Application Report
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Development of DLP3030-Q1 and DLP553x-Q1 qualified DMDs for automotive applications

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ABSTRACT

Abstract: The DLP® chip or digital micromirror device (DMD) developed by Texas Instruments (TI) has evolved tremendously in both performance and reliability since it was first invented in 1987. Customers have used DLP technology to create thousands of commercial products across a myriad of industries, including the automotive space. Refinement of the design, process, and test capabilities resulted in automotive DMDs that pass all required tests and are now qualified devices for the automotive industry. This paper provides insights into some of the quality processes and tests that helped solve unique challenges related to DMDs used in automotive applications.

Keywords: DMD; micromirror; DLP technology; HUD; high resolution headlights; quality; reliability; MEMS; head-up display; automotive qualification; DLP3000-Q1; DLP3030-Q1; DLP5530-Q1; DLP5531-Q1

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1 Introduction

TI invented the DMD in 1987 and since its commercial introduction, a variety of projector applications have used DMDs including digital cinemas, conference rooms, classrooms, home theaters, large venues, and pico displays [1]. DLP technology, with its high speed and multiple wavelength compatibility, is also being leveraged in industrial use cases such as 3D scanners, 3D printers, sensing solutions, and more. DLP Products have over 20 years of experience manufacturing and testing DMDs used in a multitude of applications. Digital cinema projectors requiring very high brightness, therefore high thermal loads, for long periods are an example where DMDs have demonstrated robust performance capability. The strong reputation for high quality displays, maturity of the technology, and TI's experience supplying integrated circuits to the automotive industry led to the decision to develop DMDs for automotive applications.

2 DMD Overview

The DMD is a MEMS-based spatial light modulator. It consists of an array of aluminum micromirrors fabricated on top of an underlying CMOS memory array (Figure 1). Each mirror is individually addressable and lands ±12° (Figure 2). When integrated into an optical system (Figure 3 and Figure 4), each landed mirror either reflects light into the projection optics or away from the projection optics. This creates an array of ON (bright) and OFF (dark) pixels. In an optical system such as this, the DMD is a digital light switch. It can use virtually any light source including lamps, LEDs, laser phosphor, and direct laser. Due to its inherently fast switching speed, the optical system can create color images by time sequencing the mirrors with a time-sequenced color source such as a color wheel, LEDs, or lasers.

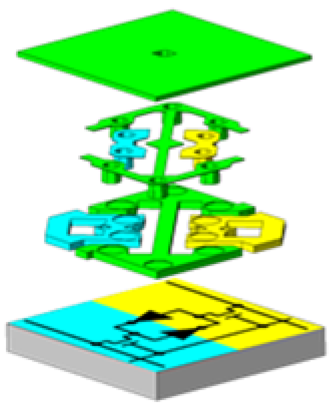

Figure 1. Illustration of a DMD micromirror

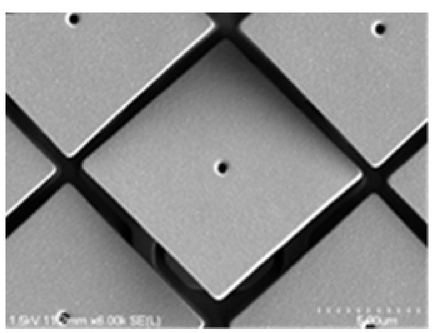

Figure 2. Top down view of a landed mirror

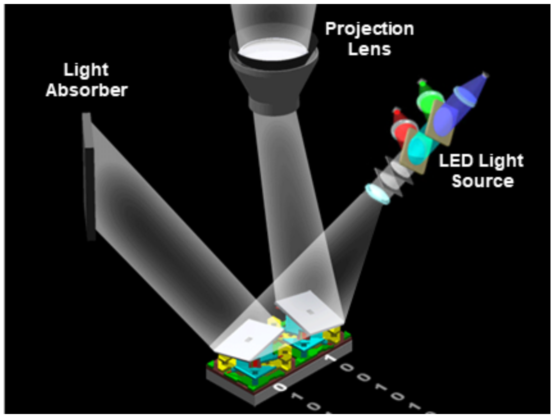

Figure 3. DMD mirrors reflect light from any source (lamp, LEDs, lasers)

