

# PORTABLE LOW-COST FLAT PANEL DETECTORS FOR REAL-TIME DIGITAL RADIOGRAPHY

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**Abstract.** The X-ray inspection is one of the most common used non-destructive testing methods in industry applications, but for the portable X-ray digital solution are not so many accessible, low-cost and versatile detection devices. The efficiency of a non-destructive X-ray portable device is represented by the quality of digital images, by its low acquisition time combined with a high resolution, in condition of low noise and at an affordable cost.

The paper presents two x-ray portable imaging systems developed by us, suitable also for aerospace NDT applications, which are also very versatile for being easily adapted for other fields that requires mobile solutions.

The first device described in the paper represent a portable large-size (210mm X 550 mm) and high-resolution (27/54 microns) flat panel detector based on linear translation of a X-Ray TDI detector, destined for various components/parts real-time transmission measurements. The second system it is also a flat panel detectors, with a size of 510mmX610mm, with the detector size from 0.2mm until 1.5 mm, which can operate by applying the dual-energy method, very useful for discriminating materials by evaluating their Atomic effective number. The high resolution and low-cost of this flat-panels widens their applicability by covering large requirements, from identifying unwanted materials within a structure until detection of very thin cracks in complex components.

## 1.Introduction

The nondestructive testing (NDT) techniques are covering very large field of applications being widely used in manufacturing, fabrication and in-service inspections. One of the most nowadays used NDT method is the Digital Radiography (DR) that has been continuously improved for increasing its spatial resolution and reducing the equipment cost.

To put in perspective in the aerospace inspection, the X-ray method is still widely using radiological films or Digital Plates (DP) techniques, this being a time-consuming process because often requires re-exposures while the data reading time is quite long. As an alternative solution, came out the flat panel X-ray detectors solution, offering a resolution as good as the film method, practically working in real-time, having an initial high price but also a lower exploitation and maintenance costs.

So, the most advanced x-ray inspections are relying on digital Flat Panel Detectors (FPDs), this type of detector being accurate and fast, delivering an image in real time compared with traditional radiological film and allowing a lower dose of radiation due to their high sensitivity. There are many companies that have developed FPDs for several fields, such as: medical application and security luggage inspection, food and pharmaceutical products control. [1,2]. An intermediate X-ray digital radiography solution, that penetrated



the market in the last decade, is based on DP [3], which is a phosphor-based sheet that is irradiated as a film, but the image is after irradiation revealed by a laser scanning technique.

Despite the recent technological improvement of the FPDs, being now designed to provide similar or even better image quality results compared to classic radiological film, still the film/plates based technique remains a widely used method due to their much lower cost compared with FPDs.

There are two major types of aircraft maintenance checks that have to be done on all commercial or civil aircrafts: routine inspections and detailed inspection. Both of them are usually done after a certain number of flight hours or cycles and the method used depends on the aircraft type, the number of flights since the last check and the cycle count. For many maintenance checks, it is absolutely necessary to verify the most important components belonging to fuselage, wings, tail, landing gear, communications systems, instruments, electrical components, etc. Regarding the inspection of aircrafts structure or mechanical subassemblies, these parts are sometimes inspected by using radiographic techniques but it may not be an easy task if the imaging components are too expensive, has poorer resolution or are too small for covering the wide region of interest.

An alternative solution to FPDs that have relatively recently developed [4,5] is based on getting 2D X-ray images by a continuously mechanical translation of a linear array detector inside a 2D detector box, adjusting the translation speed in correlation with X-ray source intensity and data integration time required.

Anyhow, such technical solution, named Linear Array Translation 2D Detector (LT2D), despite its very low-cost (sometimes as low as 10% from a FPD cost) and the possibility to design very large scanning area, still has some major drawbacks: much longer scanning time (minutes instead of tens of seconds), higher noise and it cannot be used with a pulsed X-ray sources. But, due to their very low-cost and large-size, the LT2Ds intend to become nowadays a more suitable solution for a cost-effective NDT portable X-ray industrial technique, especially where the acquisition time is not limited.

