TEXAS INSTRUMENTS
DLP5531A-Q1
DLPS182 – FEBRUARY 2022

# DLP5531A-Q1 0.55-Inch 1.3-Megapixel DMD for Automotive Exterior Lighting

## 1 Features

- Qualified for automotive applications
  - –40°C to 105°C operating DMD array temperature range
- The DLP5531A-Q1 automotive chipset includes:
  - DLP5531A-Q1 DMD
  - DLPC230-Q1 DMD controller
  - TPS99001-Q1 system management and illumination controller
- 0.55-inch diagonal micromirror array
  - 7.6-µm micromirror pitch
  - ±12° micromirror tilt angle (relative to flat state)
  - Bottom illumination for optimal efficiency and optical engine size
  - 1.3-megapixel array configured in 2:1 aspect ratio enabling high resolution and wide aspect ratio automotive applications
  - Compatible with LED or laser illumination
- 600-MHz sub-LVDS DMD interface for low power and emission
- 10-kHz DMD refresh rate over temperature extremes
- Built-in self test of DMD memory cells

## 2 Applications

- High resolution headlight
- LIDAR optical filter

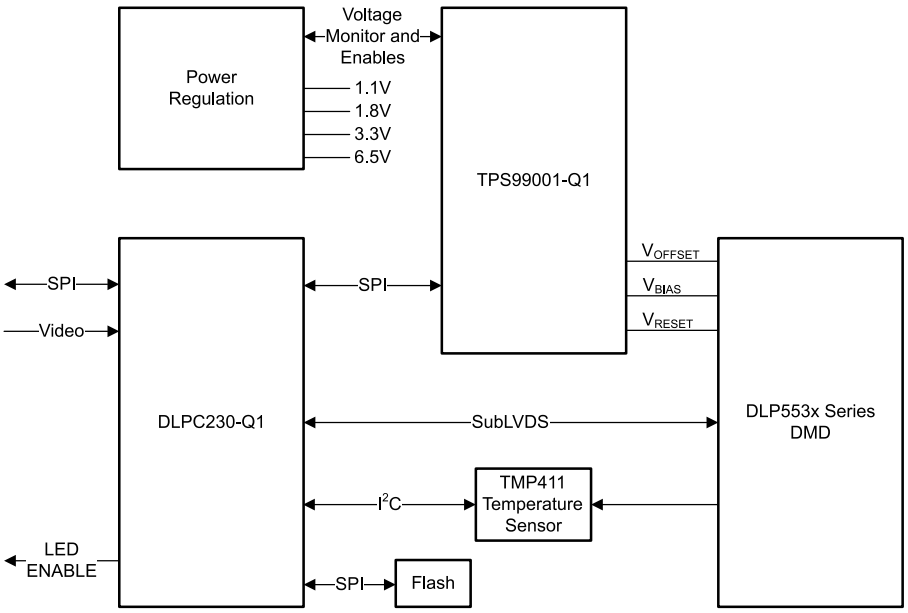
## 3 Description

The DLP5531A-Q1 automotive DMD, combined with the DLPC230-Q1 DMD controller and TPS99001-Q1 system management and illumination controller, provides the capability to achieve high performance high resolution headlight systems. The 2:1 aspect ratio supports very wide aspect ratio designs, and the 1.3-MP resolution enables high resolution symbol projection and adaptive driving beam applications. The DLP5531A-Q1 has more than 3 times the optical throughput of the preceding DLP3030-Q1 automotive DMD enabling an even larger field of view and higher lumens output. The DLP5531A-Q1 automotive DMD micromirror array is configured for bottom illumination which enables highly efficient and more compact optical engine designs. The S450 package has low thermal resistance to the DMD array to enable more efficient thermal solutions.

**Device Information**

| PART NUMBER | PACKAGE(1) (2) | BODY SIZE (NOM) |
|---|---|---|
| DLP5531A-Q1 | FYS (149) | 22.30 mm × 32.20 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.
(2) This data sheet pertains to the specifications and application of this DMD in the headlight application. Please see the DLP5530A-Q1 data sheet (DLPS181) for head-up display specifications and application information.




**DLP5531A-Q1 DLP® Chipset System Block Diagram**

An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

# Table of Contents

**1 Features**....1
**2 Applications**....1
**3 Description**....1
**4 Revision History**....2
**5 Pin Configuration and Functions**....3
**6 Specifications**....8
6.1 Absolute Maximum Ratings....8
6.2 Storage Conditions....8
6.3 ESD Ratings....8
6.4 Recommended Operating Conditions....9
6.5 Thermal Information....10
6.6 Electrical Characteristics....10
6.7 Timing Requirements....11
6.8 Switching Characteristics....14
6.9 System Mounting Interface Loads....15
6.10 Physical Characteristics of the Micromirror Array....15
6.11 Micromirror Array Optical Characteristics....17
6.12 Window Characteristics....17
6.13 Chipset Component Usage Specification....17
**7 Detailed Description**....18
7.1 Overview....18
7.2 Functional Block Diagram....18
7.3 Feature Description....19
7.4 System Optical Considerations....20
7.5 DMD Image Performance Specification....22
7.6 Micromirror Array Temperature Calculation....22
7.7 Micromirror Landed-On/Landed-Off Duty Cycle....25
**8 Application and Implementation**....26
8.1 Application Information....26
8.2 Typical Application....26
**9 Power Supply Recommendations**....30
9.1 Power Supply Power-Up Procedure....30
9.2 Power Supply Power-Down Procedure....30
9.3 Power Supply Sequencing Requirements....31
**10 Layout**....32
10.1 Layout Guidelines....32
**11 Device and Documentation Support**....33
11.1 Device Support....33
11.2 Receiving Notification of Documentation Updates....33
11.3 Support Resources....33
11.4 Trademarks....33
11.5 Electrostatic Discharge Caution....34
11.6 DMD Handling....34
11.7 Glossary....34
**12 Mechanical, Packaging, and Orderable Information**....34

## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| DATE | REVISION | NOTES |
|---|---|---|
| February 2022 | * | Initial Release |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# 5 Pin Configuration and Functions

