The use of LCoS Microdisplays in 3D Optical Surface Metrology Systems

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Modern 3D optical metrology systems use a microdisplay to project a series of complex images onto the surface of a device-under-test [1]. A camera-based inspection system is used to assess these images and calculate an accurate 3D profile. Forth Dimension Displays' fast-switching digital microdisplays are ideally suited to be used as the image source in such systems. This paper outlines the features of ForthDD's metrology-specific display and driver solution and describes the design-in of the microdisplay to metrology systems.

Key words: LCoS, Metrology, Microdisplay, 3D

1 Metrology Drive Board (SXGA-FBS)

During 2007 Forth Dimension Displays (ForthDD) undertook a consultation with 3D metrology (3DM) system manufacturers to define the requirements for the design of a metrology-specific drive board, the SXGA-FBS.

The SXGA-FBS is a flexible, re-configurable microdisplay driver designed to allow user generated images to be displayed according to user generated timings without the need for a real-time video input. Image data is stored in on-board Flash memory along with image timings and display sequences (a set of instructions that control the order and duration of displayed images).

The SXGA-FBS is small, portable and designed to be connected to a PC via RS232 or USB. This enables the user to design image patterns into a timed order using the SXGA-FBS graphical user interface (GUI) software program. At the end of this process the images and timings are loaded into Flash memory. The SXGA-FBS can then be disconnected from the PC, transported and connected to the metrology system for measurement operations.

The SXGA-FBS architecture consists of three main blocks, as shown in Figure 1. The first of these blocks is the **Bit-plane[1] Storage (non-volatile)** Flash memory. This is where user-defined images are stored (as bit-planes) following image design and ordering. This memory contains storage capacity for over 700 bit-planes. The image ordering and timing information defined by the user is stored in the **Flexible Sequencer**.

Once the SXGA-FBS is installed into the 3DM system and powered up, the bit-planes stored in the Flash are transferred into the **DDR2 Memory**. The purpose of this second memory block is to allow very fast upload of bit-plane data to the microdisplay.

1. The word bit-plane refers to the array of information representing each pixel value for that specific illumination bit. For example, an 8-bit image pattern requires the storage of eight bit-planes. The SXGA-FBS deconstructs the user defined images into bit-planes for storage and display.

The third main control block is called the **Bit-plane Manipulation / Display Driver**. This block contains the flexible sequencer and controls the image upload to the microdisplay. The flexible sequencer also sends or receives synchronisation information to or from other parts of the 3DM system, i.e. the camera or image acquisition controllers.

