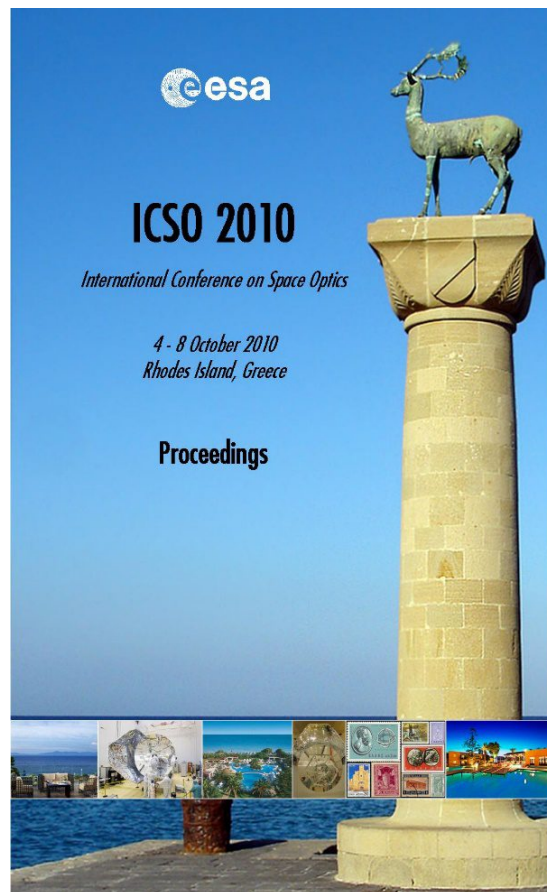


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DYNAMIC MTF MEASUREMENT

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ABSTRACT

MTF (Modulation Transfer Frequency) of a detector is a key parameter for imagers. When image is not moving on the detector, MTF can be measured by some methods (knife edge, slanted slit,...). But with LEO satellites, image is moving on the surface of the detector, and MTF has to be measured in the same way: that is what we call "dynamic MTF". CNES (French Space Agency) has built a specific bench in order to measure dynamic MTF of detectors (CCD and CMOS), especially with component working in TDI (Time delay and integration) mode. The method is based on a moving edge, synchronized with the movement of charges inside the TDI detector. The moving part is a rotating cube, allowing a very stable movement of the image on the surface of the detector. The main difficulties were:

- stability of the rotating speed
- synchronization between cube speed and charge transfer inside the detectors
- synchronization between cube position and data acquisition.

Different methods have been tested for the displacement of the knife edge:

- geometrical displacement
- electrical shift of the charge transfer clocks.

Static MTF has been performed before dynamic measurements, in order to fix a reference measurement. Then dynamic MTF bench has been set up. The results, for a TDI CCD show a very good precision. So this bench is validated, and the dynamic MTF value of the TDI CCD is confirmed.

1. INTRODUCTION

CCD detectors are usually used in the focal planes of imagers onboard satellites. For 30 years Earth remote sensing CNES's satellites have used a pushbroom mode: the image width is given by the length of the focal plane, and the image length is given by the satellite movement

Obviously, image is moving on the detector during image capture.

For low to medium resolution (10m to 1m), linear arrays performances are good enough to allow high quality images.

But for submetric resolution, so for short integration time, there are not enough photons to generate an image with a good Signal to Noise ratio.

So most of high resolution satellites use CCD's in TDI mode.

A 2D CCD array is used, with a specific clocking to achieve a movement of electric charges (generated by the photons) inside the detector, synchronized with movement of image on the detector.

It's a very simple way to increase integration time: so the number of electric charges generated inside the detector is multiplied by the number of detector rows, allowing a great improvement of the Signal to Noise ratio, and so of image quality

2. MTF DISCUSSION

2.1 MTF definition

The other key parameter of imagers is the MTF (Modulation Transfer Function). MTF is the parameter correlated with the capacity of the imager to reconstitute "sharp images". Low MTF will give blurred images, with a high crosstalk between pixels. High MTF will give images with high contrasted details.

2.2 Smearing MTF

Smearing MTF is due to the movement of image on the detector, creating a blur.

For CCD linear array sensors, smearing MTF value is 0,64

For CCD's used in TDI mode, electric charges are also moving inside the detector: the "electronic image" inside the detector follows the "optical image" on the detector, so that the smearing MTF is much better, depending of the number of phase (clocks) generating the charge transfer inside the CCD: smearing MTF of 4 phase TDI detectors can grow up to 0,99

The previous discussion was true for CCD (charge coupled device CCD). But nowadays, detectors in CMOS technology (also called APS, for Active Pixel Sensors) have appeared, first in the customer domain, and now for Space applications.

