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Germany

Evaluation of the LASER scanner "Array 2905 HD"

Scanner : LASER Scanner "2905 HD"

Producer : Array Corporation, Japan (www.array.co.jp)

Provided by: Array Corporation Europe, Netherlands (www.arrayeurope.com)

Aim of the evaluation : Investigation of system classification according to EN 14096 “Non-destructive testing (NDT): qualification of radiographic film digitisation systems”

Basis : EPRI test film according to ASTM E 1936 and EN 14096 - 1, serial number E-102 and E-099

Test device : Delivered and installed at BAM Berlin in May 2003 by Array Corp. Europe
serial number : 201230
software used : TWAIN driver ArTwain.ds, Version 1.0.0.6 from Array Corp.
Array 2905 HD Scan Suite 3.2E, Ar2905UI.dll, Version 1.2.0.1,
ASPI SCSI-Manager from Adaptec, Version 4.60
software platform: Windows 2000

Speciality : Enlarged dynamic range from D=0 up to D=4.7 with 12 bit proportional to optical density. For all scans only the maximum (12 bits) of the available data depths (8, 10 or 12 bits) was used.

Scanning speeds: Film 35x43 cm²:

50 µm pixel size, quality mode:	140 sec
50 µm pixel size, standard mode:	100 sec
50 µm pixel size, speed mode:	100 sec
100 µm pixel size, quality mode:	50 sec
100 µm pixel size, speed mode:	30 sec

time from pressing the scan button until image on screen

Results of this evaluation :

All evaluation procedures have been done according the description in prEN 14096. The software used for data analysis was the "IC.exe" program, the newest 16 bit data viewer application developed at BAM for PC based platforms. The scanner was accessed through the standard TWAIN interface, which can be called directly from IC.exe and supports full 16 bit gray scale resolution. The communication via TWAIN and SCSI to the Scanner worked well without any problem.

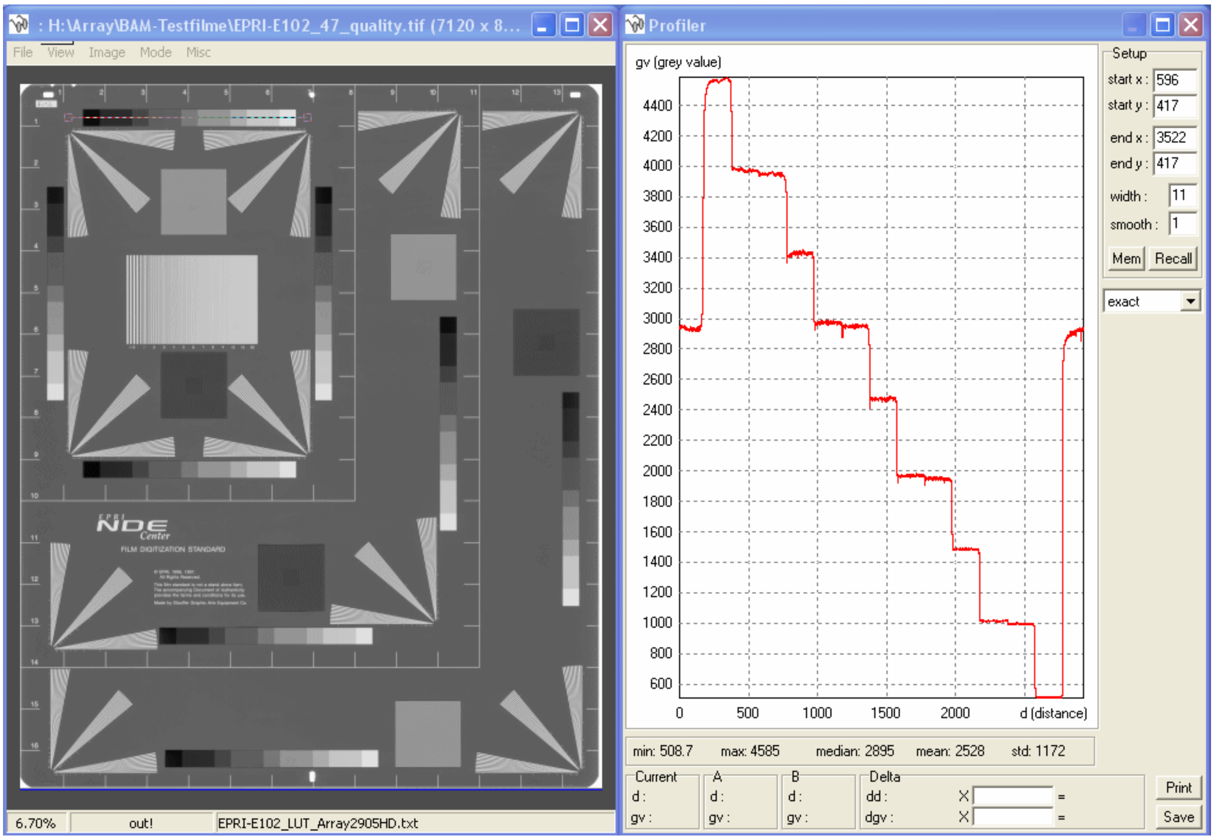


Fig.1: The digitised EPRI test film and the density-linear Characteristic Transfer Curve of the Laser Scanner "2905HD" shown by a profile (right) along the stepped density target H of the test film (position of the profile indicated by the red line in the image, left)

In fig. 1 the achieved linearity is shown. For the first time on the market a scanner was tested, which allows to handle the full density range specified in EN 14096 (D=0 … 4.5) in one working range with the required contrast sensitivity. Clearly all features of the stepped density targets can be resolved.

