X-ray light valve (XLV): a novel detectors' technology for digital mammography*

Sorin Marcovici, Vlad Sukhovatkin, Peter Oakham

XLV Diagnostics Inc., Thunder Bay, ON P7A 7T1, Canada

ABSTRACT

A novel method, based on X-ray Light Valve (XLV) technology, is proposed for making good image quality yet inexpensive flat panel detectors for digital mammography. The digital mammography markets, particularly in the developing countries, demand quality machines at substantially lower prices than the ones available today. Continuous pressure is applied on x-ray detectors' manufacturers to reduce the flat panel detectors' prices. XLV presents a unique opportunity to achieve the needed price - performance characteristics for direct conversion, x-ray detectors. The XLV based detectors combine the proven, superior, spatial resolution of a-Se with the simplicity and low cost of liquid crystals and optical scanning. The x-ray quanta absorbed by a 200 µm a-Se produce electron – hole pairs that move under an electric field to the top and bottom of a-Se layer. This 2D charge distribution creates at the interface with the liquid crystals a continuous (analog) charge image corresponding to the impinging radiation's information. Under the influence of local electrical charges next to them, the liquid crystals twist proportionally to the charges and vary their light reflectivity. A scanning light source illuminates the liquid crystals while an associated, pixilated photo-detector, having a 42 µm pixel size, captures the light reflected by the liquid crystals and converts it in16 bit words that are transmitted to the machine for image processing and display.

The paper will describe a novel XLV, 25 cm x 30 cm, flat panel detector structure and its underlying physics as well as its preliminary performance measured on several engineering prototypes. In particular, the paper will present the results of measuring XLV detectors' DQE, MTF, dynamic range, low contrast resolution and dynamic behavior. Finally, the paper will introduce the new, low cost, XLV detector based, digital mammography machine under development at XLV Diagnostics Inc.

OBJECTIVES

In many developing countries the number of breast cancers cases is increasing rather fast but their early detection is lagging due to absence of national screening programs. One of the reasons is that the user price of existing digital mammography machines is prohibitively high for the developing world. To address the large demand for low price, digital mammography machines, XLV Diagnostics Inc. is developing a novel, inexpensive, electro-optics, x-ray detectors' technology based on which good quality, digital mammography machine, suitable for the developing world that can be profitably sold for about a third of the price of the machines available today. This objective is achievable because the underlying physics of electro-optics detectors allows for separating the image acquisition from image digitization and eliminates the need for using 2D active matrix array and peripheral electronics which are the most expensive components presently used within direct conversion detectors.

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DETECTOR OPERATION

The XLV detector is a direct type detector that employs a 200 µm a-Se layer evaporated on a very thin piece of glass as a radiation absorption and detection medium. The impinging x-ray quanta are stopped by the a-Se layer and create electron-hole pairs which move under a strong electric field of 10V/µm towards the two opposing surfaces of the a-Se layer. A very thin metallic electrode covers the quanta impinging surface at the top of the a-Se layer. The bottom surface of the a-Se layer rests on a piece of thin glass. At the a-Se thin glass interface, the arriving charges create a 2-dimentional continuous charge distribution that is an analog mapping the volumetric attenuation information carried by the arriving quanta. This 2D charge distribution modulates local optical characteristics of a continuous thin liquid crystals layer positioned on the other side of the thin glass. The corresponding twisting of the liquid crystals molecules is monotonic in relation to the proximal charges and, when exposed to light, they reflect the light proportionally to their local twist. A calibrated light source illuminates the liquid crystals using simple focusing lens and filters and the reflected light is measured and digitized by an associated linear optical scanner. The optical scanner speed and pixel size are selectable. Digitized images are streamed to a computer outside the detector using standard, high speed, digital data interface.

By maintaining the image information in analog domain until is read-out by the optical scanner, no additional noise or, equivalently speaking, secondary quantum sink, is introduced. Moreover, the read-out light's intensity can be increased, if desired, to increase the overall gain.