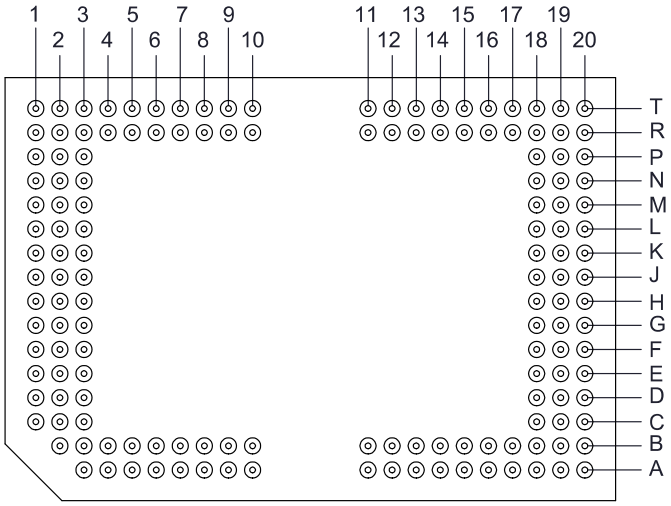


**Figure 5-1. FYS Package**
**149-Pin CPGA**
**Bottom View**

**Pin Functions - Connector Pins**

| PIN | | TYPE | SIGNAL | DATA RATE | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO. | | | | |
| **DATA INPUTS** | | | | | |
| D_AN(0) | L2 | I | SubLVDS | Double | Data, Negative |
| D_AN(1) | K2 | I | SubLVDS | Double | Data, Negative |
| D_AN(2) | J2 | I | SubLVDS | Double | Data, Negative |
| D_AN(3) | H2 | I | SubLVDS | Double | Data, Negative |
| D_AN(4) | F2 | I | SubLVDS | Double | Data, Negative |
| D_AN(5) | E2 | I | SubLVDS | Double | Data, Negative |
| D_AN(6) | D2 | I | SubLVDS | Double | Data, Negative |
| D_AN(7) | C2 | I | SubLVDS | Double | Data, Negative |
| D_AP(0) | L1 | I | SubLVDS | Double | Data, Positive |
| D_AP(1) | K1 | I | SubLVDS | Double | Data, Positive |
| D_AP(2) | J1 | I | SubLVDS | Double | Data, Positive |
| D_AP(3) | H1 | I | SubLVDS | Double | Data, Positive |
| D_AP(4) | F1 | I | SubLVDS | Double | Data, Positive |
| D_AP(5) | E1 | I | SubLVDS | Double | Data, Positive |
| D_AP(6) | D1 | I | SubLVDS | Double | Data, Positive |
| D_AP(7) | C1 | I | SubLVDS | Double | Data, Positive |
| D_BN(0) | K19 | I | SubLVDS | Double | Data, Negative |
| D_BN(1) | J19 | I | SubLVDS | Double | Data, Negative |
| D_BN(2) | H19 | I | SubLVDS | Double | Data, Negative |
| D_BN(3) | G19 | I | SubLVDS | Double | Data, Negative |
| D_BN(4) | E19 | I | SubLVDS | Double | Data, Negative |
| D_BN(5) | D19 | I | SubLVDS | Double | Data, Negative |
| D_BN(6) | C19 | I | SubLVDS | Double | Data, Negative |
| D_BN(7) | B19 | I | SubLVDS | Double | Data, Negative |

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**Pin Functions - Connector Pins (continued)**

| PIN | | TYPE | SIGNAL | DATA RATE | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO. | | | | |
| D_BP(0) | K20 | I | SubLVDS | Double | Data, Positive |
| D_BP(1) | J20 | I | SubLVDS | Double | Data, Positive |
| D_BP(2) | H20 | I | SubLVDS | Double | Data, Positive |
| D_BP(3) | G20 | I | SubLVDS | Double | Data, Positive |
| D_BP(4) | E20 | I | SubLVDS | Double | Data, Positive |
| D_BP(5) | D20 | I | SubLVDS | Double | Data, Positive |
| D_BP(6) | C20 | I | SubLVDS | Double | Data, Positive |
| D_BP(7) | B20 | I | SubLVDS | Double | Data, Positive |
| DCLK_AN | G2 | I | SubLVDS | Double | Clock, Negative |
| DCLK_AP | G1 | I | SubLVDS | Double | Clock, Positive |
| DCLK_BN | F19 | I | SubLVDS | Double | Clock, Negative |
| DCLK_BP | F20 | I | SubLVDS | Double | Clock, Positive |
| LS_CLKN | R3 | I | SubLVDS | Single | Clock for Low Speed Interface, Negative |
| LS_CLKP | T3 | I | SubLVDS | Single | Clock for Low Speed Interface, Positive |
| LS_WDATAN | R2 | I | SubLVDS | Single | Write Data for Low Speed Interface, Negative |
| LS_WDATAP | T2 | I | SubLVDS | Single | Write Data for Low Speed Interface, Positive |
| **CONTROL INPUTS** | | | | | |
| DMD_DEN_ARSTZ | T10 | I | LPSDR | | Asynchronous Reset Active Low. Logic High Enables DMD. |
| LS_RDATA_A | T5 | O | LPSDR | Single | Read Data for Low Speed Interface |
| LS_RDATA_B | T6 | O | LPSDR | Single | Read Data for Low Speed Interface |
| **TEMPERATURE SENSE DIODE** | | | | | |
| TEMP_N | P1 | O | | | Calibrated temperature diode used to assist accurate temperature measurements of DMD die. |
| TEMP_P | N1 | I | | | |
| **RESERVED PINS** | | | | | |
| VCCH | A8 | Ground | | | Reserved Pin. Connect to Ground. |
| VCCH | A9 | Ground | | | |
| VCCH | A10 | Ground | | | |
| VCCH | B8 | Ground | | | |
| VCCH | B9 | Ground | | | |
| VCCH | B10 | Ground | | | |
| VSSH | A11 | Ground | | | Reserved Pin. Connect to Ground. |
| VSSH | A12 | Ground | | | |
| VSSH | A13 | Ground | | | |
| VSSH | B11 | Ground | | | |
| VSSH | B12 | Ground | | | |
| VSSH | B13 | Ground | | | |