Characteristic Transfer Curve (CTC)

In fig.1 the following CTC was already used :

The scanner delivers 12 Bit gray values (Gv) depending on the diffuse optical Density (D) of the digitized film. A negative Look up table (LUT) is loaded into the viewer program to generate a signal proportional to the optical density for easy data analysis :

$$LUT(Gv) = 1000 * D \qquad (1)$$

All following data analysis is done on the LUT-corrected gray values according Equ. (1).

The LUT is generated by fitting a polynomial of third order of the raw gray values from the scanner with the measured diffuse optical densities of the stepped density target H as shown in fig. 1. In fig. 2 the LUT's are shown for the two working ranges used in this investigation (mode 0-4 and 0-4.7) as well as the fitted polynomials. Excel was used to generate a 12-Bit LUT from the given formula and the LUT was used to convert the gray values into diffuse optical densities according to equation 1.

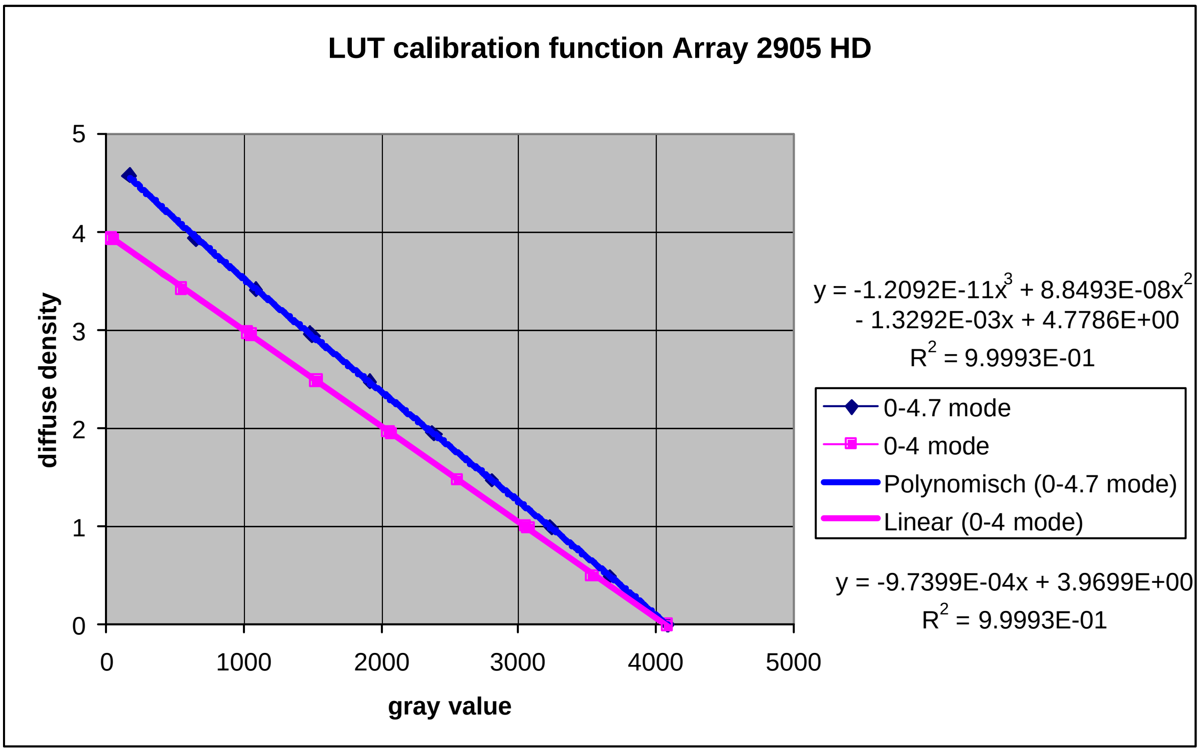


Fig. 2: Generation of a calibrated LUT according to equ. 1. The fitted LUT for the mode 0-4 is nearly perfect linear (lower formula), the LUT for the mode 0-4.7 shows small deviations from linearity for D>4, this is considered by a polynomial of 3rd order. The given formulas were used for LUT generation.

Using the LUT according to the formula given in fig. 2 (for the mode 0-4.7) on other stepped density targets of the test film E-102 or on an other test film E-99 (reduced size of 8"x10") reveals a problem :
Whereas the deviations of the diffuse optical densities of corresponding density steps of the different stepped density targets are smaller than 0.05, the digitized values can vary by up to 0.2 for optical densities higher than 3. This influence increases with higher optical densities and can be caused by optical flare during digitization. It seems to depend strongly on the uncovered width of the scanning line, which is illuminated over the full length of 14" by the scanning LASER, independent on the real film width.
An extreme example of this effect is shown in fig. 5. Clearly the scanning device reaches the physical limits. But the results of a comparable device (Lumisys LS85SDR) are even more worse. No device is known, which is able to handle this extreme case better.

Summary :
The enlarged dynamic range can be calibrated very linearly with the stepped density target, but for higher densities (especially D>4) this calibration depends on surrounding film densities. Deviations higher then $\Delta D = 0.2$ have been observed. It should be investigated, if this behavior can be changed by some optical modifications in the scanner. At least the user is able to reduce this effect by placing the film to be scanned in a high density mask covering the full width of 14".

