IMPORTANT NOTICE

BEFORE USING TECHNICAL INFORMATION, THE USER SHOULD CAREFULLY READ THE FOLLOWING TERMS.

The term “Technical Information” includes reference designs, drawings, specifications, and other information relating to TI DLP® products or applications, contained herein or provided separately in any format or via any medium.

TI is providing Technical Information for the convenience of purchasers of DLP® products (“Users”), and will not accept any responsibility or liability arising from providing the Technical Information or its use. Any use or reliance on Technical Information is strictly the responsibility of the User.

1. **No Warranty.** *THE TECHNICAL INFORMATION IS PROVIDED “AS IS”.* TI MAKES NO WARRANTIES OR REPRESENTATIONS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING LACK OF VIRUSES, ACCURACY, OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO THE TECHNICAL INFORMATION OR THE USE OF THOSE MATERIALS.

2. **Warranty for Products Not Affected.** The foregoing exclusion and disclaimer of warranty does not affect or diminish any warranty rights with regard to DLP® products. Such rights are governed exclusively by the terms of a written and signed purchase agreement with TI.

3. **Limitations and Exclusion of Damages.** IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF THE TECHNICAL INFORMATION OR THE USE OF THE TECHNICAL INFORMATION.

4. **No Engineering Services.** User is fully responsible for all design decisions and engineering with regard to its products, including decisions relating to application of DLP® products. By providing Technical Information TI does not intend to offer or provide engineering services or advice concerning User’s design. If User desires engineering services, then User should rely on its retained employees and consultants and/or procure engineering services from a licensed professional engineer (“LPE”).

5. **Compliance with Export Control Laws.** Unless prior authorization is obtained from the U.S. Department of Commerce, User may not export, re-export, or release, directly or indirectly, any Technical Information, or export, directly or indirectly, any direct product of such Technical Information to any destination or country to which the export, re-export or release of the Technical Information or direct product is prohibited by the Export Administration Regulations of the U.S. Department of Commerce (“EAR”).
<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
<th>Section</th>
<th>Summary Of Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3/31/2009</td>
<td>All</td>
<td>Initial Release ECO2096636</td>
</tr>
</tbody>
</table>

Table 1. Revision History
1. Reliability Overview

There are numerous ways to express how reliable a product is. One of the most common measures is FIT rate (failures in time) and is expressed as “failures per billion (10^9) operating hours.” The inverse of FIT rate is MTBF (mean time between failures) so MTBF = 1/FIT which is expressed as “operating hours between failures.”

It is important to understand that MTBF is not the same as life time. Even though both metrics are expressed in hours, they do not measure the same part of a product’s life. See the “bathtub” curve in Figure 1. FIT (or MTBF) measures the probability of failure for a large group of DMDs (or other components) under normal operating conditions, after they have completed all production testing (segment 1) but before the products start to wear out (segment 3). FIT rate, or MTBF, is a measure of how reliable a component is during its useful life (segment 2).

In other words, if there are 1,000,000 DMDs in the field, the FIT rate will estimate how many will fail within a given period of time for a random failure event. Life time is a measure of how long a component will operate before it reaches wear out or end-of-life (segment 3). Under normal operating conditions, a DMD will operate for >100,000 hours without any wear out failure mechanism.

![Life Characteristics “Bathtub” Curve](image)

**Figure 1 - The classic bathtub curve with 3 distinct segments: (1) early failures, (2) useful life, and (3) wear out or end-of-life.**

2. DMD Reliability Data

2.1 DMD Manufacturing Control and Qualification (see Figure 1, Segment 1)

Each new DMD technology node completes a disciplined development process. Texas Instruments starts with a Failure Modes and Effects Analysis (FMEA) to highlight risk areas. This is followed by comprehensive assessment and characterization testing to understand how robust the product is when operated in its intended application. In parallel, fabrication processes are defined and improved using Statistical Process Control (SPC).

Prior to production ramp, the DMD must complete thorough design verification tests (DVT) and qualification tests which may include life tests (e.g., hot and cold), environmental tests (e.g., thermal, mechanical, moisture resistance), visual inspections (e.g., bond wires and window blemishes), image quality evaluations and functional verifications.

In-line verifications typically include performance testing (e.g., pixel functionality), burn-in (optional short operating test), visual inspections, image quality inspections, and production samples to audit product reliability.