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**Pin Functions - Connector Pins (continued)**

| PIN | | TYPE | SIGNAL | DATA RATE | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO. | | | | |
| **POWER** | | | | | |
| VBIAS | T7 | Power | | | Supply voltage for positive bias level at micromirrors. |
| VBIAS | T15 | Power | | | |
| VOFFSET | T9 | Power | | | Supply voltage for High Voltage CMOS core logic. Supply voltage for offset level at micromirrors. |
| VOFFSET | T13 | Power | | | |
| VOFFSET | A5 | Power | | | |
| VOFFSET | B5 | Power | | | |
| VOFFSET | A16 | Power | | | |
| VOFFSET | B16 | Power | | | |
| VRESET | T8 | Power | | | Supply voltage for negative reset level at micromirrors. |
| VRESET | T14 | Power | | | |
| VDD | R4 | Power | | | Supply voltage for Low Voltage CMOS core logic; for LPSDR inputs; for normal high level at micromirror address electrodes. |
| VDD | R10 | Power | | | |
| VDD | R11 | Power | | | |
| VDD | R20 | Power | | | |
| VDD | N2 | Power | | | |
| VDD | M20 | Power | | | |
| VDD | L3 | Power | | | |
| VDD | K18 | Power | | | |
| VDD | H3 | Power | | | |
| VDD | G18 | Power | | | |
| VDD | E3 | Power | | | |
| VDD | D18 | Power | | | |
| VDD | C3 | Power | | | |
| VDD | A6 | Power | | | |
| VDD | A18 | Power | | | |
| VDDI | T4 | Power | | | Supply voltage for SubLVDS receivers. |
| VDDI | R1 | Power | | | |
| VDDI | M3 | Power | | | |
| VDDI | L18 | Power | | | |
| VDDI | J3 | Power | | | |
| VDDI | H18 | Power | | | |
| VDDI | F3 | Power | | | |
| VDDI | E18 | Power | | | |
| VDDI | B3 | Power | | | |
| VDDI | B18 | Power | | | |

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**Pin Functions - Connector Pins (continued)**

| PIN | | TYPE | SIGNAL | DATA RATE | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO. | | | | |
| VSS | T1 | Ground | | | Common return. Ground for all power. |
| VSS | T16 | Ground | | | |
| VSS | T19 | Ground | | | |
| VSS | T20 | Ground | | | |
| VSS | R5 | Ground | | | |
| VSS | R6 | Ground | | | |
| VSS | R7 | Ground | | | |
| VSS | R8 | Ground | | | |
| VSS | R9 | Ground | | | |
| VSS | R13 | Ground | | | |
| VSS | R14 | Ground | | | |
| VSS | R15 | Ground | | | |
| VSS | P2 | Ground | | | |
| VSS | P3 | Ground | | | |
| VSS | P20 | Ground | | | |
| VSS | N19 | Ground | | | |
| VSS | N20 | Ground | | | |
| VSS | M1 | Ground | | | |
| VSS | M2 | Ground | | | |
| VSS | L19 | Ground | | | |
| VSS | L20 | Ground | | | |
| VSS | K3 | Ground | | | |
| VSS | J18 | Ground | | | |
| VSS | G3 | Ground | | | |
| VSS | F18 | Ground | | | |
| VSS | D3 | Ground | | | |
| VSS | C18 | Ground | | | |
| VSS | B2 | Ground | | | |
| VSS | B4 | Ground | | | |
| VSS | B15 | Ground | | | |
| VSS | B17 | Ground | | | |
| VSS | A3 | Ground | | | |
| VSS | A4 | Ground | | | |
| VSS | A7 | Ground | | | |
| VSS | A15 | Ground | | | |
| VSS | A17 | Ground | | | |
| VSS | A19 | Ground | | | |
| VSS | A20 | Ground | | | |


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**Pin Functions - Test Pads**

| NUMBER | SYSTEM BOARD |
|---|---|
| T11 | Do not connect |
| T12 | Do not connect |
| T17 | Do not connect |
| T18 | Do not connect |
| R12 | Do not connect |
| R16 | Do not connect |
| R17 | Do not connect |
| R18 | Do not connect |
| R19 | Do not connect |
| P18 | Do not connect |
| P19 | Do not connect |
| N3 | Do not connect |
| N18 | Do not connect |
| M18 | Do not connect |
| M19 | Do not connect |
| B6 | Do not connect |
| B7 | Do not connect |
| B14 | Do not connect |
| A14 | Do not connect |

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# 6 Specifications

## 6.1 Absolute Maximum Ratings

see (1)

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| **SUPPLY VOLTAGE** | | | | | |
| VDD | Supply voltage for LVCMOS core logic<br>Supply voltage for LPSDR low speed interface | –0.5 | | 2.3 | V |
| VDDI | Supply voltage for SubLVDS receivers | –0.5 | | 2.3 | V |
| VOFFSET | Supply voltage for HVCMOS and micromirror electrode | –0.5 | | 8.75 | V |
| VBIAS | Supply voltage for micromirror electrode | –0.5 | | 17 | V |
| VRESET | Supply voltage for micromirror electrode | –11 | | 0.5 | V |
| \| VDDI–VDD \| | Supply voltage delta (absolute value) | | | 0.3 | V |
| \| VBIAS–VOFFSET \| | Supply voltage delta (absolute value) | | | 8.75 | V |
| \| VBIAS–VRESET \| | Supply voltage delta (absolute value) | | | 28 | V |
| **INPUT VOLTAGE** | | | | | |
| Input voltage for other inputs LPSDR | | –0.5 | | VDD + 0.5 | V |
| Input voltage for other inputs SubLVDS | | –0.5 | | VDDI + 0.5 | V |
| **INPUT PINS** | | | | | |
| $\lvert V_{ID} \rvert$ | SubLVDS input differential voltage (absolute value) | | | 810 | mV |
| $I_{ID}$ | SubLVDS input differential current | | | 10 | mA |
| **TEMPERATURE DIODE** | | | | | |
| $I_{TEMP_DIODE}$ | Max current source into temperature diode | | | 120 | µA |
| **ENVIRONMENTAL** | | | | | |
| $ILL_{OVERFILL}$ | Illumination overfill maximum heat load in area shown in Figure 6-1 | | | 37 | $mW/mm^2$ |
| $T_{ARRAY}$ | Operating DMD array temperature | –40 | | 105 | °C |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device is not implied at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure above or below the *Recommended Operating Conditions* for extended periods may affect device reliability.

## 6.2 Storage Conditions

Applicable for the DMD as a component or non-operating in a system.

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| $T_{stg}$ | DMD storage temperature | –40 | 125 | °C |

## 6.3 ESD Ratings

| | | | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human body model (HBM), per AEC Q100-002(1) | ±2000 | V |
| | | Charged device model (CDM), per AEC Q100-011 | ±750 | |

(1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.