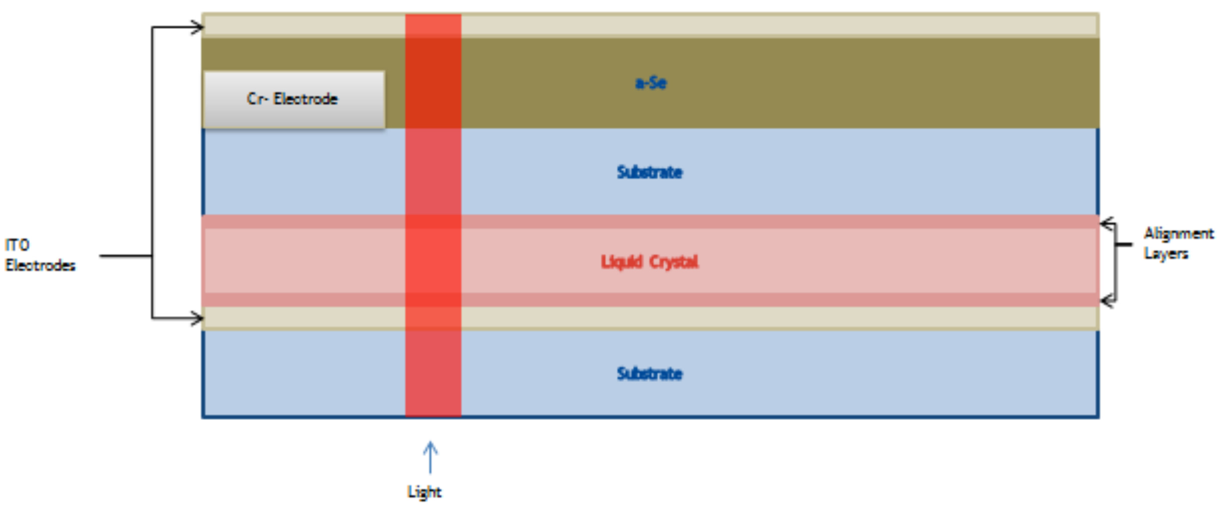

Figure 1

The electrical field is applied across a-Se and liquid crystals between to electrodes: the top electrode made of Chromium and the bottom electrode made of ITO. The liquid crystals layer has to be sandwiched between its two alignment layers and the ITO electrode is positioned below the bottom alignment layer. During x-ray quanta capture, the electric field is set at 10 V/µm and during analog image readout it is set at approximately 0.5 V/ µm. The analog, charge image stored at the thin glass interface with a-Se can be readout repeatedly because the readout is non-destructive.

The readout light source is LED based operating at 630 nm wavelength and collimated with very simple and inexpensive focusing lenses. The light reflected by the liquid crystals is read out using custom made opto-electronics mounted on the linear scanner together with a high speed, 16 bit analog-to-digital converter. The spatial resolution of the linear scanning assembly is 42 µm however, by a varying the scanning speed and electronics parameters, the pixel size can be selected dynamically for every scan. This feature allows, for example, having a fast scan at lower resolution followed by a high resolution scan taken at the nominal speed. Due to the fact the analog charge image is not digitized until the reflected light is measured by the analog-to-digital converter on the linear scanner, the gain of the XLV detector can be increased by illuminating the liquid crystals with higher intensity light.

To measure the electro-optic parameters of the sub-system formed by a-Se and liquid crystals, we built a custom test station where the reflected light is measure using a very high resolution CCD. Figure2 shows the experimental set-up and Figure 3 puts in evidence that the MTF of the optical test station is much higher than the desired MTF to be measured.