But the working mode of CMOS detectors is very different of CCD one, because the charges are converted in voltage inside the pixel itself, so no charge transfer is possible anymore.

So smearing MTF will not be so good in a CMOS detector, even if we can "emulate" a TDI mode using electronic switches inside the detector

The question of a CMOS detector dynamic MTF is not very simple, because several contributors are present.

The object of this paper is not to discuss that, but to show how this performance can be measured, for CMOS and CCD.

As TDI CCD's are now off the shelf, and as their dynamic MTF performance is well known, we will obviously make our first measurements with a CCD detector.

3. STATIC MTF MEASUREMENT

3.1 Static MTF measurement results

Our bench, based on the knife edge method gives us pretty good results.

The 2 graphics below show the results associated to the measurement of 3 successive pixels (in blue, red, and yellow).

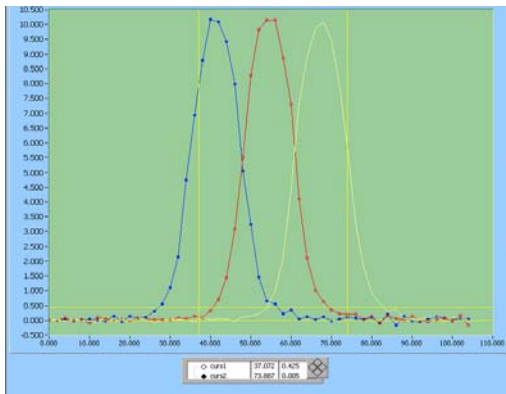


Fig 3.1-1 : LSF of the 3 pixels

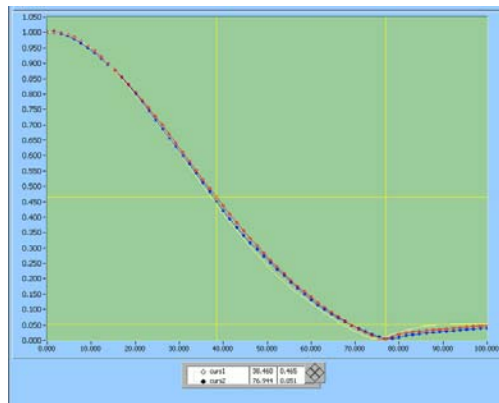


Fig 3.1-2 : MTF of the 3 pixels

Furthermore, we have performed measurements of the same pixel at several wavelengths, and with several f number of the imaging objective.

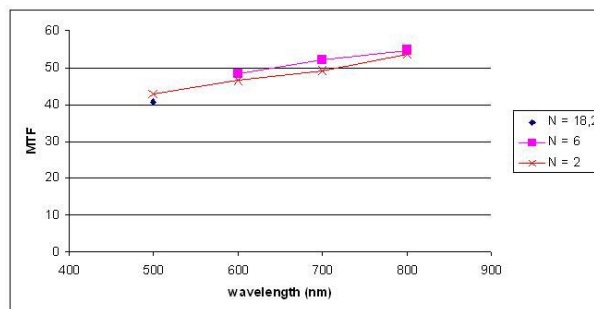


Fig 3.1-3 : MTF of the same pixel

We see that MTF increases slowly with the wavelength, that is compliant with the theory, as this detector is a thinned one.

The values at different optical f numbers exhibit a absolute accuracy of +/- 1 MTF point, that is pretty good.

4. DYNAMIC MTF

4.1 Dynamic MTF measurement methodology

Synchronized moving transitions

The measurement methodology is based on the knife edge one : but instead of keeping it still during detector voltage sampling, the knife edge is continuously moving, simulating image movement on the detector.

In order to exactly simulate what happens in the satellite, we have to perfectly synchronize the movement of the charges inside the detector with the movement on the image on the detector (see Ref 1).

Figure 4.1-1 describes the measurement principle with a 3 lines TDI detector.

As we want to measure dynamic MTF, black/white transition is now projected along the detector lines.

Each schematic of Figure 4.1-1 represents the state of charges packet (inside the detector), image (on the detector), and detector voltage output (wrt the number of line). The movement is represented by several schematics, sampled at the line period (T_{lg}) of the detector, though the movement of image is continuous, and movement of charges "pseudo continuous" (the charges displacement pitch is $1/8$ of the detector pitch, thanks to TDI 4 phase clocking).