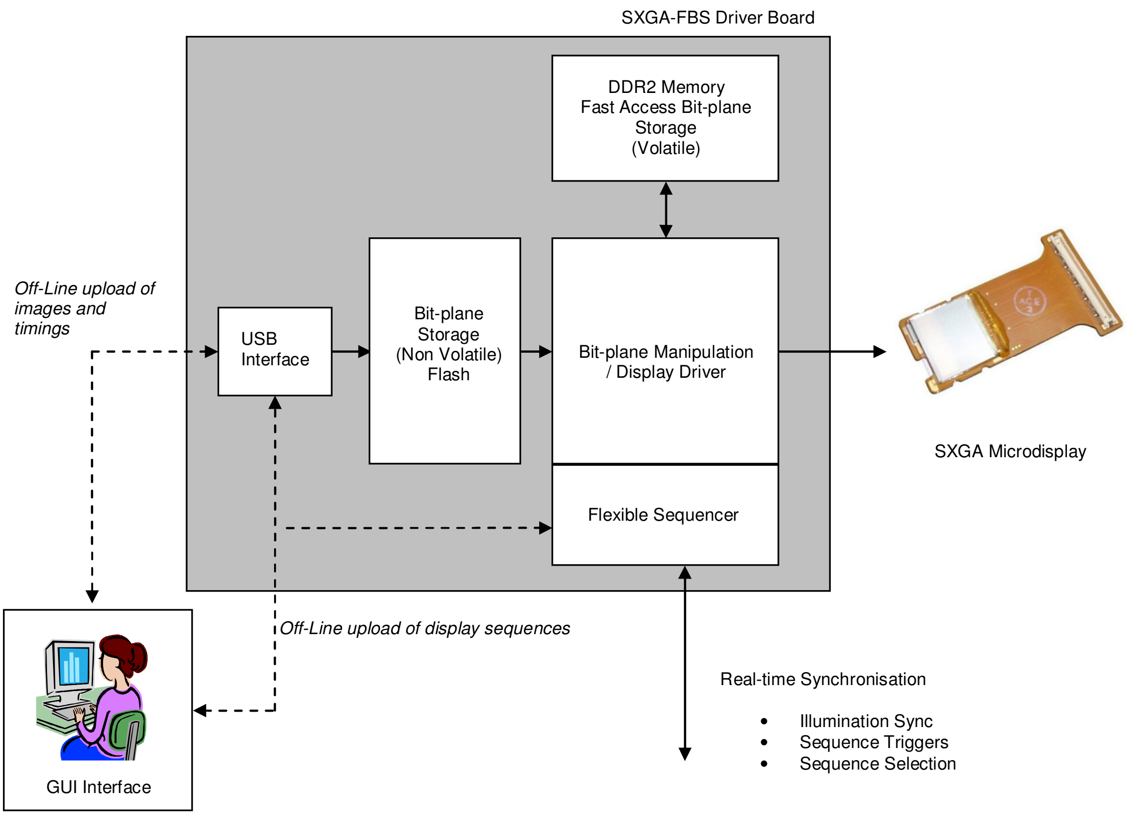

Figure 1 SXGA-FBS drive electronics functional block diagram

2 Optical Considerations

ForthDD's reflective microdisplays are based on ferroelectric Liquid-Crystal-on-Silicon technology (f-LCoS). This means each individual pixel acts as a controllable polarisation converter (a quarter-wave plate) and, when used in conjunction with a polariser, can allow or inhibit light passage into the rest of the system (i.e. be OFF or ON). Colour and greyscale are built up using a combination of colour sources and a form of time-division multiplexing called Time Domain Imaging or TDI.

Forth Dimension Displays' SXGA	
Resolution	1280 (h) x 1024 (v)
Pixel pitch	13.62um
Display Area Size	17.43mm x 13.95mm
Pixel fill factor	>92%

Table 1 SXGA microdisplay specification summary

2.1 On-axis Display Core

The on-axis display core uses a polarising beam splitter (PBS) and either the projection optics or the illumination optics is in line with the z-axis of the microdisplay. This option is more suitable for a metrology configuration where the projector is vertically above the DUT. The typical performance of an on-axis display core is shown in Table 2.

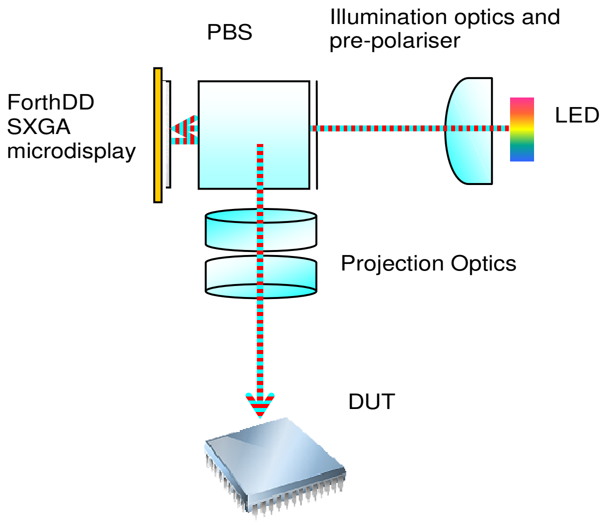

Figure 2 On-axis display core

2.2 Off-axis Display Core

The off-axis display core works without the need for a PBS in the system. The illumination is directed to the display at an angle to the z-axis and the polarisation gate is created by two crossed polarisers (a pre-polariser and an analyser polariser). This illumination method has a higher contrast than the on-axis core configuration. It may be especially suitable in the metrology application where off-axis DUT illumination is required, since the off-axis core would help the system meet the Scheimpflug principle for tilted focal planes. The typical performance of an off-axis display core is shown in Table 2.