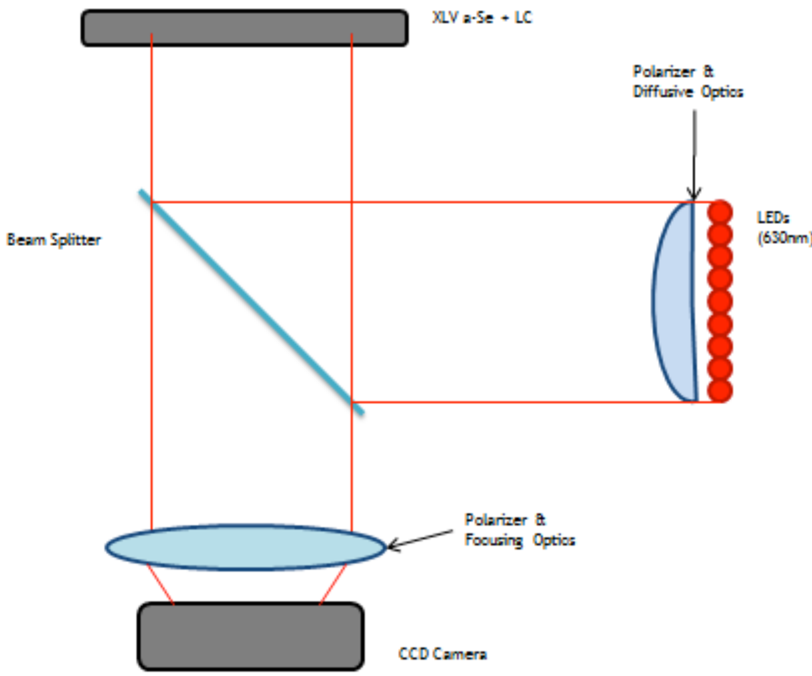

Figure 2

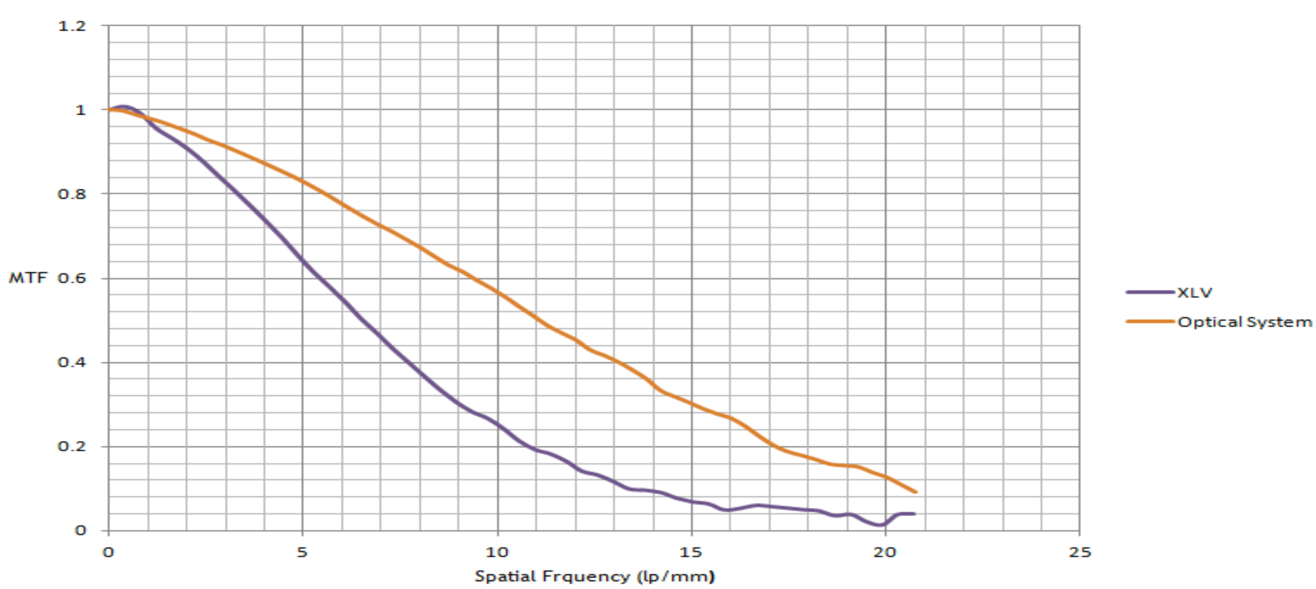

Figure 3

The DQE and the MTF of XLV based detectors' prototypes were measured in accordance with the "Determination of the detective quantum efficiency – Detector used in Mammography - IEC 62220-1-2 Ed.1, 2007" and shown encouraging results. For readers' convenience, the XLV's MTF characteristic curve is