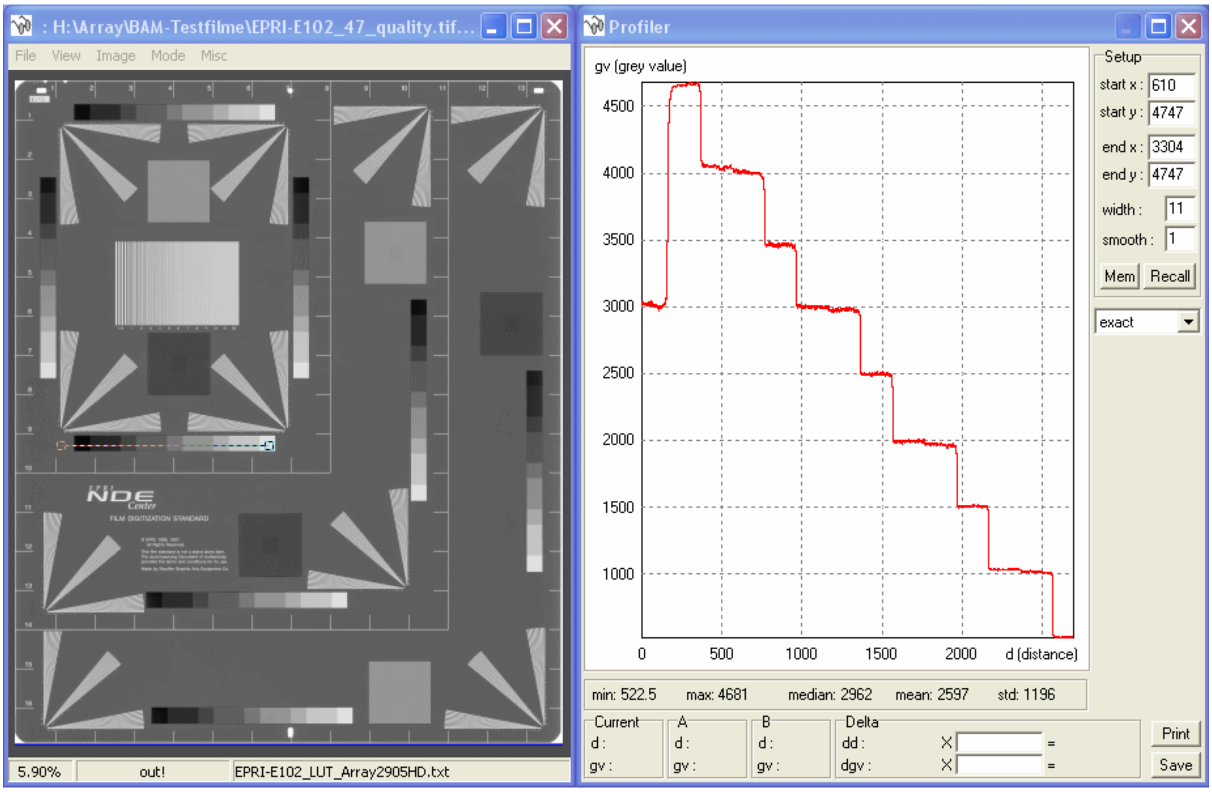


Fig. 3: Density profile of the stepped density target G at the EPRI test film E-102. The step with the highest density is digitized with D=4.6, 0.1 too high.

