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Intra-pixel CMOS APS MTF

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Abstract-- **In this work we revive the consideration of the pixel geometrical structure effect on the modulation transfer function of an image sensor, emphasize the advantages of the spot scanning MTF measurement method and propose new MTF standards.**

SUMMARY

Even though the technology development promotes the imager devices, it also makes corrections to the device's data sheets enabling better understanding and the most effective description of device performance. Since CMOS image sensors are relatively new, their features and figures of merit are not yet standardized, such that manufacturers are relatively flexible while describing their products. In many cases the data required for the imager's performance understanding is missing, for example, the characterization of sensor crosstalk (CTK), its full point spread function (PSF) and corresponding modulation transfer function (MTF) is essential for understanding of its resolution abilities. This data is required for better knowledge of the sensor and its specific faults, and for research – to enable better optimization of pixel design and imager performance.

Commonly used MTF extraction and estimation methods have been described in detail elsewhere[1-7]. For insight into the pixel geometric MTF especially for complex pixel topologies, maximum information is gained by spot scanning of the pixel. Spot scan and direct PSF measurements enabled by the unique submicron scanning system (S-cube system)[8-11] permit experimental estimation of the photodiode aperture response behavior and the depletion/diffusion structure of APS devices, i.e., it is possible to gain extremely detailed insight into the pixel aperture response; moreover, diffusion effects are readily apparent and easy to interpret in the MTF data.

In this work we present the PSF measurements obtained by the system, define an "inter" and "intra" pixel MTF and compare them with a fully theoretical MTF model results and with an ideal MTF profile estimation calculated for all spatial frequencies. The model covers the symmetrical photocarriers diffusion effect together with the impact of the pixel geometrical structure.

MTF definition and corresponding measurement methods, (e.g., pattern modulation) do not account for the influence of the pixel construction on the response signal. The pixel as a whole is considered; therefore the obtained MTF should be denoted as inter-pixel MTF.

On the opposite site, it was already proved that pixel construction along with the photocarriers diffusion effects are the determining factors of the CMOS APS MTF behavior. Spot scanning method introduces a different connotation of MTF measurement, providing insight into the imager pixel structure, and its influence on the imager response; therefore the obtained MTF should be denoted as intra-pixel MTF.

We compare the results obtained from industrial grade CMOS camera. Inter-pixel MTF obtained by the manufacturer via regular pattern projection method is compared to the intra-pixel MTF achieved using S-cube system via 2-D Fourier transform on the measured true PSF. Fig. 1 show respectively the MTF curves comparison and their divergence implied by the intra-pixel effects accounted by S-cube system and missed by manufacturer, which grows with frequency and calculated to be more then 20% at Nyquist frequency. In Fig. 2 we intend to emphasize the difference between "inter" and "intra"-pixel MTF. Four curves compare 1-D MTF; Intra-pixel MTF calculated respectively to extracted LSF. Inter-pixel MTF obtained from the simulated inter-pixel PSF. The comparison reveals the essential difference between corresponding MTF functions, especially in the low spatial frequencies range, and therefore confirms the hypothesis indicating the necessity of intra-pixel MTF for its correct representation.

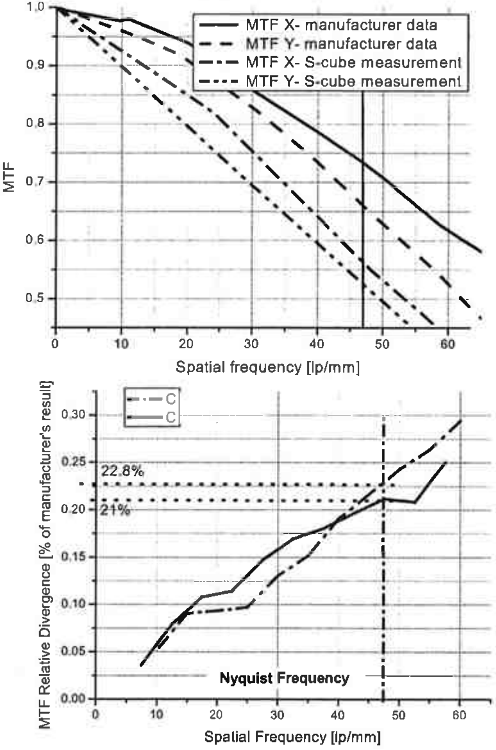

Fig.1: Upper - The difference between the inter-pixel MTF obtained by the manufacturer via regular pattern projection method and the intra-pixel MTF achieved using S-cube system via 2-D Fourier transform on the measured true PSF. Lower - The calculated divergence between inter and intra-pixel MTF.