shown below in comparison with top-of-the-line digital mammography machines in commercial use today.

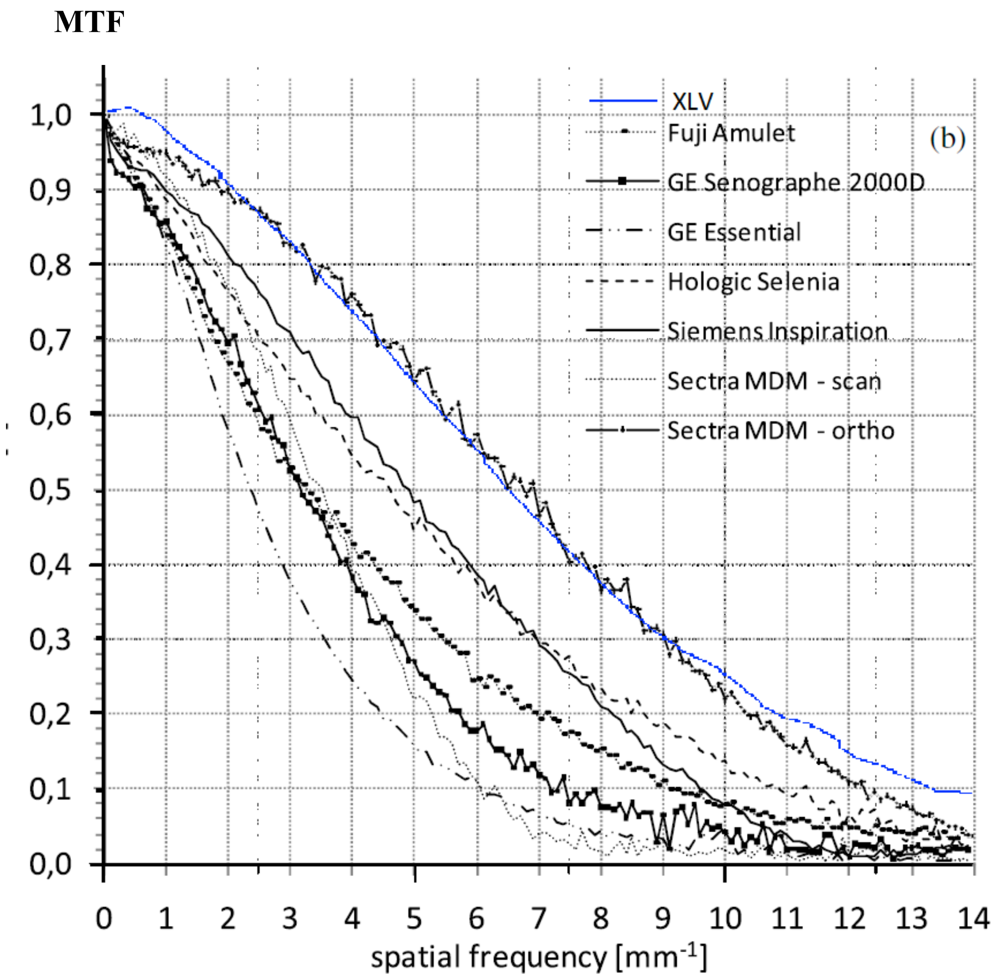

Figure 4

The results demonstrate that the XLV prototype detector's MTF is equal to the MTF of the top-of-the line detectors for digital mammography and provides for the required special resolution necessary for an effective breast cancer screening machine.