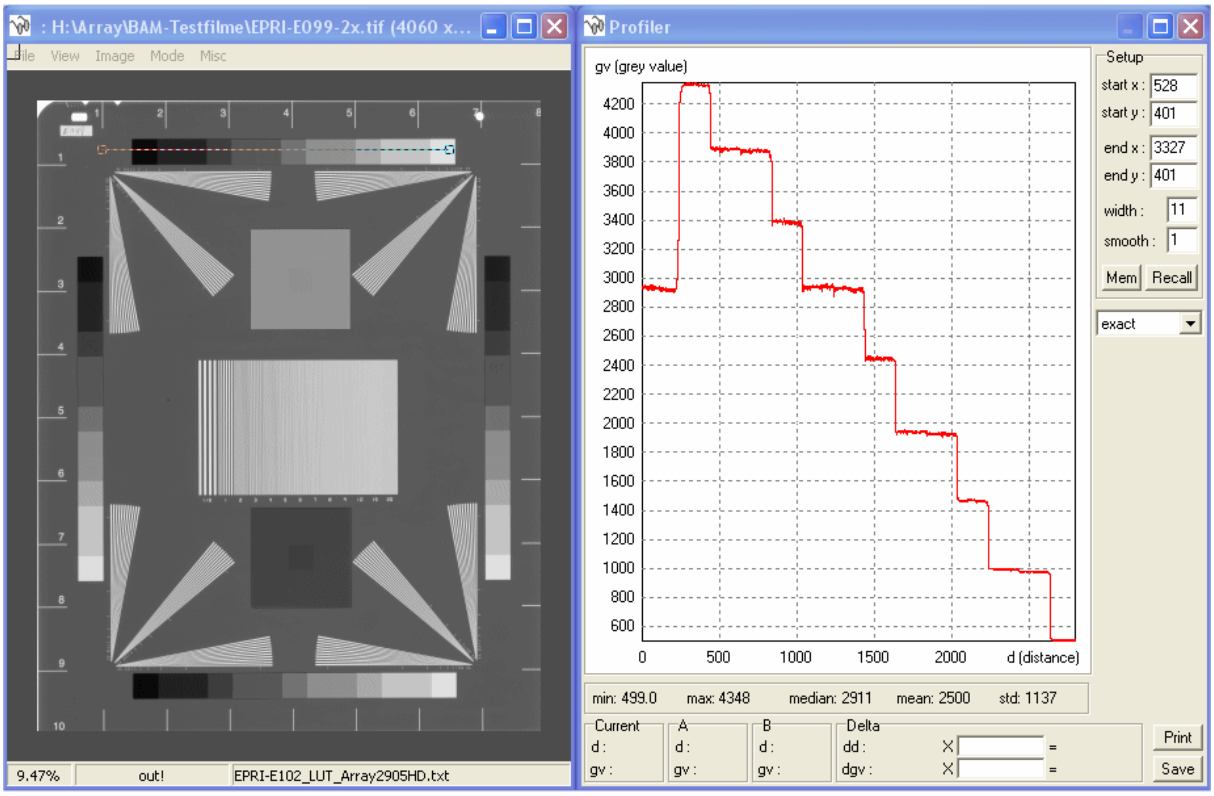
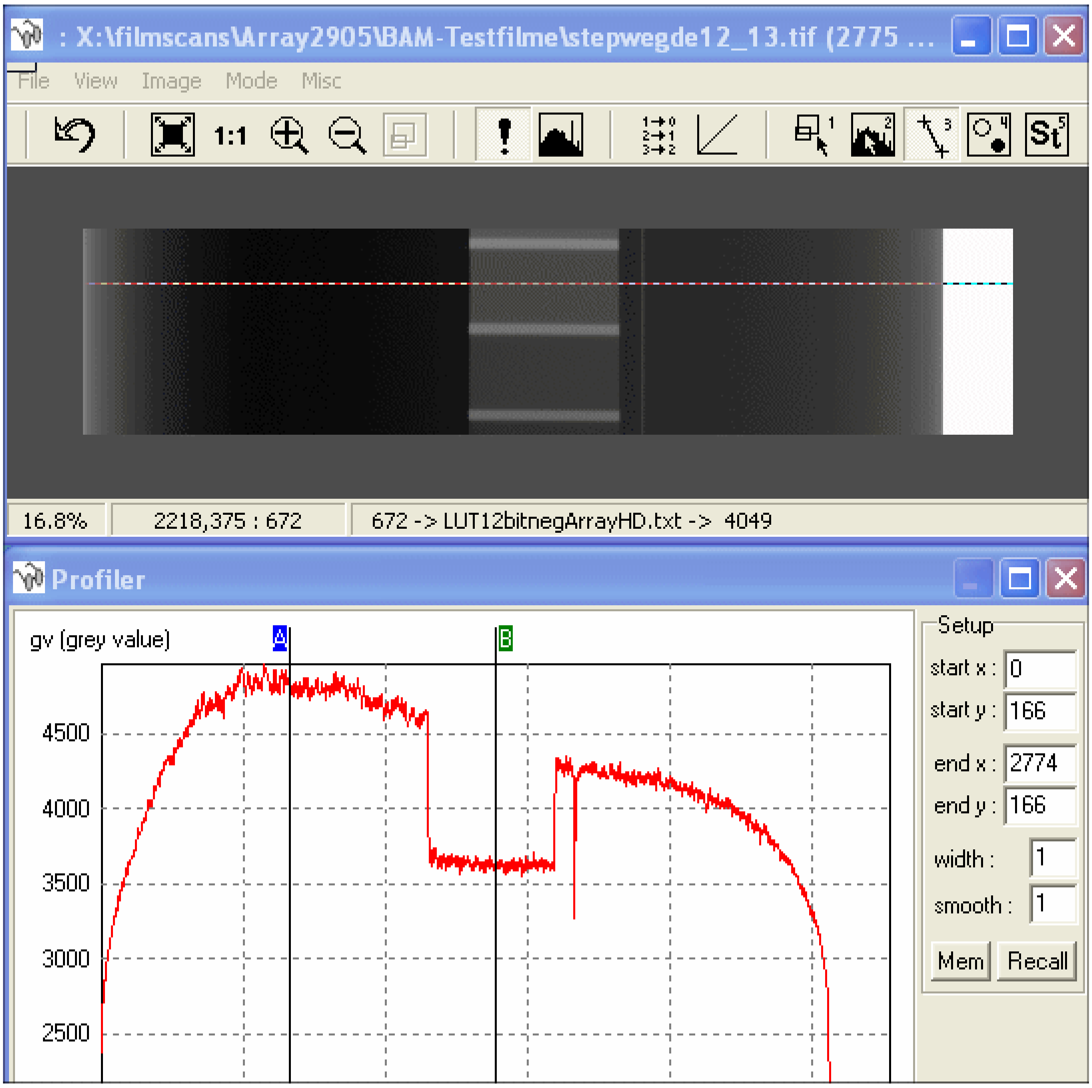


Fig. 4: Density profile of the stepped density target H at the EPRI test film E-99 (smaller size), the step with the highest density is digitized with D=4.3, 0.2 too low.



<u>Fig. 5:</u> Extreme example for optical flare from background. A two inch wide stepped density target is covered with high density film (D>6) on both sides. Flare from outside the dark films reduces the digitized density values from 6 down to 4! In pos. B the density of the analyzed step is reduced from 3.78 to 3.63.

<u>Density Contrast Sensitivity (DCS)</u>

The estimation of the density contrast sensitivity is based on the evaluation of the standard deviation of the calibrated gray value of a step on the stepped density target of the test film as shown in fig. 1. To exclude extra noise from dust and scratches on the film it is important to visually check the image on the monitor at a zooming factor of 1, i.e. each pixel in the data file is displayed on the monitor. Contrast and brightness have to be adjusted accordingly to see the image noise from each step during the measurement. Our software ensures undistorted standard deviations by an additional check of the median S/N (signal to noise ratio), calculated independently for each line in the selected rectangle. A correct estimation of the standard deviation of the selected scan area is done, if the S/N calculated by the quotient of mean data value and the standard deviation is equal to the mean S/N of the lines.

In fig. 6 a high-pass filtered image of the stepped density target (the part with densities D>2.9) is shown. The high-pass allows evaluating the noise visually inside the steps, simultaneously for all densities. With increasing density the visual noise impression is changing, i.e. especially for densities higher than 4 bandwidth limitations are visible in direction of the LASER-scan movement. This indicates a low-pass filtering for noise reduction at higher densities, which was not observed in other scanner models before.

