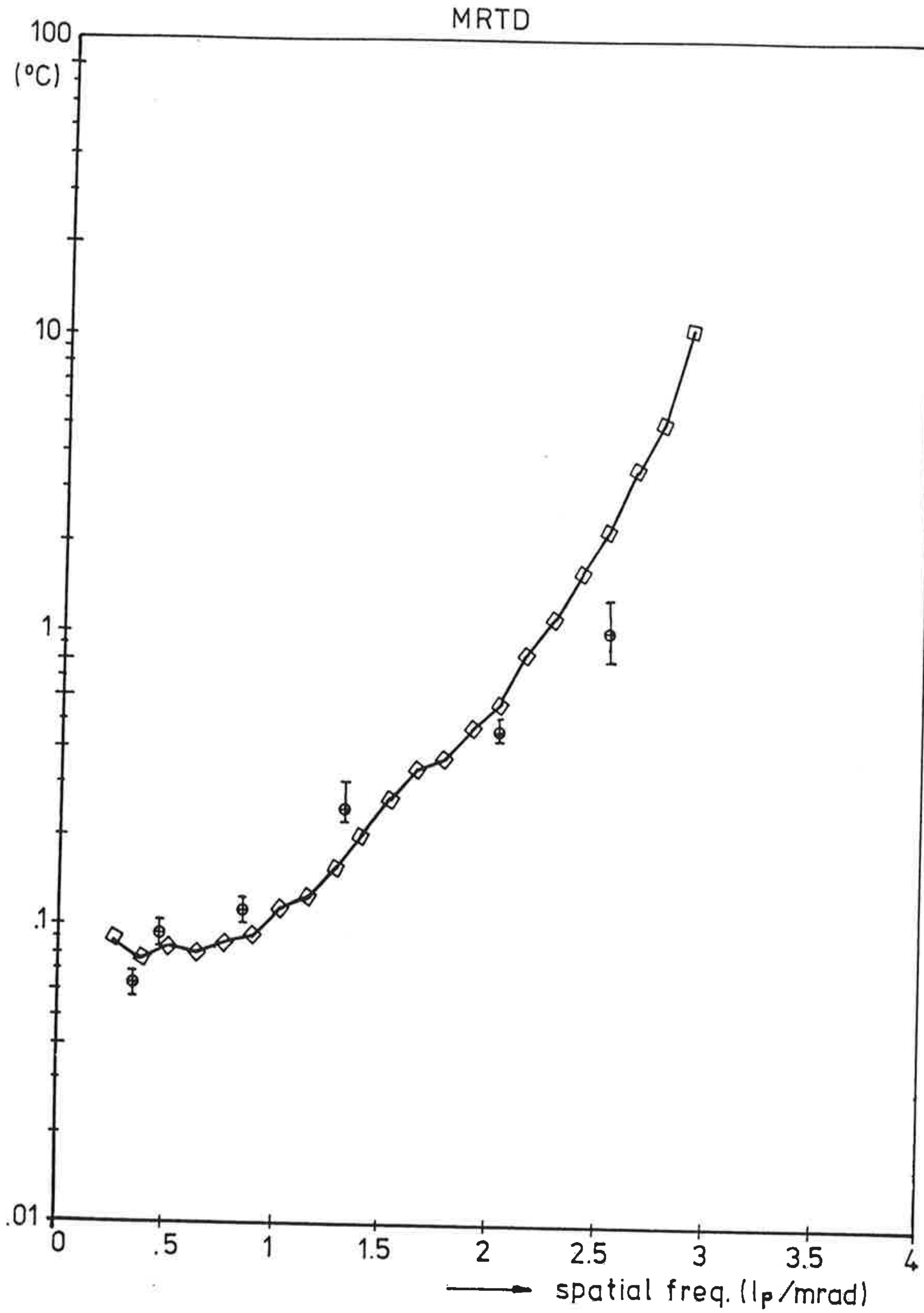


Figure 9: MRTD, calculated by means of formula (1) (IR18)
⊕ are measured according to classical method
errors bars indicated