2.2 DMD FIT RATE (see Figure 1, Segment 2)

Texas Instruments continuously reviews field failures reported by DLP® projector customers to estimate the DMD field failure rate. A detailed review, in 2006, of the FTP pixel architecture included the .7XGA and .6SVGA...
devices. Both were 14 micron, 12 degree pixels. As is evident in Table 1, the FIT rate for DMDs with FTP pixels is estimated to be <200 failures per 10^9 hours or an MTBF of >5,000,000 hours between failures. Newer pixel technologies are performing similarly although a detailed study has yet to be completed.

Table 1. DMD FIT Rate

<table>
<thead>
<tr>
<th>Year</th>
<th>FIT Rate (x10^9)</th>
<th>MTBF (hours/fail)</th>
<th>Mirror Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>&lt;200</td>
<td>&gt;5,000,000</td>
<td>14u, 12 tilt FTP</td>
</tr>
</tbody>
</table>

2.3 DMD Life Time (see Figure 1, Segment 3)
Numerous accelerated life tests have confirmed that DMD life time correlates well to operating temperature. With proper system thermal design approaches, it is likely that most systems will never experience a DMD wear out. A secondary factor that correlates to life time is mirror duty cycle…what percent of the time a mirror is turned ON as compared to how long it is turned OFF.

Life time can be increased dramatically by lowering the temperature and/or periodically cycling the mirrors (thus reducing the duty cycle). It is also important to note that the definition of failure is typically assumed to be a DMD with 2 or more added defects. If the system is more resistant to nonfunctional mirrors then the life time is also much greater.

Some applications where lifetime has been estimated include:
- Data projectors: DMD temperature typically 60-65C and high duty cycle; DMD lifetime typically >10,000 hours. This translates to 10 years of operation for typical conference room projectors.
- HDTVs: DMD temperature typically 45-50C and low duty cycle; DMD lifetime typically >60,000 hours. This many hours translates to over 10 years for typical consumer TV applications.
For other applications, contract a DLP distributor or a TI Applications Engineer.

2.4 DMD Life Tests
TI has performed tests that have confirmed the DMD is robust over time. For example, 9 DMDs have been continuously operating on an accelerated test since December 1995. As of December 2008, these 9 DMDs had accumulated over 108,000 operating hours and over 5.7 trillion mirror cycles. This is equivalent to nearly 400,000 normal operating hours. This test confirms that hinges do not break and mirrors remain functional for very long periods of time.

Several life tests (both hot and cold) have been extended to over 10,000 hours with no added defects. This includes several projector and TV tests that have completed over 10,000 hours with no defects or degradation. Obviously each application is different and results may vary depending on design constraints and product requirements.

2.5 Digital lifetime

It is important to note in the above discussion that the digital nature of the DMD is what separates it from other spatial light modulators. One of the advantages that the DMD has over analog technologies is the exceptional stability of its image quality over time as measured by indices such as color uniformity, contrast ratio, and white point. This is an inherent characteristic of the DMD. Because the DMD operates in a digital mode, it is not sensitive to the analog changes in its structure that may develop until those changes reach a level that cause a switching failure or defect.

Since the operational profile for each system differs, the design approach should comprehend how a DMD functions over that operational profile and the number of defects the system can tolerate. When designing a system based on DLP technology, design it in such a way that at the end of its expected lifetime under the harshest of operating conditions.
conditions, there is still operating margin to spare. So instead of “failing gracefully” like analog technologies, the DMD will not fail at all throughout the defined operational profile.

3. Application Examples

3.1 Diverse Applications
The DMD is a spatial light modulator with an ever-expanding number of diverse applications. There are 3 major application families:
- Projection
- Wavelength Selection
- Sensing

Within these families, DLP technology is uniquely suited to address many opportunities such as: maskless direct imaging, rapid prototyping, volumetric displays, spectroscopy, hyper-spectral imaging, optical networking, 3-D metrology, biometrics, etc. What makes this possible is the DMDs capability to:
- Process and modulate light
- Operate in a broad spectrum (UV, IR, and Visible)
- Exhibit extremely fast switching time
- Provide very high resolution mirror arrays

3.2 DLP Projection Technology: The Digital Solution
To illustrate the digital nature, and the inherent benefits, of DLP technology, the following section explores a typical projection application. For example, in both theory and practice, DLP® technology does not experience image degradation or color decay over time. The Digital Micromirror Device (DMD) is a spatial light modulator that creates the image in a projector based on DLP® technology.