As the detector is a CCD the output voltage corresponds to the charges packet that was in the bottom line at the previous frame.

All this sequence corresponds to the movement of a transition on all the detector lines: we will call this sequence a "one shot sequence".

During a one shot sequence, the relative position of the black/white transition and the charges packet stays the same.

We see on this figure that the transition line corresponds to the 3rd line readout from the detector.

The output voltage of this 3rd line corresponds to a specific position on the image transition wrt position of packet of charges (around the half of the pixel).

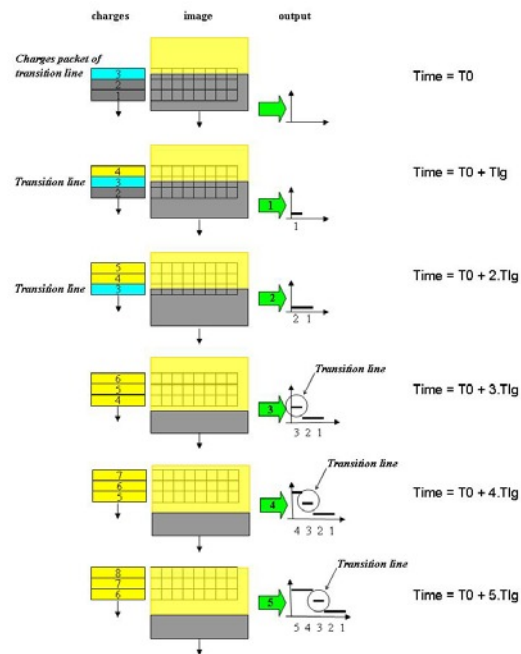


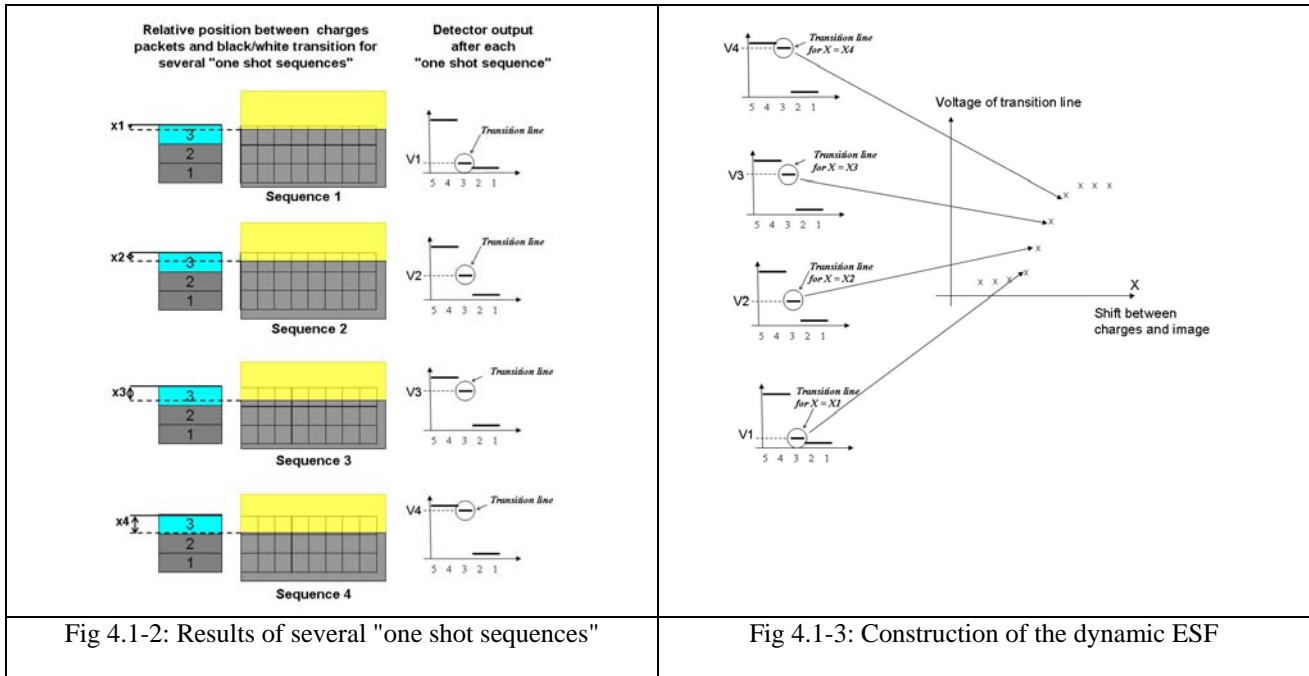
Fig 4.1-1: "one shot sequence" of synchronized moving transition

Knife edge method with moving transition

Now we have to explain how we measure the MTF itself.