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## 6.4 Recommended Operating Conditions

Over operating free-air temperature range (unless otherwise noted)(1)

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| **SUPPLY VOLTAGE RANGE** | | | | | |
| VDD | Supply voltage for LVCMOS core logic<br>Supply voltage for LPSDR low-speed interface | 1.7 | 1.8 | 1.95 | V |
| VDDI | Supply voltage for SubLVDS receivers | 1.7 | 1.8 | 1.95 | V |
| VOFFSET | Supply voltage for HVCMOS and micromirror electrode | 8.25 | 8.5 | 8.75 | V |
| VBIAS | Supply voltage for mirror electrode | 15.5 | 16 | 16.5 | V |
| VRESET | Supply voltage for micromirror electrode | –9.5 | –10 | –10.5 | V |
| \| VDDI–VDD \| | Supply voltage delta (absolute value) | | | 0.3 | V |
| \| VBIAS–VOFFSET \| | Supply voltage delta (absolute value) | | | 8.75 | V |
| **CLOCK FREQUENCY** | | | | | |
| $f_{max}$ | Clock frequency for low speed interface LS_CLK | | | 120 | MHz |
| $f_{max}$ | Clock frequency for high speed interface DCLK | | | 600 | MHz |
| | Duty cycle distortion DCLK | 44% | | 56% | |
| **SUBLVDS INTERFACE** | | | | | |
| $\lvert V_{ID} \rvert$ | SubLVDS input differential voltage (absolute value)(2) | 150 | 250 | 350 | mV |
| $V_{CM}$ | Common mode voltage (2) | 700 | 900 | 1100 | mV |
| $Z_{LINE}$ | Line differential impedance (PWB/trace) | 90 | 100 | 110 | Ω |
| $Z_{IN}$ | Internal differential termination resistance(3) | 80 | 100 | 120 | Ω |
| **ENVIRONMENTAL** | | | | | |
| $T_{ARRAY}$ | Operating DMD array temperature(5) | –40 | | 105 | °C |
| $ILL_{UV}$ | Illumination, wavelength < 395 nm (4) | | | 2 | mW/cm $^2$ |
| $ILL_{OVERFILL}$ | Illumination overfill maximum heat load in area shown in Figure 6-1 | | | 28 | mW/mm $^2$ |

(1) *Recommended Operating Conditions* are applicable after the DMD is installed in the final product.
(2) See Figure 6-6 and Figure 6-7
(3) See Figure 6-8
(4) The maximum operation conditions for operating temperature and UV illumination shall not be implemented simultaneously.
(5) Operating profile information for device micromirror landed duty-cycle and temperature may be provided if requested.

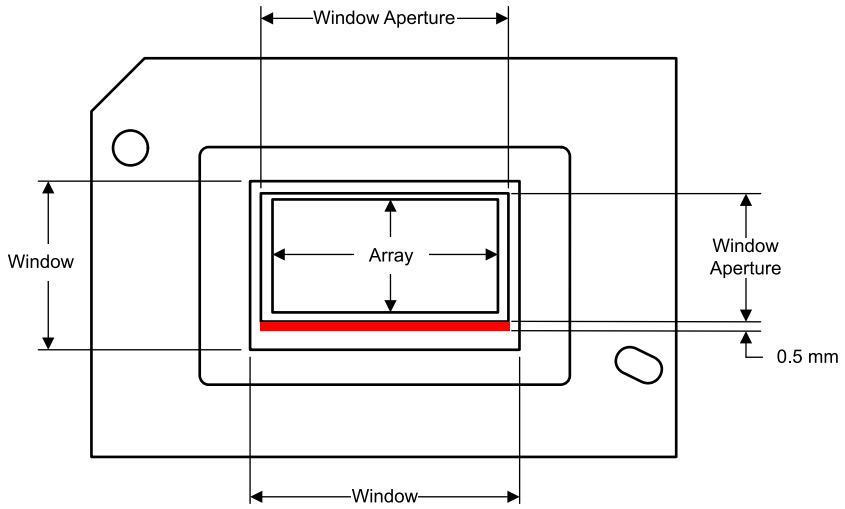


**Figure 6-1. Illumination Overfill Diagram**

## 6.5 Thermal Information

| THERMAL METRIC | | DLP5531A-Q1 FYS (CPGA) 149 PINS | UNIT |
|---|---|---|---|
| Thermal resistance | Active area-to-test point 1 (TP1) (1) (2) | 1.3 | °C/W |
| Thermal resistance | Active area-to-temperature sense diode (1) (2) | 0.8 | °C/W |

(1) The DMD is designed to conduct absorbed and dissipated heat to the back of the package. The cooling system must be capable of maintaining the package within the temperature range specified in Section 6.4. The total heat load on the DMD is largely driven by the incident light absorbed by the active area, although other contributions include light energy absorbed by the window aperture and electrical power dissipation of the array. Optical systems should be designed to minimize the light energy falling outside the window clear aperture since any additional thermal load in this area can significantly degrade the reliability of the device.
(2) The thermal resistance values provided here assumes a non-uniform illumination profile. Refer to Section 7.6 for details.

## 6.6 Electrical Characteristics

Over operating free-air temperature range (unless otherwise noted) (1)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **CURRENT** | | | | | | |
| $I_{DD}$ | Supply current: VDD(2) | VDD = 1.95 V | | | 310 | mA |
| $I_{DDI}$ | Supply current: VDDI(2) | VDDI = 1.95 V | | | 55 | mA |
| $I_{OFFSET}$ | Supply current: VOFFSET | VOFFSET = 8.75 V | | | 6 | mA |
| $I_{BIAS}$ | Supply current: VBIAS | VBIAS = 16.5 V | | | 1 | mA |
| $I_{RESET}$ | Supply current: VRESET | VRESET = -10.5 V | | | -4.5 | mA |
| **POWER** | | | | | | |
| $P_{DD}$ | Supply power dissipation: VDD(2) | VDD = 1.95 V | | | 604.5 | mW |
| $P_{DDI}$ | Supply power dissipation: VDDI(2) | VDDI = 1.95 V | | | 107.25 | mW |
| $P_{OFFSET}$ | Supply power dissipation: VOFFSET | VOFFSET = 8.75 V | | | 52.5 | mW |
| $P_{BIAS}$ | Supply power dissipation: VBIAS | VBIAS = 16.5 V | | | 16.5 | mW |
| $P_{RESET}$ | Supply power dissipation: VRESET | VRESET = -10.5 V | | | 47.25 | mW |
| $P_{TOTAL}$ | Supply power dissipation: Total | | | | 828 | mW |
| **LPSDR INPUT** (3) | | | | | | |
| $V_{IH(DC)}$ | DC input high voltage | | 0.7 × VDD | | VDD + 0.3 | V |
| $V_{IL(DC)}$ | DC input low voltage | | –0.3 | | 0.3 × VDD | V |
| $V_{IH(AC)}$ | AC input high voltage | | 0.8 × VDD | | VDD + 0.3 | V |
| $V_{IL(AC)}$ | AC input low voltage | | –0.3 | | 0.2 × VDD | V |
| $\Delta V_T$ | Hysteresis ($V_{T+} – V_{T–}$) | See Figure 6-9 | 0.1 × VDD | | 0.4 × VDD | V |
| $I_{IL}$ | Low–level input current | VDD = 1.95 V; $V_I$ = 0 V | –100 | | | nA |
| $I_{IH}$ | High–level input current | VDD = 1.95 V; $V_I$ = 1.95 V | | | 300 | nA |
| **LPSDR OUTPUT** (4) | | | | | | |
| $V_{OH}$ | DC output high voltage | $I_{OH}$ = -2mA | 0.8 × VDD | | | V |
| $V_{OL}$ | DC output low voltage | $I_{OL}$ = 2mA | | | 0.2 × VDD | V |
| **CAPACITANCE** | | | | | | |
| $C_{IN}$ | Input capacitance LPSDR | $f$ = 1 MHz | | | 10 | pF |
| | Input capacitance SubLVDS | $f$ = 1 MHz | | | 20 | |
| $C_{OUT}$ | Output capacitance | $f$ = 1 MHz | | | 10 | pF |
| $C_{RESET}$ | Reset group capacitance | $f$ = 1 MHz (1152 X 144 micromirrors) | 350 | 400 | 450 | pF |
| $C_{TEMP}$ | Temperature sense diode capacitance | $f$ = 1 MHz | | | 20 | pF |