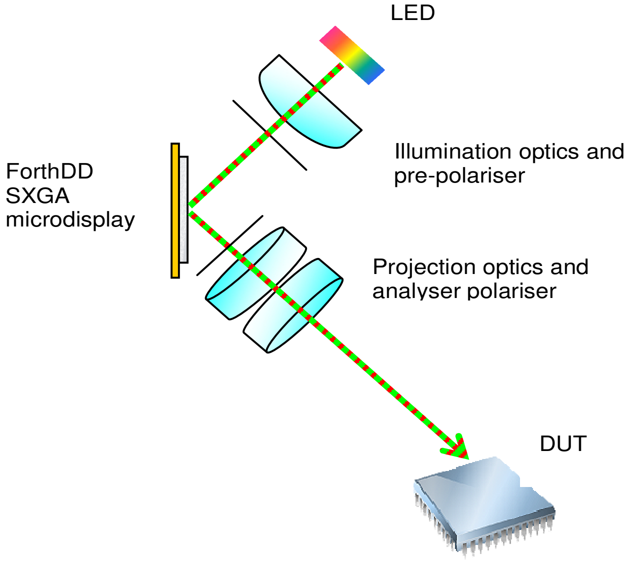

Figure 3 Off-axis display core

Illumination at F/3.2[1]	On-axis Display Core	Off-axis Display Core
Red contrast	1150 : 1	1200 : 1
Green contrast	1050 : 1	1100 : 1
Blue contrast	650 : 1	700 : 1
White contrast	1005 : 1	1050 : 1

Note 1: At F/numbers greater than 3.2 the contrast increases.

Table 2 Comparison between on-axis and off-axis display cores

2.3 Illumination optics and light capture

The preferred illumination method for optimum performance is to use either LED or laser sources, although lamp and colour wheel systems can also be used. The fast-switching of solid-state light sources fits well with ForthDD's fast-switching microdisplay, and enables best contrast and image quality.

2.3.1 LED Illumination

High brightness LEDs such as Luminus Phlatlight or Osram Ostar are typically used for projection applications with ForthDD LCoS microdisplays. The illumination can either be passed through a light pipe or fly's-eye lens arrays to homogenise and shape the beam. When using LEDs, Étendue is a consideration since LEDs have a large emitting area and typically a wide angle of illumination.

The Étendue of the ForthDD SGXA at F3.2 is:

$$\varepsilon_{Display} = \frac{\pi.A}{4.F^2} \quad \text{at F/3.2} \qquad \varepsilon = 18.6\,\text{mm}^2\text{/sr}$$

ε is the Étendue
A is the area
F is the F-number

In our demonstrator LED engine, three Luminus Phlatlights are used. These sources have a 16:9 aspect ratio (AR) and in order to match this to the SXGA's 5:4 AR, a tapered light pipe is used prior to the illumination relay optics. Around 80% of the light generated by the LED is within the display Étendue. Well designed illumination optics, which conserve Étendue, will allow most of this light to be used by the display core, minus polarisation losses.

2.3.2 Laser Illumination

Lasers are the most suitable light source to use with ForthDD TDI for two reasons. Firstly, they have a very low Étendue which allows almost 100% of the light to be collected by the display. Secondly, they are linearly polarised so there are no large polarisation losses. Lasers can also be overdriven when pulsed at low duty cycles and ForthDD's high pixel fill factor reduces diffraction effects.

3 System Considerations and GUI

The USB connection on the drive board allows the image design and ordering functions to be performed on a PC whenever necessary. ForthDD have developed GUI software to aid the system integrator with this. The software allows the editing of image order and timing and will optimise the system performance within a set of design rules.

3.1 Deferred DC Balancing

Ferroelectric LCoS material requires a charge balancing maintenance routine, known as DC balancing, which means that an 'inverse' image must be shown following each positive image on the display. In typical applications, this inverse image is inserted immediately after the positive image during a time when the sources are switched off, thus making the inverse image invisible to the viewer. This 'interleaving' of the inverse image has image quality benefits in video applications but for 3DM applications these benefits are not felt. It also reduces illumination duty cycle and system brightness. A typical 'interleaved' sequence structure is shown in Figure 4.

In order to increase system brightness for the metrology application, ForthDD has developed a system where the displaying of the inverse image can be deferred. In this system, the inverse image is shown during a time when the inspection camera is not exposed to light, e.g. during camera transfer times, between camera exposure periods, or during DUT movement. A 'deferred' sequence structure is shown in Figure 5.

The GUI software maintains these DC balancing rules during image ordering and ensures maximum system brightness during exposure windows.