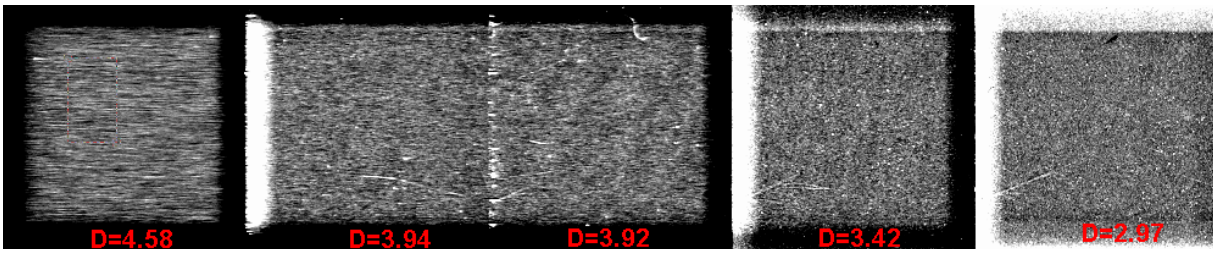


Fig. 6: High-pass filtered image (moving average by 49x49 pixel subtracted from original image) showing the noise distribution in the stepped density targets for density steps D=3 (right) up to D=4.5 (left). For the highest density step the noise appears filtered (reduced high frequencies) and has horizontal structures. Pixel size 50 µm.

It is expected from physics that the noise level increases with increasing film density. The evaluation of the standard deviation (STD) for all steps of the stepped density target H was done for different pixel sizes (50µm and 100 µm) and scanning modes (speed, standard and quality). The density contrast sensitivity (DCS) on a pixel size corrected scale (scanning aperture with 100 micron diameter, see EN 14096 - 1) was calculated according to:

$$DCS = 0{,}002 * STD * \text{pixel size} / 88{,}6\ \mu m \qquad (2)$$

In fig. 7 and 8 the results of this evaluation are shown.
For a scan with 50 micron pixel size the DCS does not exceed the limit of 0.02 for the quality scan mode for all optical densities between 0 and 4.5 within the measurement error (ca. 0.03) as required by EN 14096. Whereas for the speed and standard scan modes this DCS limit is exceeded and should not be used for applications according to EN 14096.
The measurements showed a limitation of the increasing DCS for densities higher than 2.5. This must be a result of the filtering as discussed already in connection with fig.6.
The scans with 100 micron pixel sizes showed worse DCS values. This is not surprising, because only the pixel distance was changed by the scanner; the optical set-up (mainly the size of the laser spot on the film for illumination) was unchanged. This degenerates the scanning performance for larger pixel sizes. In contrast to this a correct digital sub-sampling of high-resolution scan data to lower pixel resolution did not degenerate the DCS. This is demonstrated by the 100 µm sub-sampled data set from 50 µm scan data. Prior to this sub-sampling by a factor of two, i.e. the average of 2x2 pixels is stored as down-sampled pixel, an anti-alias filtering by a 3x3 low-pass filter was done. This ensures that the MTF will reach nearly zero at the sampling frequency and reduces the noise contribution too.

Summary:
Only the scanning mode “quality” fulfils the requirement DCS< 0.02 according to EN 14096 (within the measuring error). The dynamic range “0-4.0” can be classified as digitisation class “DB”, the dynamic range “0-4.7” can be classified as scanning class “DS”.

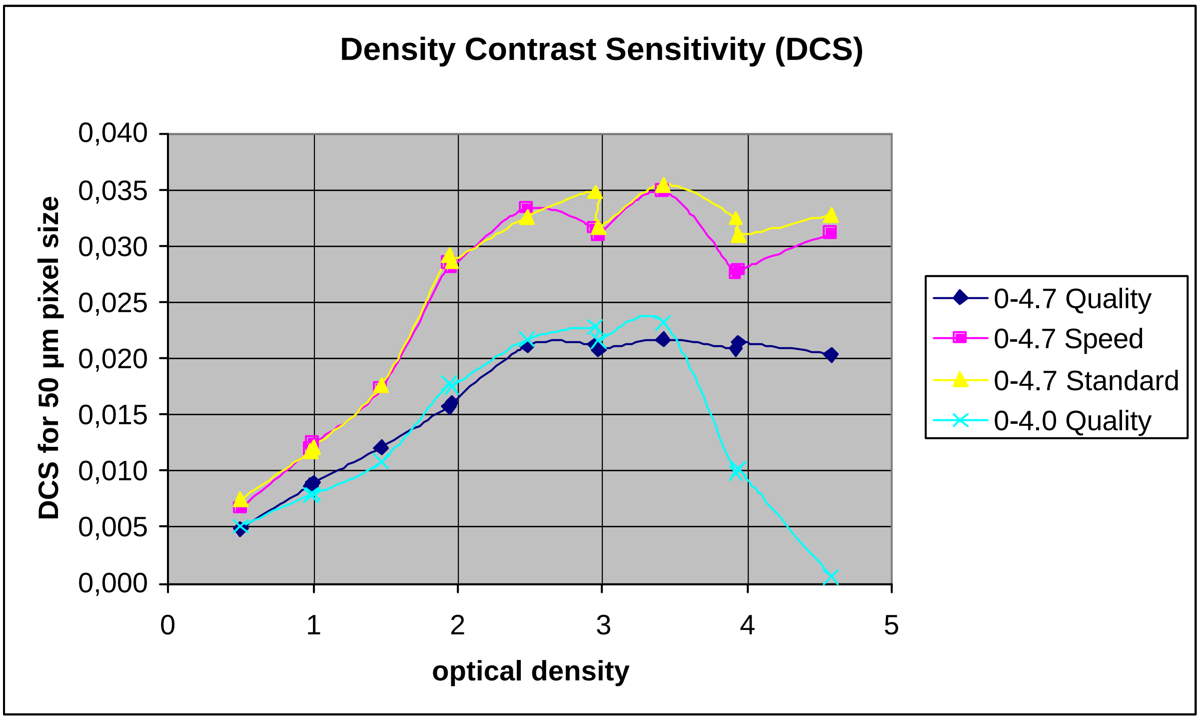


Fig. 7: Density contrast sensitivity for scans with 50 µm pixel size and different scanning modes on the scanner "2905 HD"

