Modulation transfer function of electron-bombarded CCD

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The modulation transfer function (MTF) is the key parameter to judge the ability of the image sensor to detect a sharp transition in luminance and a periodically repeated transition in luminance at the plane of the sensor. The data-sheets of the image sensors present MTF measured for light luminance. Because we use the sensor CCD39-02 (Marconi, pixel size 24 × 24 Fm) in our application [1] in directly electron-bombardment mode, we have measured MTF for an electron beam in the range of up to 5 keV.

There are two possibilities how to measure the MTF: First: to project the sharp transition in luminance on the sensor, i.e. to modulate the source of luminance (electron beam in our case) by an edge. Second: to project a stripe pattern on the sensor, i.e. to modulate an electron beam by a rectangular-shaped mesh. In both cases we meet the problem of nonhomogeneous current density of the illuminated beam. For our measurement we used a low voltage SEM using the beam energies down to needed 5 keV. The specimen chamber is large enough to position the CCD sensor and to place a sufficiently large multi-pin feedthrough to connect the sensor with the electronics.

The image area of the sensor was positioned directly under the primary electron beam. The electron beam was defocused by switching off the objective lens. The aim was to create a homogeneous electron beam illuminating the image area of the sensor. The store area of the sensor and on-chip amplifier were protected against electrons by shielding having a circ hole only above image area of the sensor.

First we evaluated the MTF from the measured edge spread function. The energy of the impinging electrons was set 4 keV (EBS gain -300). This is the optimum working value as follows from [1], so we measured the MTF under the conditions planned for practical use. The sensor was bombarded with an electron beam of -5 nA/cm^2. We obtained the edge spread function as a line scan via the image of a straight edge projected on the sensor (integration time for image -5 ms). The edge, mechanically connected with the shielding, was situated approximately 1 mm above the sensor surface and was made by one side of the slot (Figure 1). Two measurements were made: first, the edge of the slot was oriented perpendicularly to the serial register - MTFhorizontal, second, the edge was oriented parallel to the serial register - MTFvertical. Next we calculated MTF by using a standard proces: edge spread function - *derivative* - line spread function - *Fourier transform* - MTF. The calculation was made by Matlab.

The SEM with a Schottky cathode was used for the measurement. The noise of the cathode current and nonhomogeneous current density of the defocused beam negatively influence the image of the edge and, as a consequence, deteriorate the calculated result. Theoretically, we need the homogeneity of the illumination beam to be better than the dynamic range of the sensor (under conditions used for the measurement, mainly temperature) for the measurement of MTF. Low quality of illumination causes fluctuation of the image signal in the illuminated half -part of the edge image. To suppress this effect and to increase the quality of the image of the edge, an almost saturated image was acquired by setting the appropriate illumination dose.

Then, we will verify the results obtained by the first method. We will project the stripe distribution on the sensor, i.e. we modulate an electron beam by a rectangular-shaped mesh. This method follows directly from the definition of the MTF,

$$MTF(f_s) = \frac{U_{pp}(f_s)}{U_h},$$

where $U_{pp}(f_s)$ is the peak-to-peak image signal under stripe illumination with a spatial frequency f_s and U_h is the image signal under homogeneous illumination. This method is more affected by noise and nonhomogeneity of the electron beam because all parameters, i.e. a set of $U_{pp}(f_s)$ and one U_h must be measured under the same signal level and under homogeneous illumination.

The problem of noise can be eliminated by the measurement of both parameters of the ratio $U_{pp}(f_s)/U_h$ at the same time. A possible experimental realization of such a measurement is to project the mesh only on the first half of the image area of the sensor and to project a non-modulated electron beam image on the second-half of the image area of the sensor. Thus we obtain both parameters at the same conditions.

The problem of nonhomogenity can be eliminated by averaging. U_h can be obtained as an average signal from the area illuminated by a non-modulated beam. $U_{pp}(f_s)$ can be obtained as an average of a set of line scan from the area illuminated by a mesh-modulated beam.

The decrease of the MTF measured by the edge projection method for a maximum spatial frequency is small and it is approximately the same for both horizontal and vertical directions (Figure 2): *MTF(20.8)* - 0.75 . -2.5 dB. The measurements of the MTF using the stripe projection method is being carried out [2].

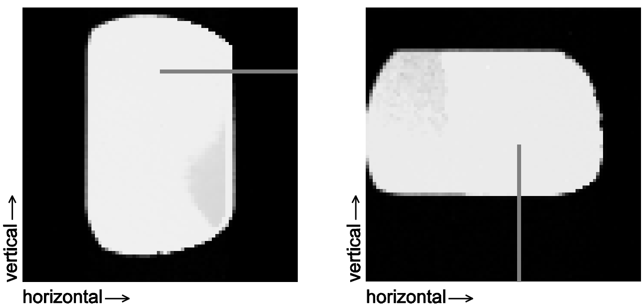

Figure 1: E-beam images of slot. Half-lines used for MTF's computation are marked.

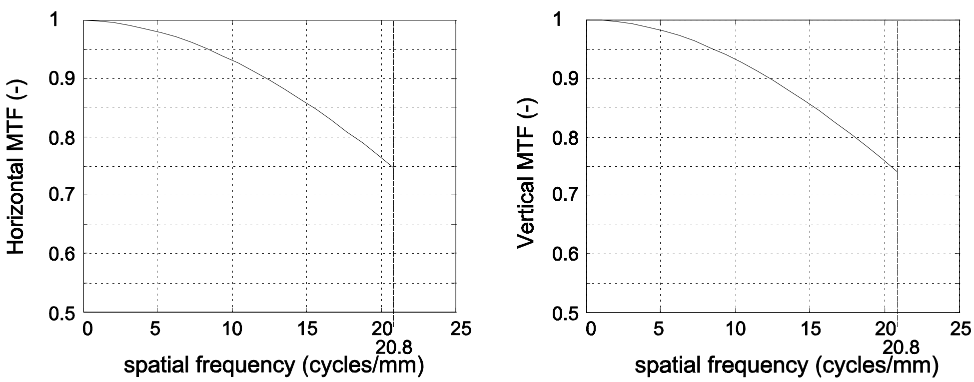

Figure 2: Horizontal MTF (left) and vertical MTF (right).

1. M. Horáček, Review of Scientific Instruments, **Vol.** 74 (2003), No. 7, p. 3379.
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