Preliminary DQE evaluation also indicates that the performance of XLV based digital mammography detectors will be similar to the typical one for 200µm a-Se detectors.

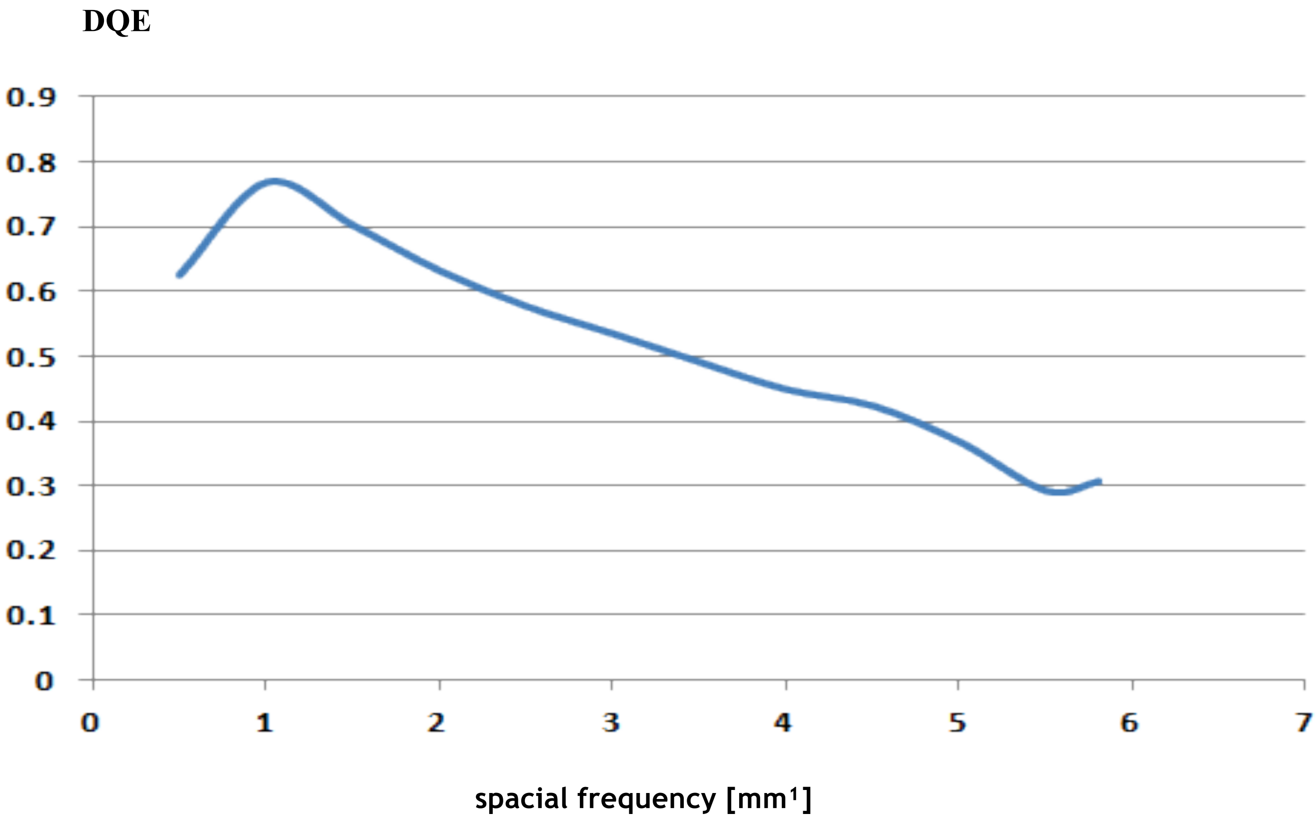

Figure 5

XLV detector's dynamic range is determined mainly by the response of the liquid crystals and the optical scanner. To cover the desired dynamic range for digital mammography, the selected liquid crystals must provide an electro-optic characteristic extending beyond fourteen bits and the associated optical scanner ADC to operate with 16 bits resolution and minimum pixel size is 42 µm.