(1) Device electrical characteristics are over *Recommended Operating Conditions* unless otherwise noted.
(2) Supply power dissipation based on non–compressed commands and data.
(3) LPSDR input specifications are for pin DMD_DEN_ARSTZ.
(4) LPSDR output specification is for pins LS_RDATA_A and LS_RDATA_B.


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## 6.7 Timing Requirements

Device electrical characteristics are over *Recommended Operating Conditions* unless otherwise noted

| | | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|
| **LPSDR** | | | | | | |
| $t_r$ | Rise slew rate (1) | (20% to 80%) × VDD | 0.25 | | | V/ns |
| $t_f$ | Fall slew rate (1) | (80% to 20%) × VDD | 0.25 | | | V/ns |
| $t_{W(H)}$ | Pulse duration LS_CLK high(3) | 50% to 50% reference points | 0.75 | | | ns |
| $t_{W(L)}$ | Pulse duration LS_CLK low(3) | 50% to 50% reference points | 0.75 | | | ns |
| $t_{su}$ | Setup time(3) | LS_WDATA valid before LS_CLK ↑ or LS_CLK ↓ | 1.5 | | | ns |
| $t_h$ | Hold time(3) | LS_WDATA valid after LS_CLK ↑ or LS_CLK ↓ | 1.5 | | | ns |
| **SubLVDS** | | | | | | |
| $t_r$ | Rise slew rate(2) | 20% to 80% reference points | 0.7 | 1 | | V/ns |
| $t_f$ | Fall slew rate(2) | 80% to 20% reference points | 0.7 | 1 | | V/ns |
| $t_c$ | Cycle time DCLK(3) | | 1.61 | 1.67 | | ns |
| $t_{W(H)}$ | Pulse duration DCLK high(3) | 50% to 50% reference points | 0.75 | | | ns |
| $t_{W(L)}$ | Pulse duration DCLK low(3) | 50% to 50% reference points | 0.75 | | | ns |
| $t_{WINDOW}$ | Window time(3) (4) | Setup time + Hold time | 0.3 | | | ns |
| $t_{LVDS-ENABLE+REFGEN}$ | Power-up receiver(5) | | | | 2000 | ns |

(1) Specification is for DMD_DEN_ARSTZ pin. Refer to LPSDR input rise and fall slew rate in Figure 6-2
(2) See Figure 6-3
(3) See Figure 6-4
(4) See Figure 6-5
(5) Specification is for SubLVDS receiver time only and does not take into account commanding and latency after commanding.