Because appeared that is not available in the market a 2D device that can have all the wanted features, such as: low-cost, to be easy to handle, to provide high-resolution radiographic images and to allow a reasonable short acquisition time, we decided to develop a LT2D that can provide almost all requirements in a reasonable manner. Our solution is based on using as linear array a TDI (Time Delay Integration) detector [6,7], which is a 2D linear array of X-ray detectors that integrates their multiple detectors lines data in one data line at output. The final image is in this way many times averaged by synchronizing object movement with the internal array lines data shift. Such image has much less noise due to averaging technique involved and also a much higher dynamic range. With our linear flat panel detector we are able so to deliver a high-quality and high-resolution images having the option to adapt a bigger scanning area than the previous models, while maintaining a good quality-price ratio.

## **2.Flat panel -TDI detector**

The device contains a linear TDI detector with 256 lines of pixels is presented in **Figure 1** and each pixel has 54 microns pitch, ensuring a spatial resolution better than 7 lp/m (line pairs/mm).



**DALSA Argus TDI X-Ray detector**

Physical resolution: 4080 (H) x 256 (V) pixels

Pixel size: 54  $\mu\text{m}$

Field of view: 110,5 mm x 6.9 mm

Binning mode: 2x2

Line rate: 200-2000 Hz

X-ray image resolution: up to 7.5 lp/mm

Scanning speed: 2-8 cm/s

**Figure 1.** The TDI detector used in our TDI-based Flat Panel detector

This method of line scanning based on the concept of accumulating multiple exposures from the same sample position provides a better integration time (down to 1mS/line) and greater scanning speed (up to 10 cm/s) than any other methods, but for properly working with TDI detector is absolutely necessary to synchronize the object scanning speed with data acquisition shift frequency. The **Figure 2** represent two images of the TDI flat-panel detector we have developed, presenting its front view and the inside components distribution.



**Figure 2.** The Flat-Panel detector developed based on TDI detector

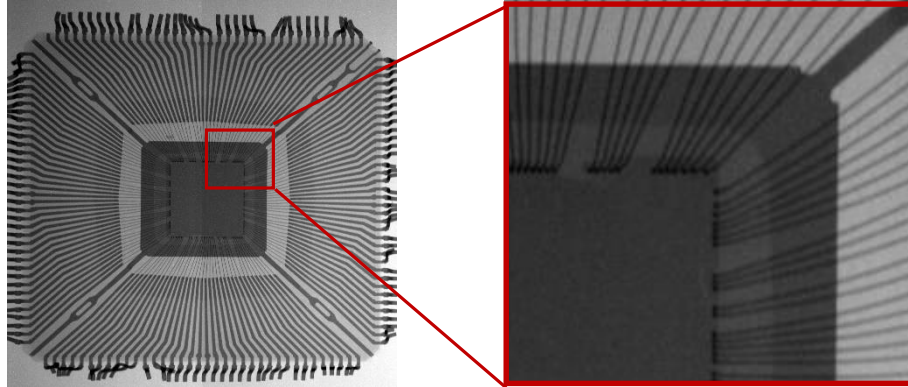
The table below presents the main features of TDI-based Flat Panel detector:

Operating area (Wx H) mm	220 x 450 (at request could be. 440 x 900)
Converter type/connection	Programmable gain/16 bit / Ethernet wireless
Scanning speed	Programmable from 5 to 50 sec (~1-10 cm/s)
Detector pitch (binning 2)	54 $\mu\text{m}$
Signal to noise ratio	12000:1
Batteries duration	more than 80 scans

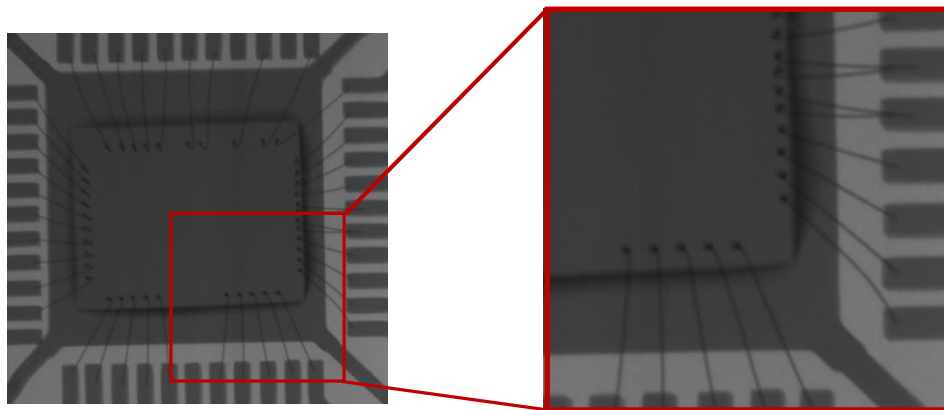
Besides the TDI flat-panel's high sensitivity and high resolution images, another advantage provided by our device is the high signal to noise ratio (around 12000:1), which is very important when high-quality X-ray images are required.