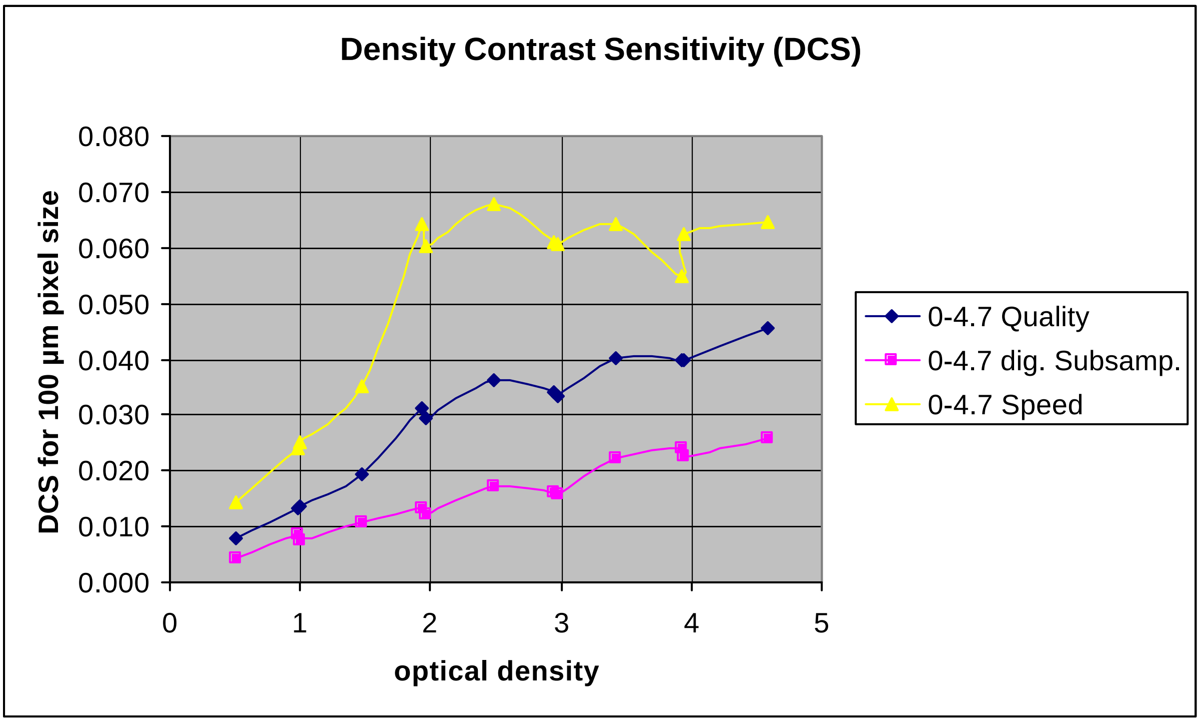


Fig. 8: Density contrast sensitivity for scans with 100 µm pixel size and different scanning modes on the scanner "2905 HD"

Modulation Transfer Curve (MTF)

For the calculation of the MTF a profile across the sharp edge target of the test film is used (see fig. 9). To reduce noise effects 11 neighboured profiles are integrated and saved for the MTF calculation according to EN 14096. After differentiation and FFT the magnitude spectrum gives the MTF of these data. Plots of all resulting MTF`s are given in fig. 10 for 50 µm pixel size and fig. 11 for 100 µm pixel size.

MTF's for 50 µm pixel size are evaluated for the vertical direction (fig. 10, green curve), horizontal direction (fig. 10, red curve) and additional for the speed mode (fig. 10 blue curve). Whereas the vertical MTF is determined mainly by the LASER spot, the horizontal MTF is influenced by the scanning speed too. The decay of the vertical MTF to only 50% at Nyquist frequency (max. sampling spatial frequency determined by the pixel size) indicates that the LASER spot is smaller than the pixel distance of 50 µm. Ideally a LASER spot diameter of 100 µm will generate a MTF decay to zero at Nyquist frequency for a pixel distance of 50 µm. This will minimize any alias effect and give best S/N ratio values. The LASER spot of the device "2905 HD" is smaller, which allows alias effects and reduces the DCS values, but increases the contrast for fine details. The measured MTF in horizontal direction depends on the scanning speed and is faster decaying for higher integration times (quality mode). So in horizontal direction the additionally influence of the read-out electronics to the MTF can be observed, whereas the vertical direction is influenced only by the optical set-up.