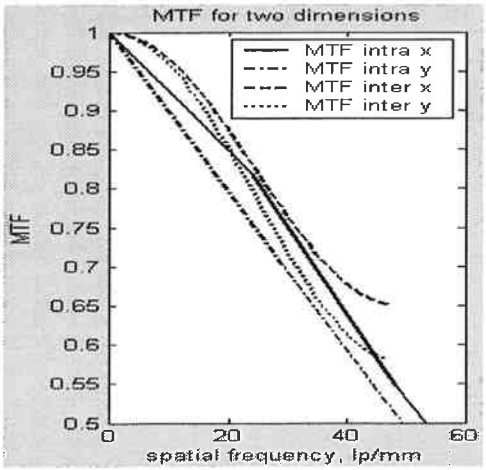

Fig. 2: 1-D Inter & Intra-pixel MTF comparison: two lines represent the intra-pixel MTF calculated for each axis respectively to LSF obtained by integration from the measured PSF and additional two lines represent the inter-pixel MTF calculated for the corresponding pixel subarray without consideration to the observed intra-pixel diffusion effects.

In this work, we also formulate simple theoretical approach for the PSF estimation for CMOS image sensors. Calculations are based on the parameters reported for the standard CMOS 0.35-µm technology process data, and compared (see Figs. 3&4&5) with the scanning results of various 7µm pitch APSs fabricated in the same technology. Note that the sensors described in this part of our work were fabricated according to our design in comparison to the previously mentioned industrial grade sensors. Good agreement between the values obtained for the theoretical and experimental (S-cube system) approaches verifies the ability of the theoretical intra-pixel MTF estimation.

Presented results confirm that theoretical and experimental True 2-D intra-pixel MTF (accounting structure intra-pixel effects) reliable estimation is possible. The degradation of the imager performance caused by the diffusion effects is apparent from the intra-pixel MTF.

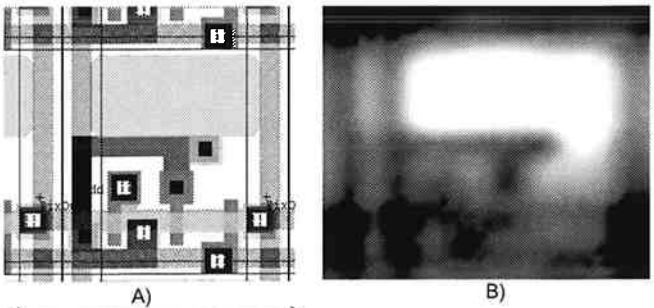

Fig. 3: Comparison between the design layout (A) and the actual electrical scan result (B), obtained by the S-cube system for a pixel fabricated in standard CMOS 0.35µm technology (after [3]). In (B) the lighter areas indicate a stronger response.

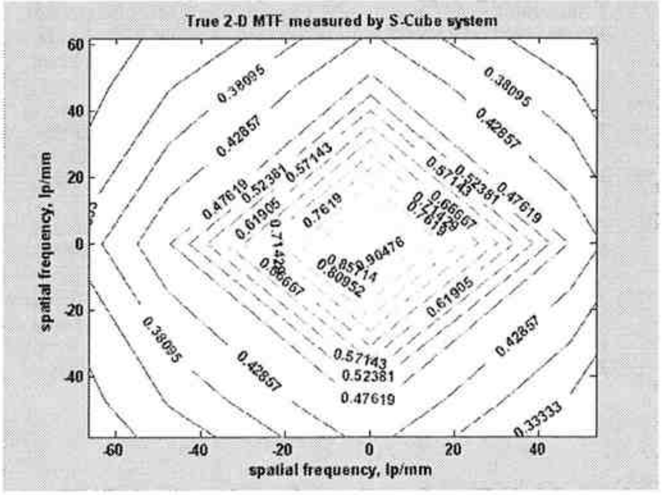

Fig. 4: The true MTF contour plot calculated via the symmetrical 2-D Fourier transform from the measured PSF.

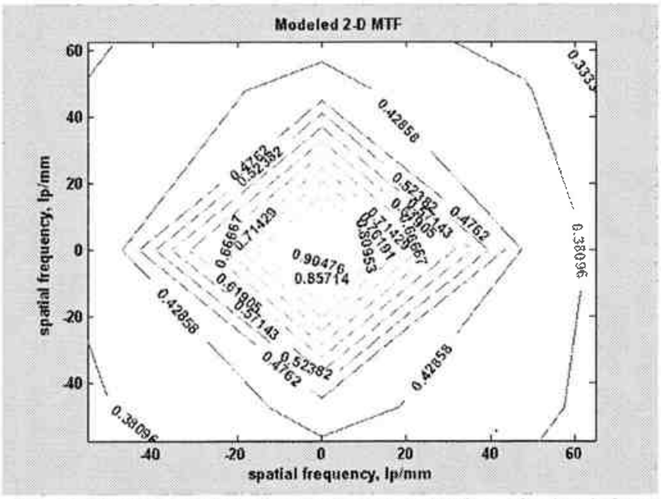

Fig. 5: Modeled MTF contour representation obtained from the analytically calculated PSF, via the 2-D Fourier transform.

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