The LT2D detector is potentially useful for a large number of applications and we are presenting in following a few representative scans of two Integrated Circuits (IC), some Powder Metallurgy (PM) samples in green and sintered stage and other components. During the investigations that have been performed, we have used a minifocus and a microfocus x-ray sources, depending on the resolution required,. When a higher spatial resolution was necessary, that could be easily achieved by the TDI Flat Panel detector if a magnifying set-

up and a microfocus x-ray source would be used. **Figure 3** represent a digital radiographic image of an IC that was investigated to verify the system high-resolution by evaluating the internal bonding wires in a magnifying set-up. The inside bonding wires with a diameter of  $25\ \mu\text{m}$  are clearly visible and the resolution is obtained at a set-up magnification of 3X, which means an image pixel size of around  $18\ \mu\text{m}$ .



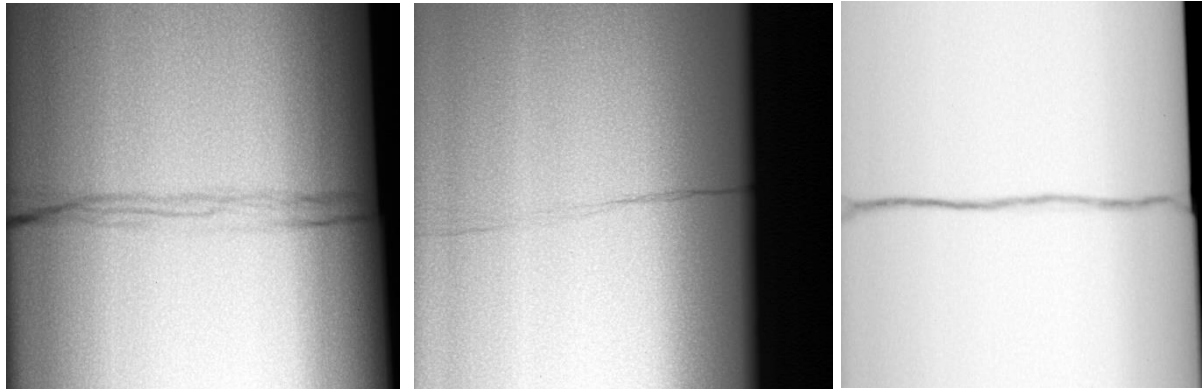
**Figure 3.** The digital images of an Integrated Circuit and a zoomed part of it obtained by using our TDI-based LT2D revealing 25 microns bonding wires



**Figure 4.** Radiographic image of another chip obtained using TDI-based LT2D where 18 microns bonding wires are clearly visible.

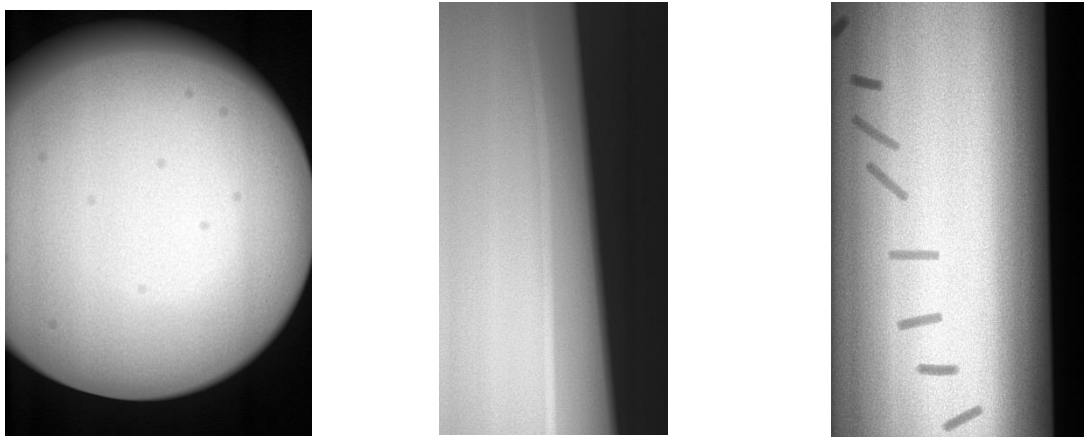
The microfocus x-ray source used has a focal spot size of 5 microns and maximum voltage of 160kV and the image was acquired at 70 kV and  $110\ \mu\text{A}$ , with a scanning speed of 2 cm/s. Another chip that has been tested in the same conditions is presented in **Figure 4**. The high-resolution and high signals to noise ratio of the LT2D allow us to see the smallest wires (18 microns) and the details of the chip die.