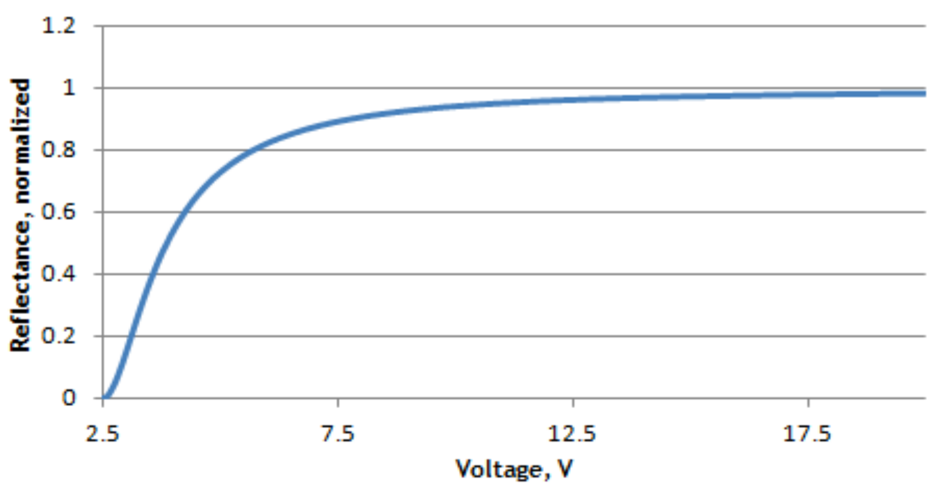

Figure 6

XLV advantages

- There is no front-end noise due to data lines ' capacitance because there are no data lines
- The readout is nondestructive so the charge image can be read multiple times before erasure
- The readout can be dynamically set to different speeds and pixel sizes
- Without adding noise, the readout light intensity can be varied to increase output signal

XLV based digital mammography machine

The inherent simplicity of the XLV detectors' technology provides for the opportunity to design a very robust and inexpensive digital mammography system by tightly integrating the detector with the compressing stand. Minimum control and calibration circuitry required for detector's operation allows that the majority of functions be executed in a very efficient and economic manner by the electronics resources already resident within the compression stand. Moreover, the compression stand itself can be engineered in a modular way conducive to rapid, remote testing and easy serviceability. The XLV digital mammography machines will be first equipped with a 25 cm x 30 cm detector to be followed, at a later date, by an 18 cm x 24 cm detector. All image processing and image presentation functions will be similar to those of mammography machines already in use.

Summary

XLV was proven to be a cost effective technology for producing good quality, large area, x-ray detectors for digital radiography. In particular, the work described in this paper demonstrated XLV suitability for medical imaging applications demanding very high spatial resolution like the one for digital mammography. Both XLV detectors and XLV digital mammography machines open a new avenue for developing good quality yet economic digital radiography machines.

Acknowledgement

The authors want to acknowledge Prof. John Rowlands' seminal contributions to the development of XLV scientific theory and its underlying basic technologies.

Patents

US5847499 - Apparatus for generating multiple x-ray images of an object from a single x-ray exposure

US6052432 – Method of generating multiple images of an object from a single x-ray exposure

US7687792 – X-ray light valve based digital radiographic imaging system

Contact

Sorin Marcovici, XLV Diagnostics Inc., 290 Munro St., Suite 2311, Thunder Bay, ON P7A 7T1, Canada, sorin@xlvdiagnostics.com