We run several "one shot sequence" for several relative positions (x on Figure 4.1-2) of black/white transition according to charges packets one.

Each "one shot sequence" gives a detector output, where we clearly see the voltage of the transition line depends on "x".



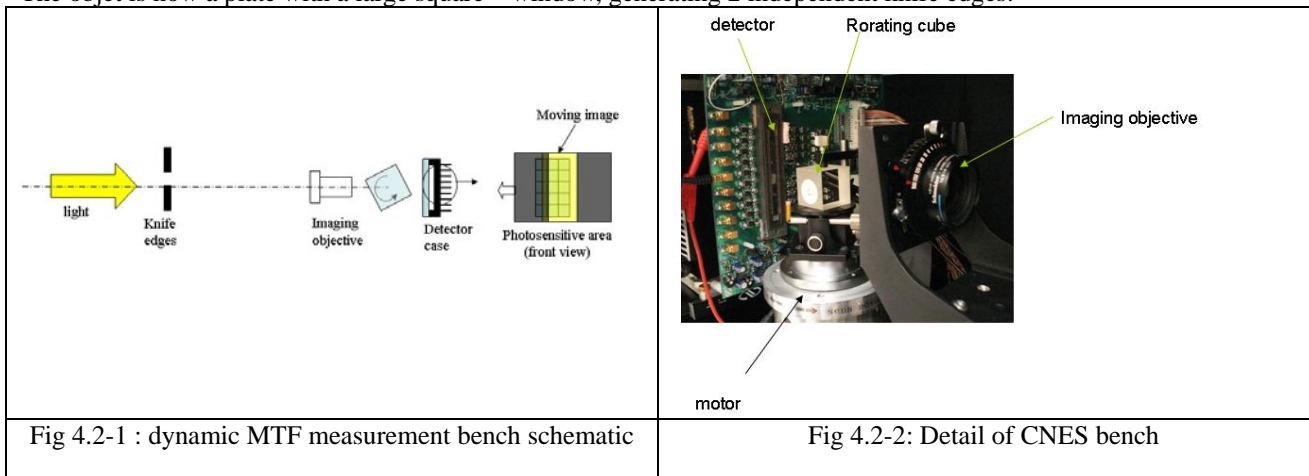
Now we just have to plot the voltage of the transition line wrt "x" (shift between charges and image), for the several sequences : this gives the dynamic edge spread function of the detector (see Fig 4.1-3).

So we now just have to complete the process like for the static case: derivation, FFT and Objective correction, to finally obtain the dynamic MTF of the detector.

4.2 Dynamic MTF measurement bench

The dynamic FTM bench is derivated from the static one, having added a rotating cube to create the image movement (see Fig 4.2-1 and 4.2-2).

The objet is now a plate with a large square window, generating 2 independent knife edges.



It is easy to demonstrate that for small rotation angle, image movement is linear on the detector.

The advantage of the rotating element is that several sequences can be taken in the same configuration (one per cube rotation), allowing readout averaging and stability assessment.

Obviously all these elements have to be carefully aligned.

One of the major implementation difficulties is to perfectly synchronize the movement of the image and the displacement of charges inside the detector.

4.3 Strategy of synchronization

Speed of image is given by :

$$V_{image} (mm.s^{-1}) = \omega (rd.s^{-1}) \times \frac{(n-1) \times e}{n}$$

Where

ω is the angular speed of the rotating cube

n is the optical index of the cube

e is the dimension of the cube

Average speed of charges inside the detector is :

$$V_{charges} (mm.s^{-1}) = \frac{Pixel_pitch}{Line_time}$$

The strategy for synchronization is the following :

- line time is given by the application : so it can not be changed.
- we precisely adjust the angular speed of the cube : the success criterion is the stability of the detector output over several cube rotations. Figure 4.3-1 gives 8 successive detector frames (for 8 cube rotations), showing the stability of the level of the transition line :