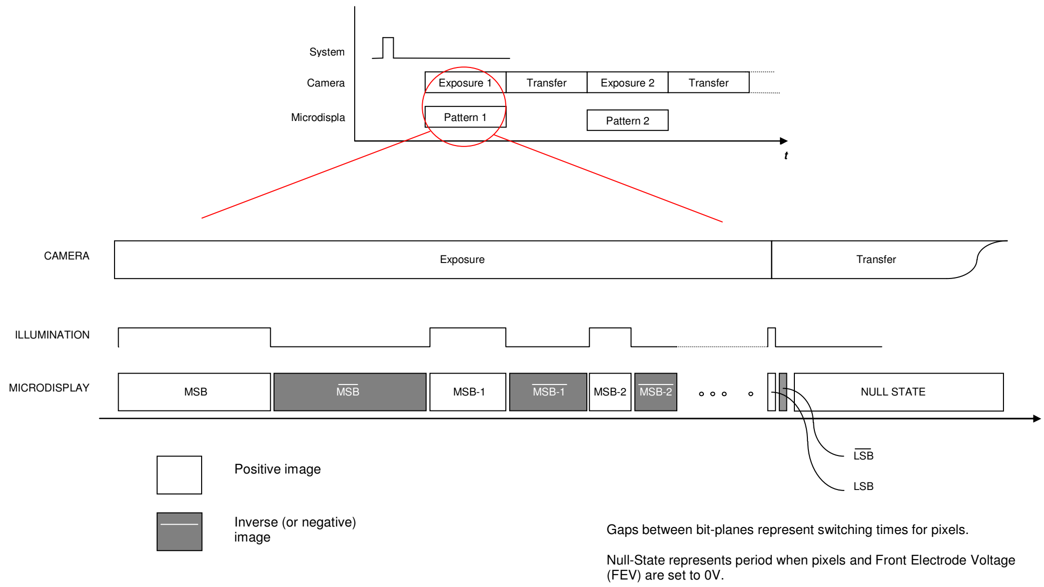

Figure 4 ‘Interleaved’ sequence structure, where the inverse image is shown **during** the exposure window - useful for video applications

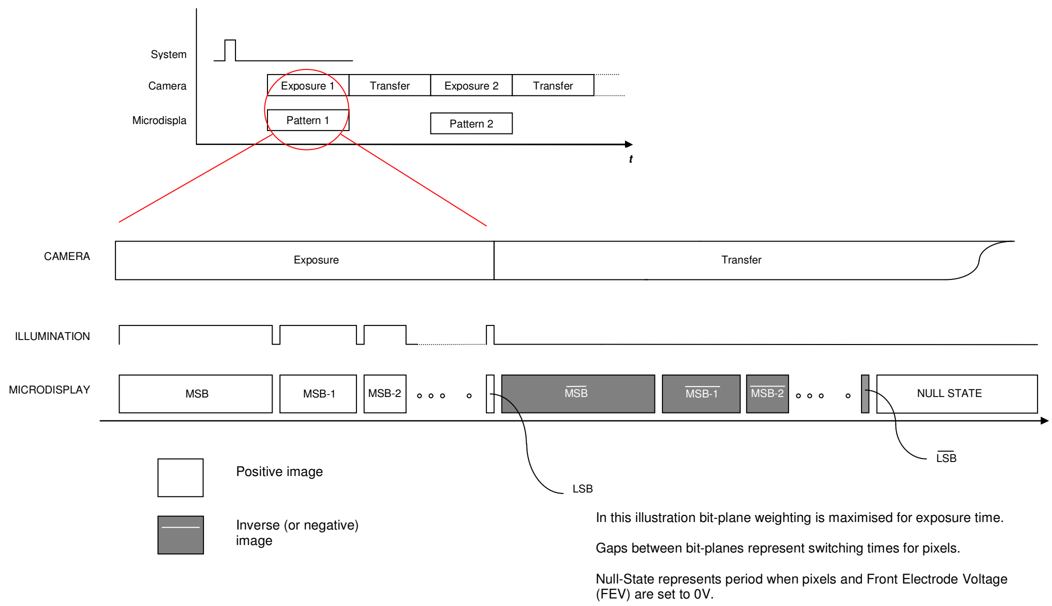

Figure 5 ‘Deferred’ sequence structure, where the inverse image is shown **after** the exposure window - useful for 3DM applications

Image frame rate	Exposure Time (+ve image)	Inverse image time (-ve image)
1-bit 60Hz	0.3ms	0.3ms
8-bit 60Hz	2.5ms	2.5ms
10-bit 60Hz	3ms	3ms

Note: The display must be DC balanced (i.e. both +ve and -ve images shown) within a maximum of 100ms.

Table 3 Typical system timings

4 Conclusions

The features of a tailor-made microdisplay solution for 3D optical surface metrology systems have been presented. The optical architectures described offer promising optical performance using solid state light sources. The emphasis on system flexibility allows 3DM manufacturers the freedom to design and integrate other parts of the system around ForthDD's high-performance SXGA-FBS system.

5 Acknowledgements

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6 References

[1] Riehemann, S., Palme, M., Kuehmstedt, P., Notni, G., 'LCoS based Projection Systems for Optical Metrology'. *SID 2003 Digest* 256 – 259