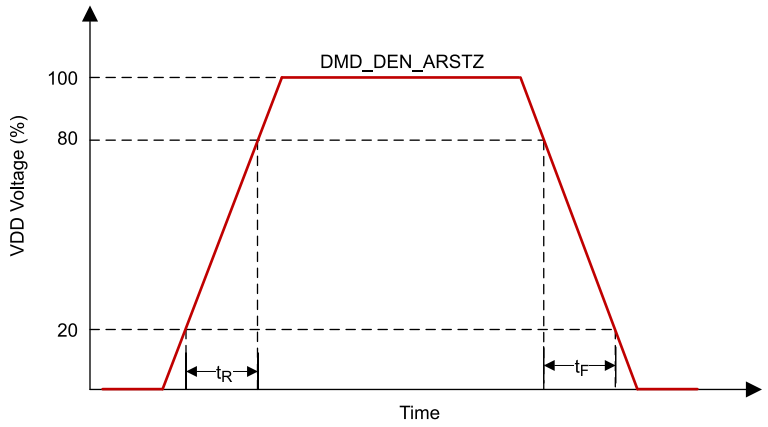



**Figure 6-2. LPSDR Input Rise and Fall Slew Rate**

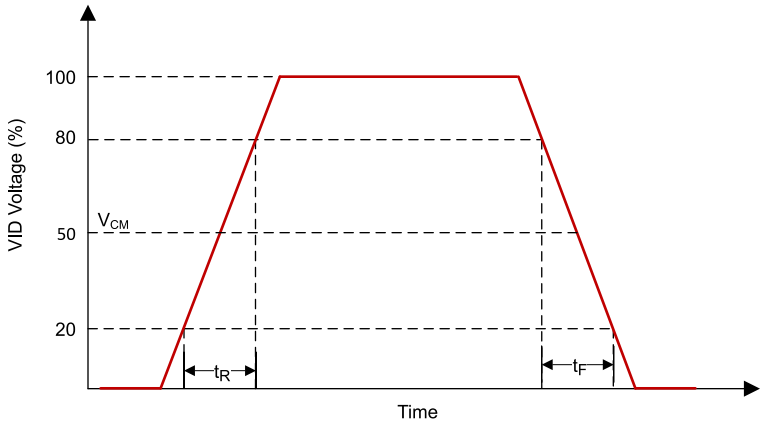



**Figure 6-3. SubLVDS Input Rise and Fall Slew Rate**

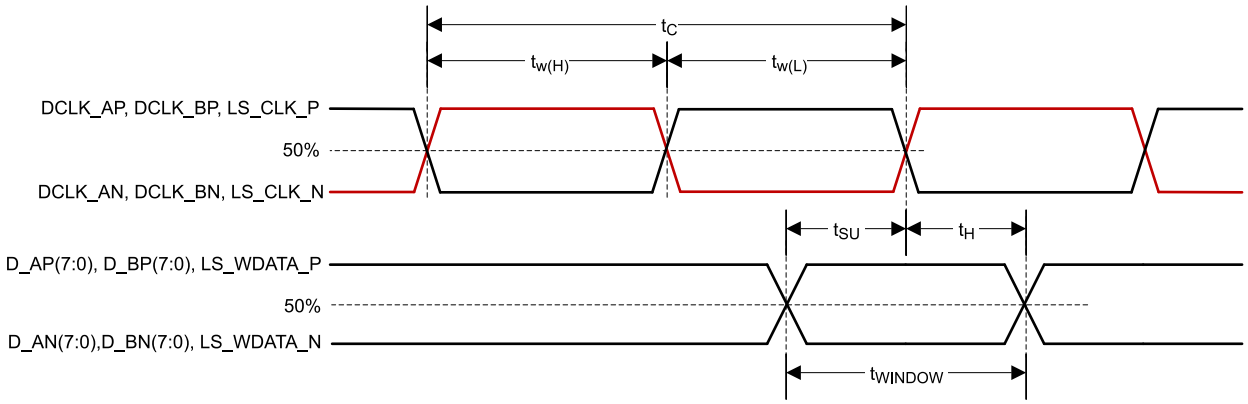
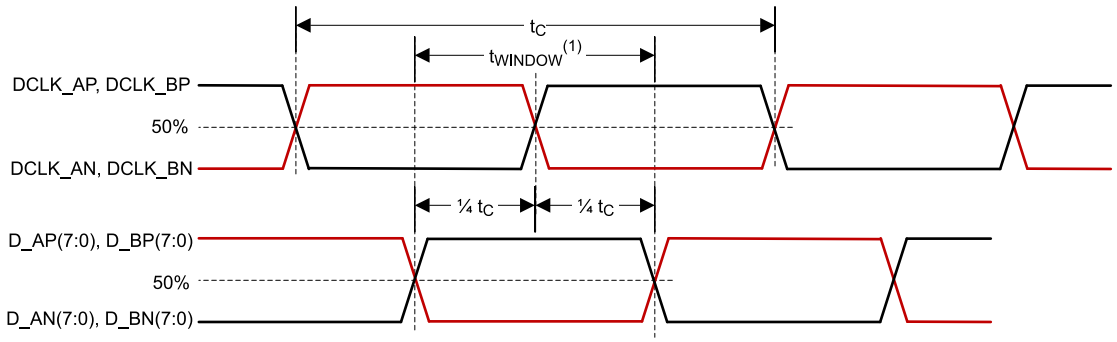



**Figure 6-4. SubLVDS Switching Parameters**




(1) High-speed training scan window

**Figure 6-5. High-Speed Training Scan Window**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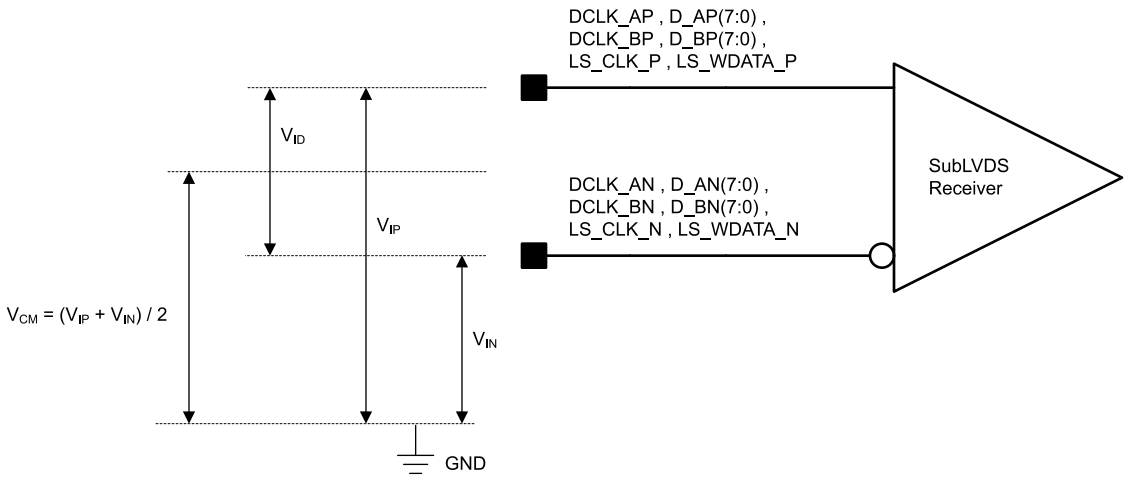