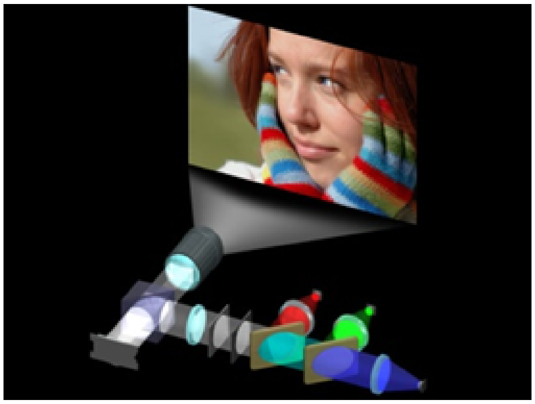

Figure 4. DMD in an LED-based optical system

3 The use of DMDs in Automotive Applications

Using DLP technology in an automotive display is a natural fit. It has the right size, resolution, image performance, and brightness capability desirable for automotive applications.

DLP technology supports augmented reality head-up displays (HUDs) with wide 10- by 5-degree field of views (FOV) or greater. The excellent solar load performance of DLP technology supports long virtual image distances of 10 meters or more, projecting full color images and animated graphics that appear to float out over the road in front of the vehicle. One of the primary applications for an augmented reality display is to display Advanced Driver Assistance Systems (ADAS) information that could significantly improve the driving experience [2].

DLP technology offers high resolution with more than one million addressable pixels. In a headlight application, this exceeds the resolution of existing adaptive driving beam (ADB) technologies by more than 10,000 times. Designers can use this new programmable ADB solution to develop headlight systems that maximize brightness for drivers on the road while minimizing the glare of oncoming traffic or reflections from high-gloss traffic signs. The technology works with any light source including LED and laser illumination allowing precise control of light distribution on the road with customizable beam patterns. Since the system has the capability to partially or fully dim individual pixels, designers can develop high-resolution headlight systems that allow drivers to keep their high beams on while operating their vehicle in sub-par conditions [3].

4 DMD Quality and Reliability Development

Since the early days of DMD development, accelerated life testing has been a key analysis component. Performing a failure mode and effects analysis (FMEA) to identify potential failure mechanisms has been a standard practice for all new micromirror devices. The goals of the FMEA are to assess potential risk mechanisms, determine if those risks might affect the device during its expected operation time, and identify accelerated test conditions to highlight each mechanism for faster learning. Each FMEA item was appropriately addressed to reduce their respective risk level. The following paragraphs provide examples of some interesting FMEA items [4].

Hinge Fatigue: Early in the development of the DMD, a potential failure mechanism addressed was hinge fatigue. This is the idea that if the mirrors continuously turned on and off, that eventually the hinge would bend or break. Although there was no evidence of this being a problem, tests were designed to explore it. To test if there was a hinge fatigue mechanism, several DMDs started on an accelerated life test in December 1995 and have continuously operated since then. Over 23 years (and 10 trillion ON/OFF cycles) later, they are still operating without signs of hinge fatigue. Although these results may seem surprising at first, they are easily explained. Metal fatigue models assume stresses build up between grain structures. The DMD hinge is a thin-film metal that does not have a grain structure like bulk metals do. Therefore, the stresses dissipate along the surface, not between grains. TI confirmed this phenomenon during early DMD development [5].

Mechanical Integrity: Since the mirrors are small, the FMEA suggested mechanical integrity concerns, specifically resulting from shock and vibration. Accelerated shock and vibration testing confirmed that the micromirrors are mechanically robust. Similar to the discussion about hinge fatigue above, the explanation is quite simple. Since the mirrors are so small, the resonant frequency of the mirrors is in the range of 100 kHz to 2000 kHz. Therefore, the mirrors are unaffected during normal handling, assembly and operation where frequencies are typically < 2000 Hz, well below the device resonance.