Since many aircraft components includes parts made by PM technique, we further analyzed some green and sintered parts made from metal powder that is compacted almost into net shape and then sintered at high temperature. So, after manufacture such parts, because of their weakly cohesive structure, some small defects like cracks or density variations may occur. These types of PM components, that are relatively common within aerospace products, require a 100% post-manufacture inspection and here is a good example where a high-resolution X-ray Digital radiography is beating many other NDT techniques.



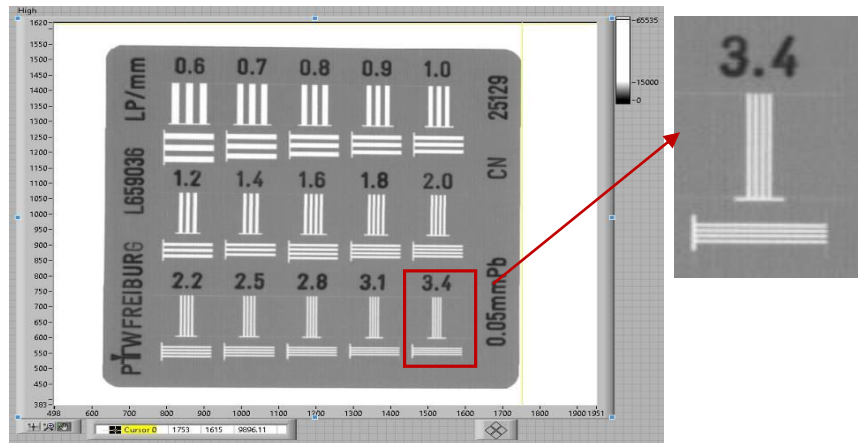
**Figure 6.** Green and sintered parts cracks detected by TDI based LT2D

Further, we choose two types of PM samples to be analysed: the green and sintered parts, presented in **Figure 6**, where fine cracks has been found in some regions and three different green and sintered samples manufactured with Copper wire and spheres insertions for evaluation the sintering technique (**Figure 7**).

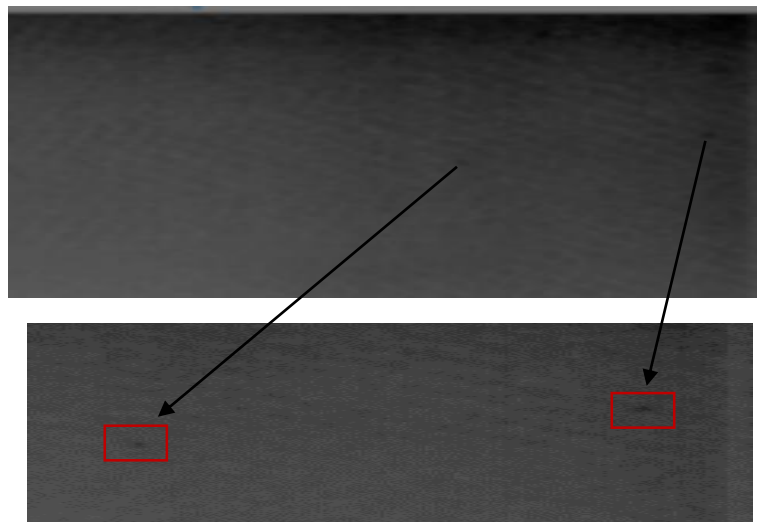


**Figure 7.** Green and sintered samples with Cu insertions

Another set-up solution that has been tested is based on using our TDI-based Flat panel detector and a minifocus x-ray source with a focal spot size of 1.2 mm and a maximum tube voltage of 160 kV. To evaluate the resolution that can be usual obtained by using the minifocus x-ray source, we scan a LPM resolution indicator placed not so far from the detector and the result can be seen in **Figure 8**, where a resolution better than 3.4 line pair/mm has been achieved. The **Figure 9** presents radiographic images of a full polymerized pre-impregnated composite sample and a zoomed part of it where two red rectangles highlights some spots, quite difficult to be detected by other inspection techniques, but after the x-ray inspection we discover that they appear to be small weak points within the material.