**Figure 6-6. SubLVDS Voltage Parameters**

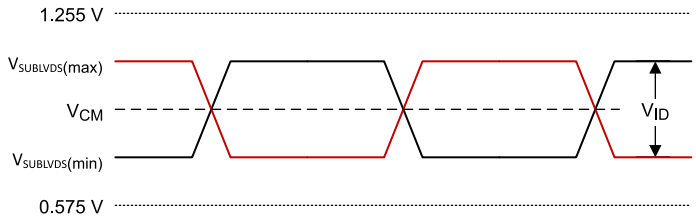


**Figure 6-7. SubLVDS Waveform Parameters**

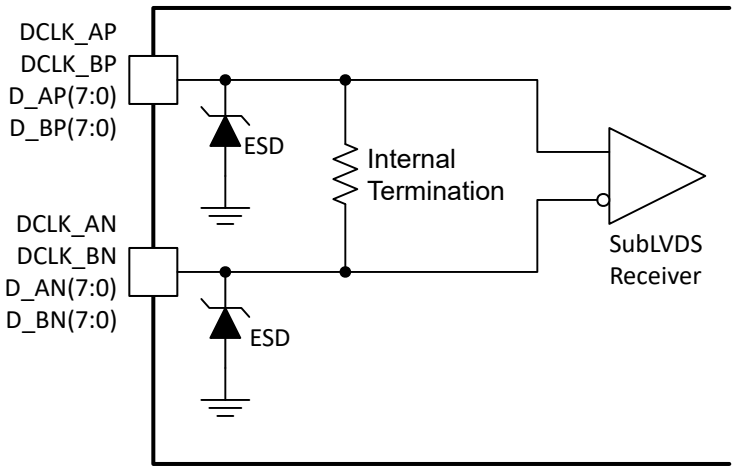


**Figure 6-8. SubLVDS Equivalent Input Circuit**

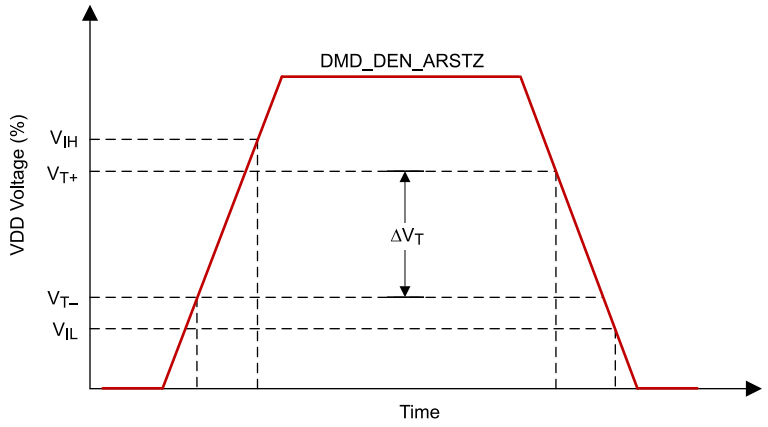


**Figure 6-9. LPSDR Input Hysteresis**

## 6.8 Switching Characteristics

Over operating free-air temperature range (unless otherwise noted)(1)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $t_{PD}$ | Output propagation, clock to Q, rising edge of LS_CLK (differential clock signal) input to LS_RDATA output.(2) | $C_L$ = 45 pF | | | 15 | ns |
| | Slew rate, LS_RDATA | | 0.5 | | | V/ns |
| | Output duty cycle distortion, LS_RDATA_A and LS_RDATA_B | | 40% | | 60% | |

(1) Device electrical characteristics are over Recommended Operating Conditions unless otherwise noted.
(2) See Figure 6-10 and Figure 6-11

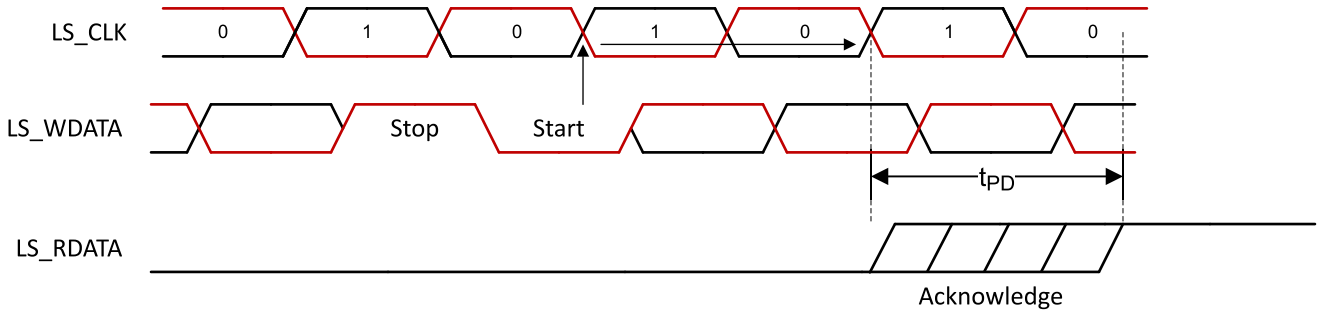


**Figure 6-10. LPSDR Read Out**

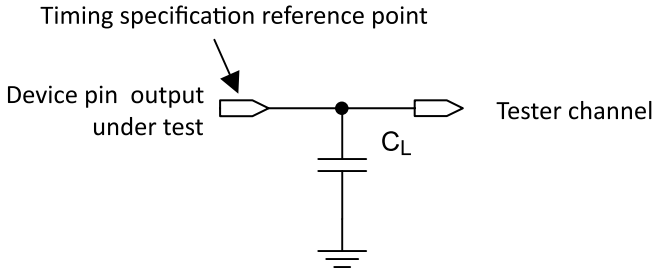


**Figure 6-11. Test Load Circuit for Output Propagation Measurement**


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## 6.9 System Mounting Interface Loads

| PARAMETER | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| Condition 1: Maximum load evenly distributed within each area (1) | | | | | |
| | Thermal Interface Area | | | 110.8 | N |
| | Electrical Interface Area | | | 111.3 | |
| Condition 2: Maximum load evenly distributed within each area (1) | | | | | |
| | Thermal Interface Area | | | 0 | N |
| | Electrical Interface Area | | | 222.1 | |

(1) See Figure 6-12

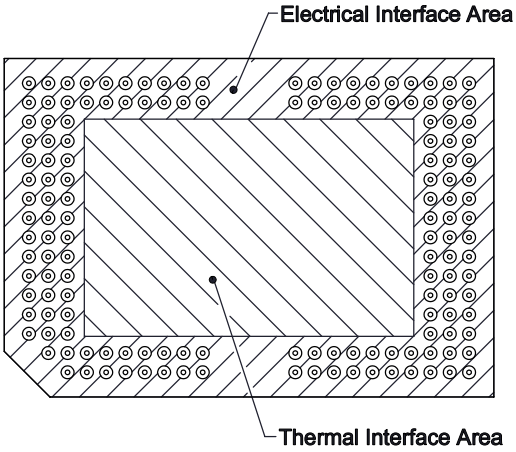


**Figure 6-12. System Interface Loads**

## 6.10 Physical Characteristics of the Micromirror Array

| PARAMETER | | | VALUE | UNIT |
|---|---|---|---|---|
| M | Number of active columns(1) | | 1152 | micromirrors |
| N | Number of active rows(1) | | 1152 | micromirrors |
| ε | Micromirror (pixel) pitch - diagonal(1) | | 7.6 | µm |
| P | Micromirror (pixel) pitch - horizontal and vertical(1) | | 10.8 | µm |
| | Micromirror active array width | (P × M) + (P / 2) | 12.447 | mm |
| | Micromirror active array height | (P x N) / 2 + (P / 2) | 6.226 | mm |
| | Micromirror active border | Pond of micromirrors (POM) (2) | 10 | micromirrors/side |

(1) See Figure 6-13
(2) The structure and qualities of the border around the active array includes a band of partially functional micromirrors called the POM. These micromirrors are structurally and/or electrically prevented from tilting toward the bright or ON state, but still require an electrical bias to tilt toward OFF.