5 DMD Qualification for Automotive Applications

In order to evaluate if the DMD was capable of meeting automotive quality and reliability requirements, TI called on its vast and historical DMD knowledge. Existing data was compared to typical automotive specifications. Leveraging a mature package node (“Type-A”) and a mature chip technology (DLP3000 DMD), TI created a design capable of meeting performance and environmental automotive requirements.

Although this well-known display device was more commonly found in consumer goods, it was determined that some process enhancements and expanded DMD qualification tests provided a path for meeting automotive specifications. Some examples include statistical process controls (SPC) to tighten process distributions, modified equipment to reduce variability, new tests and inspections to screen weak parts, and some minor design changes. In parallel, standard qualification tests and conditions were reviewed and sample quantities adjusted as necessary to meet the intent of the automotive requirements. As TI performed each test, the device proved to be mechanically and environmentally robust for an automotive application.

The DLP3000-Q1 (Figure 5, left side) is a 0.3" micromirror array with over 400,000 mirrors. It was the first DMD that completed all required development, qualification, and production tests for automotive applications. Reference [6] describes the development process and results of the DLP3000-Q1 in more detail.

Although the DLP3000-Q1 DMD was qualified for automotive applications, the operating temperature range was limited to the equivalent of an AEC-Q100 Grade 3. TI set a goal to design a DMD capable of meeting the equivalent of an AEC-Q100 Grade 2 with an operating temperature range of –40°C to +105°C. The next generation package and process resulted in DMDs with the desired capability. Figure 5 (center) is a photo of the DLP3030-Q1 DMD that uses the same micromirror array as the DLP3000-Q1 in a hermetic wafer-level package. Figure 5 (right side) is a photo of the DLP553x-Q1 DMD with a larger micromirror array (0.55”, 1.3 million mirrors) in the same hermetic wafer-level package.

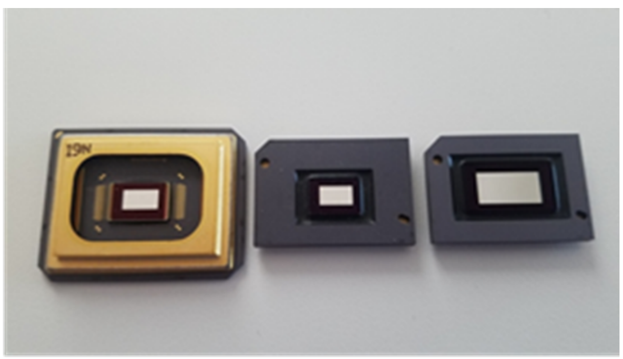

Figure 5. DLP3000-Q1 (left) as compared to the new DLP3030-Q1 (center) and DLP553x-Q1 (right)

The DMD Qualification Test Plan was modified to better match the test methods, test requirements, and quantities required by AEC-Q100, the automotive specification for qualification of integrated circuits. As an example, standard DMD test conditions require stress conditions for variable frequency vibration at 20-g peak acceleration and stress conditions for constant acceleration at 10-kg force. Since AEC-Q100 requires 50-g peak acceleration and 20-kg force, respectively, automotive DMDs were tested at the more stressful conditions and passed. The outline of some of the tests successfully completed is included in Table 1. The DMDs passed all the required environmental and operating tests and are therefore rated for –40°C to +105°C array operating temperature at full performance (i.e. no performance derating).