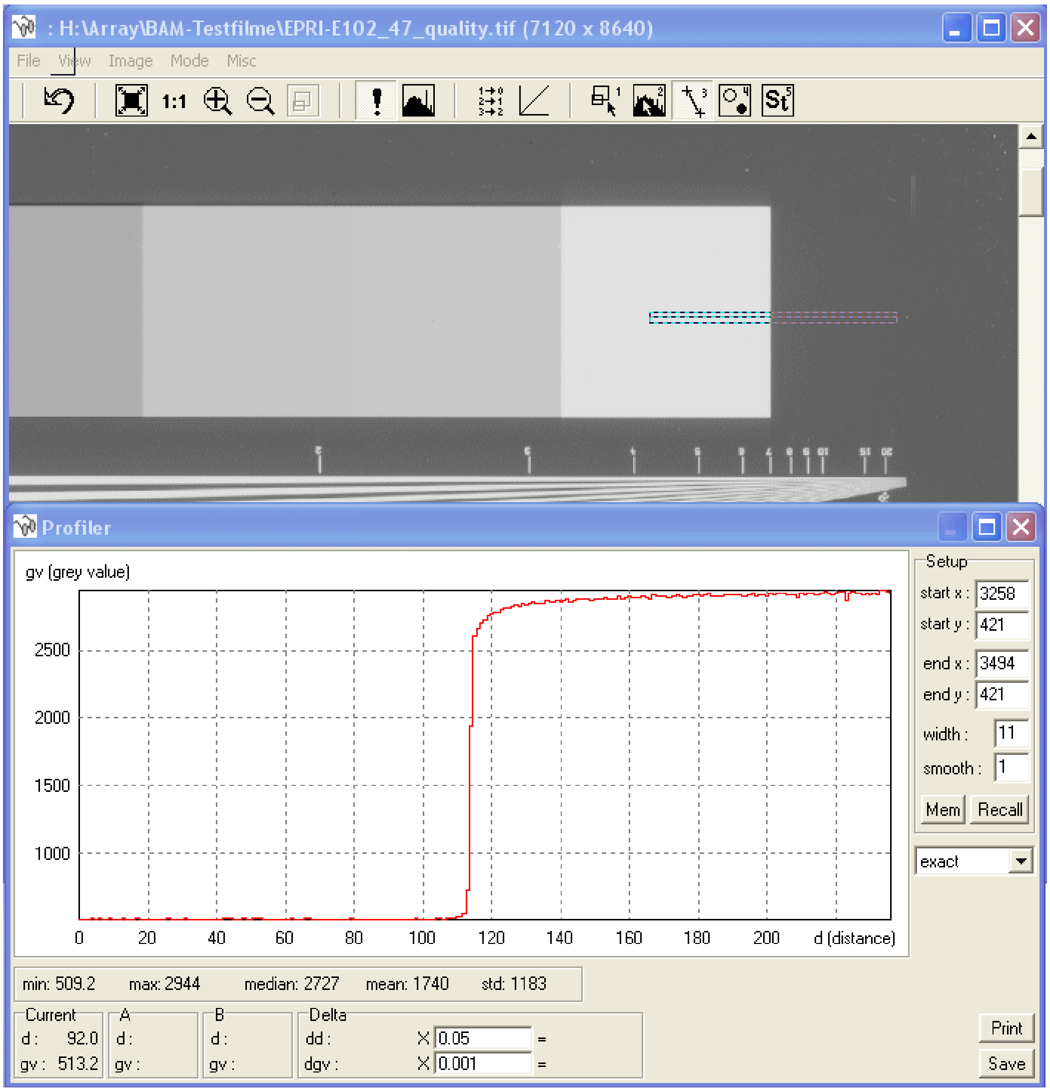


Fig.9: Extraction of an integrated profile for MTF calculation (horizontal direction).

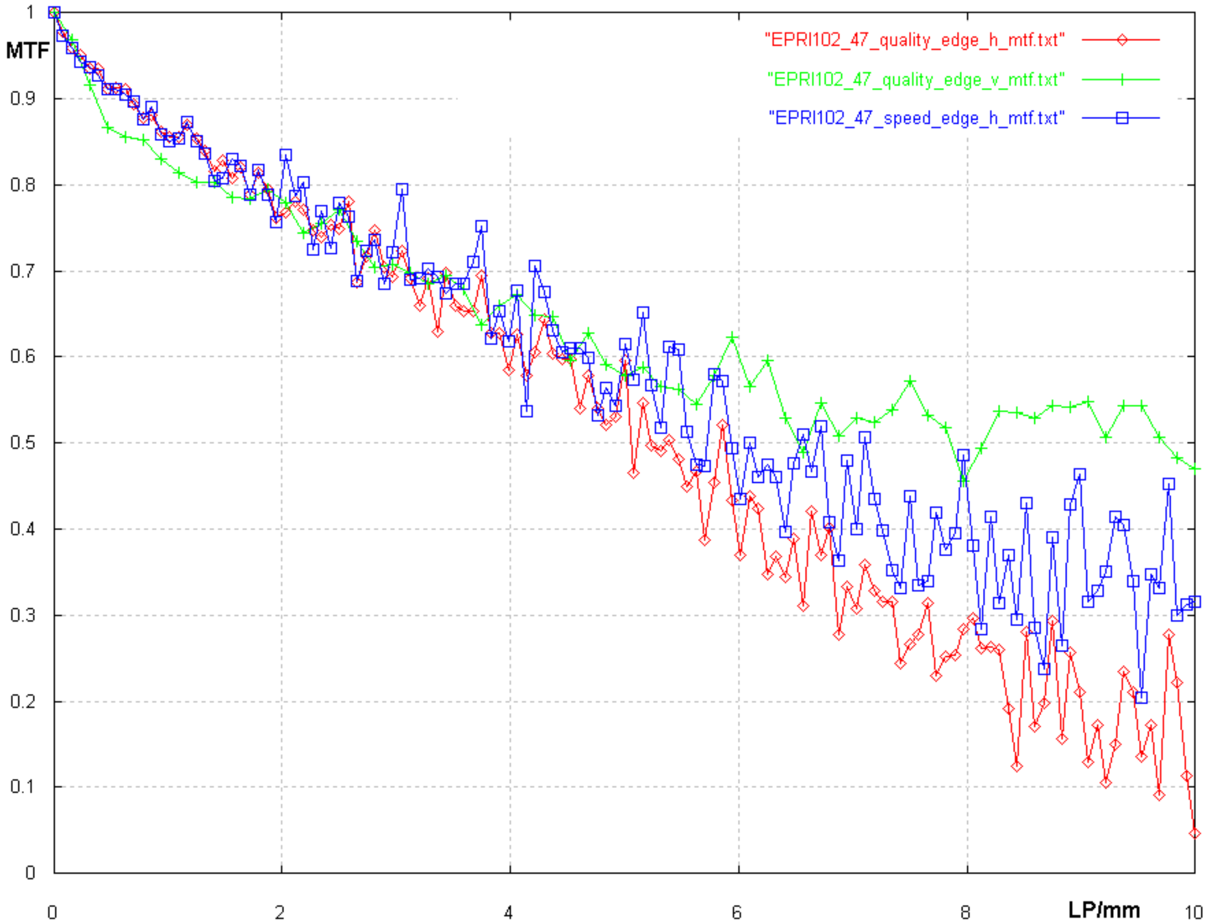


Fig. 10: Measured MTF`s for 50 µm pixel size of the scanner "2905 HD". Green curve vertical MTF in quality mode, blue curve horizontal MTF in speed mode, red curve horizontal MTF in quality mode. The MTF 20 % point is at 9 LP/mm.