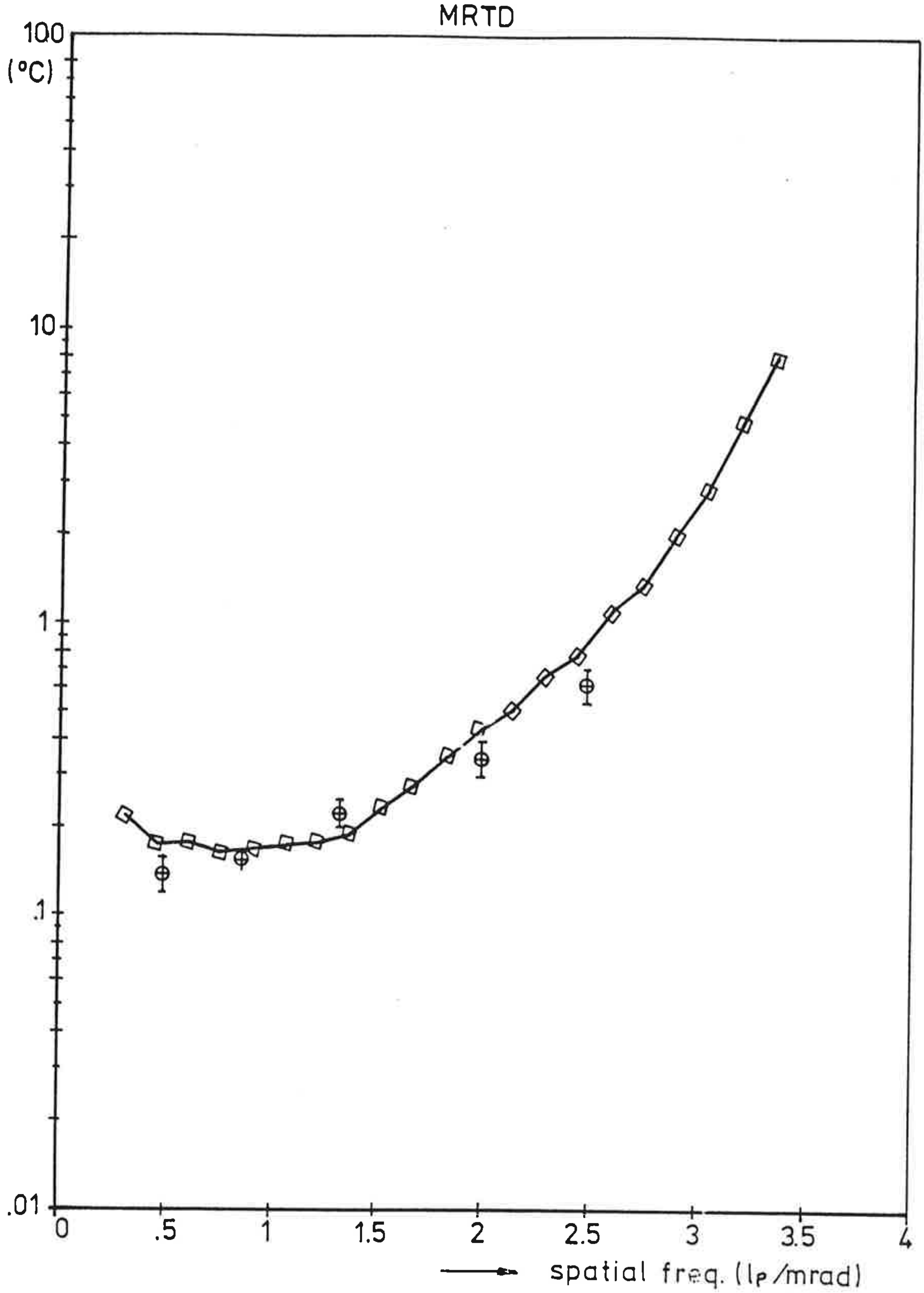


Figure 10: MRTD, obtained for prototype imager; ⊕ points with error bars, according to classical method

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