Table 1. Outline of some automotive qualification tests completed for the DLP3030-Q1 and DLP553x-Q1 DMDs

Test Category	Tests	Conditions
Accelerated Environment Stress Tests	Unbiased HAST	110°C/85% RH, 264 hrs
	Temperature Cycling	–55°C/125°C, 1000 cyc
	Power Temp Cycling	–40°C/105°C, 1000 cyc
	High Temp Storage	125°C, 1000 hrs
	Low Temp Storage	–40°C, 1000 hrs
Accelerated Lifetime Tests	High Temp Operating	105°C, 1000 hrs
Package Assembly Integrity	Wire Bond Shear Wire	Standard
	Bond Pull	Standard
Cavity Package Integrity	Mechanical Shock	1500 g, 0.5 ms
	Vibration	50 g, 20 to 2000 Hz
	Acceleration	20,000 g
	Fine/Gross Leak	Standard
	Package Drop	Standard
	Die Shear/Pull	Standard
Electrical Verification	ESD	HBM, CDM
	Electrical Distribution	Per data sheet
	Characterization	Per data sheet

Tests such as temperature cycling, mechanical shock, vibration, wire bond pull and ESD are performed the same way for a DMD as they are for a standard integrated circuit. These tests are consistent with the expectations of semiconductors used in the automotive industry. The conditions for operational tests can be unique due to the nature of the MEMS element. The mirror operation tests are rigorous and designed to mimic how the customers utilize the DMD in an application.

6 Production Part Approval Process

The automotive industry has specific requirements for suppliers. TI and DLP Products are fully compliant with ISO 9001:2015 and IATF 16949 requirements. Certificates are available on www.ti.com. ISO and IATF certification requires organizations to have a Production Part Approval Process (PPAP) recognized by customers. Qualification plans and summaries are standard elements of a PPAP. The Automotive Industry Action Group (AIAG) identifies additional elements. These PPAP elements include design FMEAs, process FMEAs, process flow diagrams, control plans, measurement system analysis studies, material performance test results, and records of compliance with customer specific requirements. Multiple submission levels refine the content of the PPAP to meet a customer's specific needs.

The FMEA process, in particular, is central to the automotive mindset. Its primary purpose is to identify risks and develop action plans during the development of an automotive device. In the case of DMD development for use in automotive applications, multiple FMEAs were evaluated and periodically updated to ensure appropriate measures were implemented. The FMEA process identified and addressed reliability mechanisms specific to the DMD. This resulted in the release-to-market of automotive-grade DMDs.

7 Automotive Experience

Texas Instruments has a long history as a supplier of semiconductor parts to the automotive market. Devices developed using best practices with mature wafer technologies and package types meet automotive customers' stringent quality requirements. The linear biCMOS technology upon which the DMD is built is one such mature technology node. High volumes of automotive semiconductors have been delivered from this same process node over a period of more than 15 years from multiple TI fabrication facilities around the world. The base wafer process upon which the automotive DMD is built is well proven in the field.

TI regularly releases high quality devices to automotive production. Still, automotive is a journey, and TI's automotive new product development process continues to be refined. Regular improvements to the development process combined with innovation in automotive process and packaging technology has increased the rate of new product introduction. In recent years, research and development investments in automotive products have steadily increased resulting in 19% of all TI revenue coming from the automotive market in 2017.

Today, TI has a broad and deep portfolio of 6000 automotive qualified devices. Figure 6 shows the four main market sectors for which TI supplies automotive grade semiconductors.

Figure 6. TI innovation focuses on four applications sectors

8 Conclusion: Automotive DMD

For more than twenty years, the long-term reliability of the DMD has been demonstrated across diverse consumer products as well as more demanding use cases such as digital cinema and industrial equipment. With this field history established, the time was right to leverage TI's best practices for the development of automotive ICs and make DLP technology available for use in automotive Head-Up Displays, high-resolution headlights, and other applications. The goal achieved is an automotive DMD with the expected level of quality and reliability that automotive customers demand.

The first automotive DMD (DLP3000-Q1) met the desired requirements and was released to market in April 2015. The next generation automotive DMDs (DLP3030-Q1 and DLP553x-Q1) using advanced packaging technologies completed qualification and were released to market in early 2018.

9 References

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