The corresponding MTF curves will decay even slower, if the pixel size is further increased from 50 µm to 100 µm (see fig.11). From theory it is expected that by changing only the pixel distance without changing the optical system will just clip the MTF measured for 50 µm at the new Nyquist frequency of 5 LP/mm (MTF at 0.5 – 0.6). In reality the MTF for 100 µm pixel distance is reduced by the read-out electronics further and decreases more for longer integration times (quality mode).
The ideal case can be simulated by a digital sub-sampling, applying an anti-alias filter before, of scan data with the rated resolution of 50 µm (see fig. 11 green curve). This will give the lowest alias artefacts and optimizes the S/N ratio too, as shown in fig. 8.
From these measurements it follows, that a scanning makes sense only at the rated resolution of 50 micron. The increase of pixel distances to higher values degenerates the performance of the scanner, but reduces of course the scanning time per film. Reduced pixel sizes (e.g. for films exposed with Ir 192 or Co 60 and an inner unsharpness of more than 100 µm) can be generated by digital sub-sampling of 50 µm scan data with a higher quality compared to the direct scanning at the reduced pixel size.

Summary:

The device “2905 HD” has a maximal spatial resolution of 9 LP/mm (MTF 20 % value). The MTF in vertical and horizontal direction is different, depending on the scanning speed. The LASER spot is smaller than the optimal fitted to the rated pixel distance of 50 µm, which give sub-optimal performance concerning alias-artefacts and maximum S/N ratio (and following best DCS values).

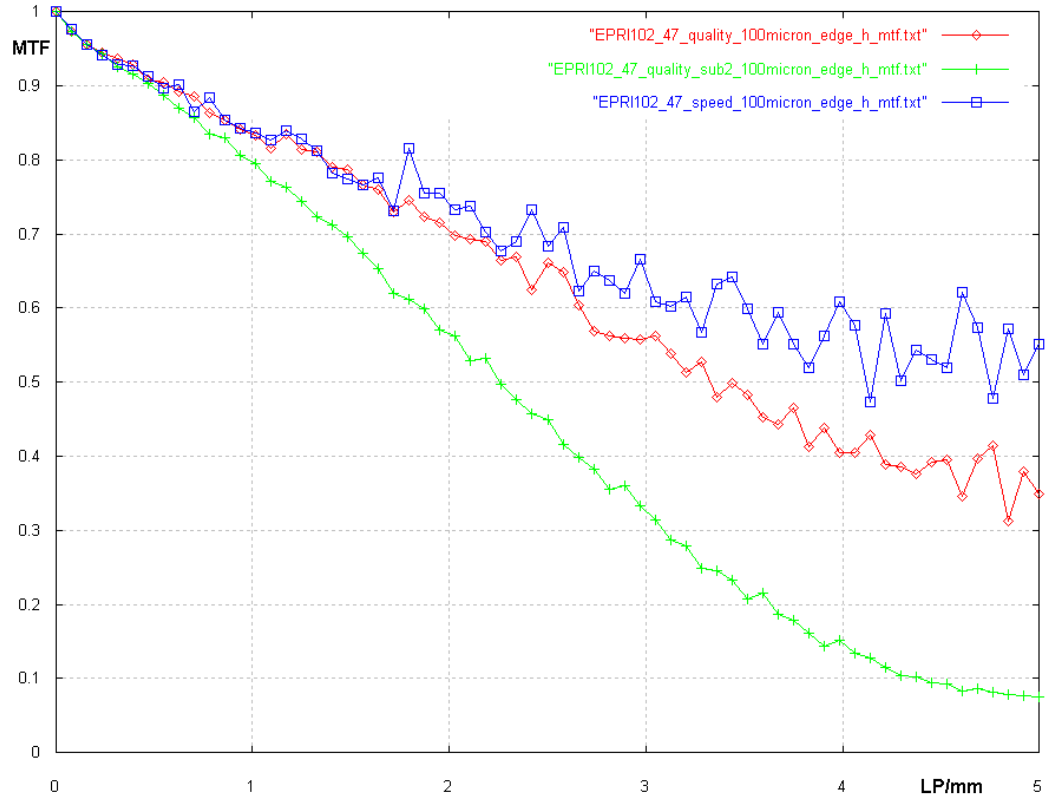


Fig. 11: Measured MTF`s for 100 µm pixel size of the scanner "2905 HD" (in horizontal direction), blue curve for speed mode, red curve for quality mode. The green curve is generated by digitally sub-sampling the 50 µm scan data with an anti-alias filter (3x3 low-pass). This ensured the MTF decay to nearly zero at Nyquist frequency.

Conclusions :

The evaluated LASER scanner "2905 HD" fulfils the basic requirements for density contrast sensitivity for NDT applications (DCS <0,02 with 12 bits data depth). At a pixel size of 50 micron all requirements according to EN 14096 are fulfilled and the scanner can be classified to class

(density range "0-4"): DB 9
(density range "0-4.7"): DS 9

The scanner class DS according to EN 14096 part 2 require a sensitivity of DCS = 0.02 in the density range from D=0.5 to D=4.5. The scanner is able to handle the full dynamic range of D=0 up to D=4.7 in the same working range, an impressive step forward compared with other scanners.

A problem in exact density reproduction for densities D>3 was identified during the tests. There is an influence of light flare originating from areas with low optical densities and/or film widths smaller than 14". But this flare does not reduce the density contrast sensitivity and following the reproduction of low contrast indications.

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