**Figure 8.** Radiographic image of a LPM resolution indicator.



**Figure 9.** Polymerized pre-impregnated composite material with two weak points zoomed and highlighted by red rectangles

### 3. Dual-energy Flat Panel detector

A proper method used to detect hidden materials, or to discriminate between different types of materials (organic, inorganic or metallic) is the “dual-energy” technique. The technique can be used in the same time for materials discrimination investigation and also for defects detection, when detectors size used are quite small. For example, the device could be useful for identification of the organic materials (such as water) which have infiltrated within metallic structures and also to see the internal structure dimensions. The dual-energy Flat Panel detector based on "dual-energy" method we developed is presented in **Figure 10** and a table with its features description is following.

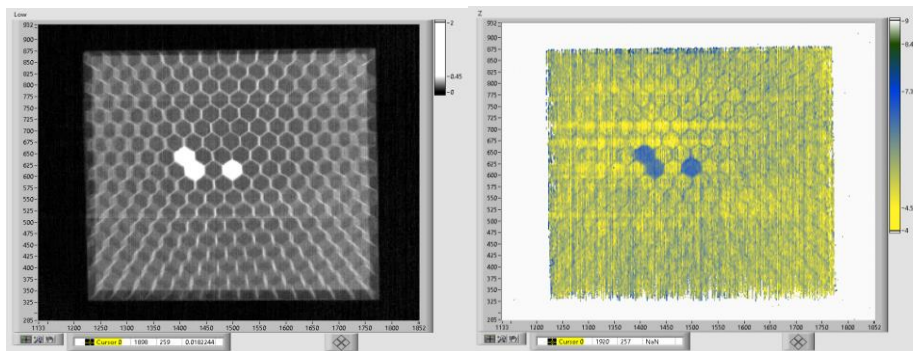


**Figure 10** .The dual-energy Flat Panel detector developed

The table below table presents the main features of the dual-energy Flat Panel detector:

Operating area (Wx H) mm	512 x 624
Images	B&W Low and High energies and coloured in Zeff values
Scanning speed	Programmable between 2 to 120 sec
Detector pitch	0.2 (0.4, 0.8 or 1.5 mm at request)
Weight	5 kg
Dimensions (L x H xW), mm	550 X 800 x 36
Batteries powered	For more than 30 scans
Connection	Wireless

The dual-energy Flat Panel device contains a linear array detector consisting of 2560 individual detectors/pixels that allows recording a big volume of data - one image size has around 40 MB - by using a BeagleBone microcontroller board. Each individual detector has a dimension of 0.2 mm which makes the flat panel detector also useful for detection of small defects. The scanning speed of entire range can be programmed from 10 to 120 seconds which is a great advantage, taking into account the time required for a film processing. Even if the scanning area is around 512 mm X 624 mm this device can be easily handled for large surface successive scan, because of its relatively low weight of around 5 kg and without needs of any cable connections. To test the efficiency of dual-energy flat panel detector, we investigate a honeycomb structure sample where we inserted few drops of water into some structure cells. The scanning result is presented in **Figure 11**, where a minifocus x-ray source that operated at 160kV was used. The classical radiographic images from left side shows the presence of foreign materials but, in the right side, due to the “dual energy” technique, the effective atomic number computed identifies the foreign materials as being water.



**Figure 11**. The radiographic images of the honeycomb structure with water infiltrated

## 4. Conclusions

The Flat Panel detector based on a linear translation of a TDI type detector presented above is very useful for a large field of NDT applications due to its high-resolution that can provide high-quality radiographic images at low-cost and high-speed. Also the dual-energy Flat Panel solution presented offers also a unique combination of features, by having the possibility to detect the content of various type materials combined with the dimensional NDT evaluation of the structures. A forthcoming important technique, which is foreseen to have a strong impact to X-ray 3D inspection, and we are interested to further develop based on present achievement, is the digital computed Laminography technique based on TDI detector focus scan [10]. The high-sensitivity and the high signal-to-noise ratio achieved by the TDI detector would allow to minimise the x-ray power necessary for such inspection and to capture very good images while the object/detector is moving, making it suitable for this new technique.

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