For a single-chip projector, each pixel (picture element) in the image corresponds to a single mirror. The mirrors turn ON and OFF like a digital switch. When a mirror is ON, it reflects light through a projection lens creating a pixel on the projection screen. When a mirror is OFF, it reflects light away from the projection lens creating a dark pixel on the projection screen. To create a brighter pixel, the corresponding mirror is turned ON more than it is turned OFF. Conversely, to create a darker pixel, the corresponding mirror is turned OFF more than it is turned ON. To create a grayscale image, each mirror in the array is turned ON or OFF at the appropriate duty cycle so that the array shows an image with a continuum of bright-to-grey-to-dark pixels. Regardless of the grey level of each pixel, the micromirror creating that pixel is only turning ON or OFF, thus it is truly digital.

An important aspect of the DLP digital technology is the reflectivity of the DMD. Since the pixels are created by reflecting light off the micromirrors, and since the micromirrors have a constant reflectivity (roughly 92%), the brightness of each projected pixel is constant. This means that as a projector ages, the micromirrors will still reflect 92% of the light that hits them. For lamp-based projection systems, the lamp itself can degrade over time but once it is replaced, the projected image will be just as bright as it was when it was brand new because the micromirrors are still reflecting 92% of the light.

To create color in a DLP projector, designers can use LEDs (or other solid-state light sources such as lasers) or a rotating color wheel. The projector manufacturer determines the initial color performance by mixing and adjusting the colors in their factory. DLP projectors create colors digitally in the same manner as the grayscale images described above. If a blue pixel is desired, the corresponding micromirror is turned ON when the blue LED is ON (or the blue filter rotates in front of the light) and it is turned OFF while the other LEDs are on (or the other color filters are in front of the light.) This results in a blue pixel projecting on the projection screen. For a bright blue pixel, the micromirror is ON the entire time the light is blue. For a dimmer blue pixel, the micromirror is ON for part of the blue illumination time and OFF for the rest of the blue illumination time. For a purple pixel, the corresponding micromirror is ON while the blue and red lights are on and turned OFF for the remainder of the time. In this manner, millions of different color combinations are available by turning micromirrors ON or OFF at different duty cycles and at different times during the color illumination.
3.2.1 Comparison of Digital Technology to Analog Technology

Resulting from the discussion above, the color integrity therefore, is defined by three variables:

1. The reflectivity of the micromirrors – aluminum mirror surface remains constant at ~92% (in the visible spectrum) throughout the life of a DMD.
2. The amount of time the micromirrors are ON and OFF at any given time interval – mirrors are controlled digitally to within several microseconds similar to other digital technologies.
3. The robustness of the color illumination – LED color output is stable and the color wheel filter material does not degrade or change color over time, light exposure, heat and use.

As is evident from the stability of these 3 factors, DLP technology provides a solution that is inherently robust.

3.2.2 Factors Contributing to Instability of Analog Light Modulating Technologies

Other technologies use organic elements to transmit light, analog modulating structures, and 3 independent color filters. This results in an inherently unstable color system.

1. Organic elements degrade when exposed to light and heat therefore they transmit a different amount of light over time.
2. Analog structures control light throughput by modulating how much light gets through. As the analog elements degrade, the ability to control the light throughput also degrades.
3. With three independent color filters, when one light modulator starts to degrade, the entire mix of colors changes resulting in a color shift over time and often a blotchy look as different parts of a modulator degrade at a different rate.

4. Guidelines for high reliability

To assure high reliability and long life time, the following should be considered:

- Lower temperature will extend life time
- Lower mirror duty cycle will extend life time
- Avoid prolonged exposure to very high (>70C) or very low (<0C) temperatures
- Avoid prolonged exposure to high levels of UV unless the device has been certified for UV applications
- Avoid operating at high UV and high temperature for any length of time

5. Limitations

The DMD is not presently qualified for medical (life-sustaining) applications, space applications, military (ITAR) applications, automotive applications, or applications with exposure to extreme high or low temperature.

6. For Further Research and Reference