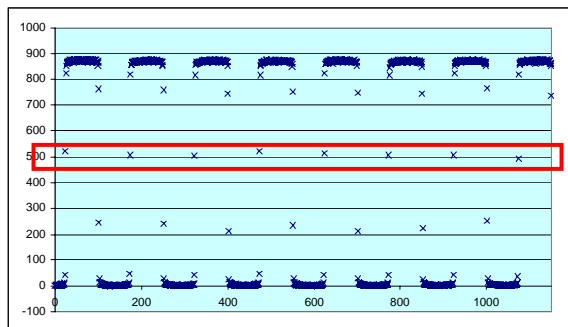


Fig. 4.3-1 stability of transition line level

In order to improve the accuracy, we have decided to keep only frames for which the transition level stays in a range of +/- 1% .

- to ensure that relative position of black/white transition and charges packet stays stable, we have chosen to re-synchronize the detector clocking at each cube rotation, with a signal given by the rotating motor, and corresponding to a precise position of the motor.

As said before, in order to improve accuracy, we run several one shot sequences for the same configuration of relative position between black/white transition and packet charges inside the CCD.

4.4 Image/charges relative position change

There are several ways to change the relative position between the image of the B/W transition on the detector, and the charges packets inside the detector, as shown in Figure 4.1.2 :

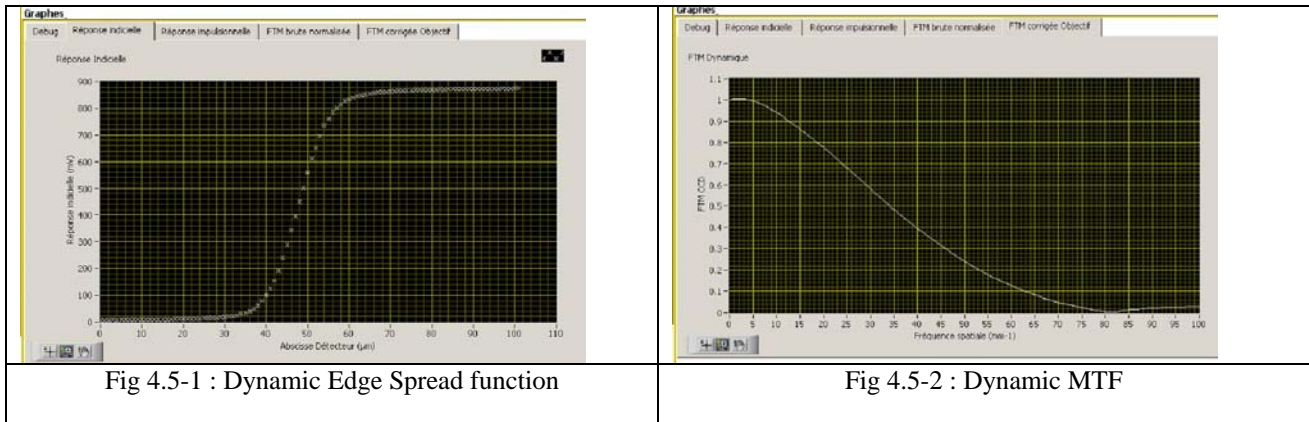
- mechanical shift of the knife edge
- mechanical shift of the detector
- electronic shift of the charges packet

The third way is obviously the most accurate, as electronic delay is very easy to set up with high resolution and stability.

The principle is to change the detector clocking sequence: when the motor passes in regard with an specific absolute position, the detector clocking starts. So we just have to slightly delay the start time of the clocking to create a shift of the charges packet inside the detector

4.5 Results

Measurements have been performed with a TDI CCD (20 lines, 13 μ pitch) operating with a vertical (line) frequency of 10 kHz. Results are shown below :



We can now compute the part of the dynamic MTF due to relative movement of charges and image (smearing MTF), by forming the ratio between measured dynamic MTF and measured static MTF, for the same pixel, or column, as dynamic MTF is measured on the whole column of the detector : the calculated value is close to the theoretical value (0,99).

Several measurements performed at different dates give very reproducible results.

So these measurements validate our dynamic MTF bench.

8. CONCLUSIONS

As the dynamic MTF bench is now validated by measurement on a CCD TDI whose smearing MTF is well known, we can know envisage to measure dynamic MTF of CMOS detectors, because this performance is not as well simulated as for CCD ones.

CNES is deeply involved in the development of such detectors, and will made soon such measurements.

ACKNOWLEDGMENTS

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