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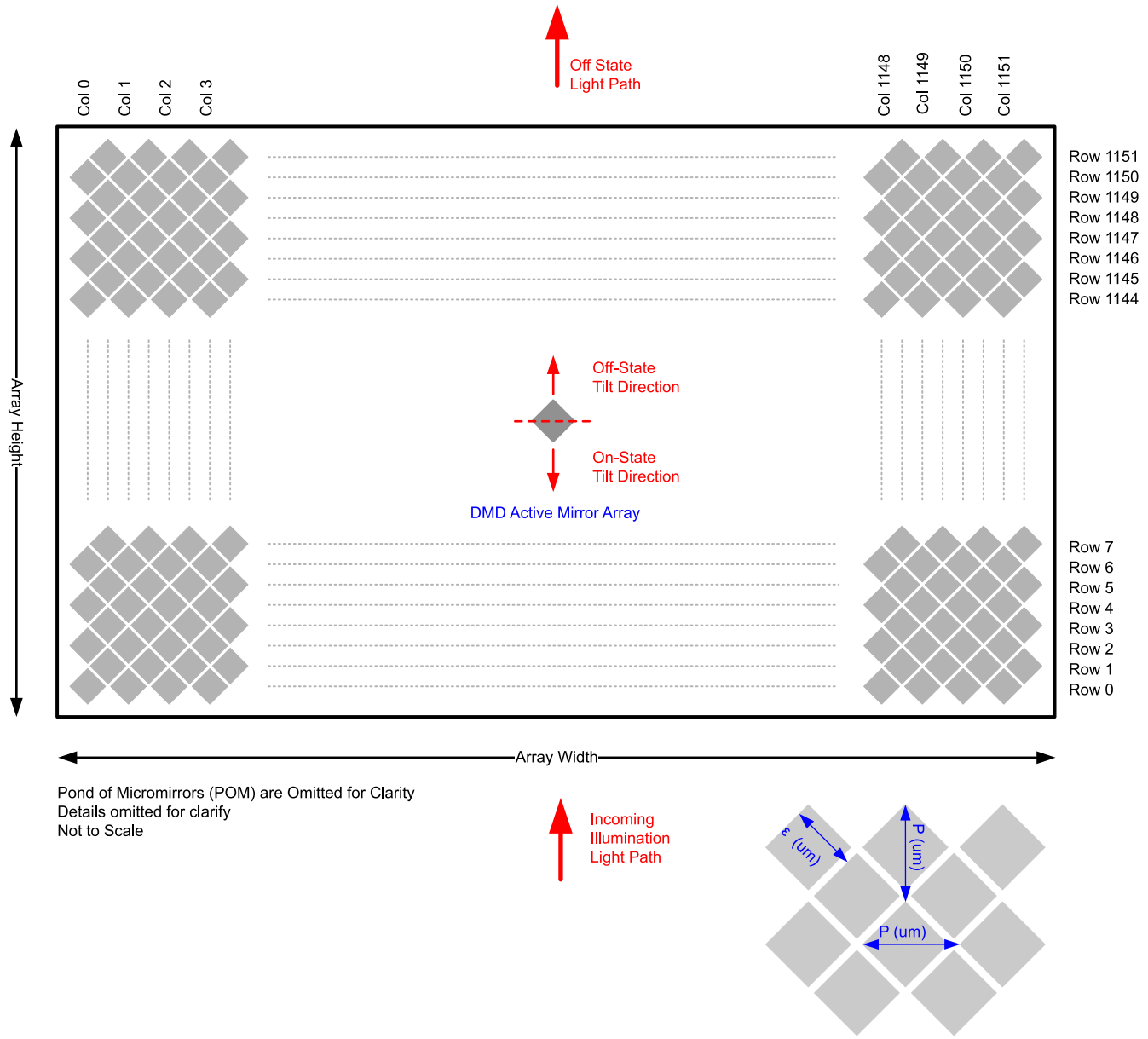


**Figure 6-13. Micromirror Array Physical Characteristics**


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## 6.11 Micromirror Array Optical Characteristics

| PARAMETER | TEST CONDITIONS | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| Micromirror tilt angle | DMD landed state(1) | | 12 | | degree |
| Micromirror tilt angle tolerance(2) | | –1 | | 1 | degree |
| DMD efficiency(3) | 420 nm - 700 nm(4) | | 66% | | |

(1) Measured relative to the plane formed by the overall micromirror array at 25°C.
(2) For some applications, it is critical to account for the micromirror tilt angle variation in the overall optical system design. With some optical system designs, the micromirror tilt angle variation within a device may result in perceivable non-uniformities in the light field reflected from the micromirror array. With some optical system designs, the micromirror tilt angle variation between devices may result in colorimetry variations, system efficiency variations, or system contrast variations.
(3) DMD efficiency is measured photopically under the following conditions: 24° illumination angle, F/2.4 illumination and collection apertures, uniform source spectrum (halogen), uniform pupil illumination, the optical system is telecentric at the DMD, and the efficiency numbers are measured with 100% electronic micromirror landed duty-cycle and do not include system optical efficiency or overfill loss. This number is measured under conditions described above and deviations from these specified conditions could result in a different efficiency value in a different optical system. The factors that can influence the DMD efficiency related to system application include: light source spectral distribution and diffraction efficiency at those wavelengths (especially with discrete light sources such as LEDs or lasers), and illumination and collection apertures (F/#) and diffraction efficiency. The interaction of these system factors as well as the DMD efficiency factors that are not system dependent are described in detail in DLPA083A
(4) A non-operational micromirror is defined as a micromirror that is unable to transition between the on-state and off-state positions.

## 6.12 Window Characteristics

| PARAMETER | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| Window material designation | | | Corning Eagle XG | | |
| Window refractive index | at wavelength 546.1 nm | | 1.5119 | | |
| Window aperture (1) | | | | See (1) | |

(1) See the mechanical package ICD for details regarding the size and location of the window aperture.

## 6.13 Chipset Component Usage Specification

The DLP5531A-Q1 is a component of a chipset. Reliable function and operation of the DLP5531A-Q1 requires that it be used in conjunction with the TPS99001-Q1 and DLPC230-Q1, and includes components that contain or implement TI DMD control technology. TI DMD control technology consists of the TI technology and devices used for operating or controlling a DLP DMD.

**Note**

TI assumes no responsibility for image quality artifacts or DMD failures caused by optical system operating conditions exceeding limits described previously.

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# 7 Detailed Description

## 7.1 Overview

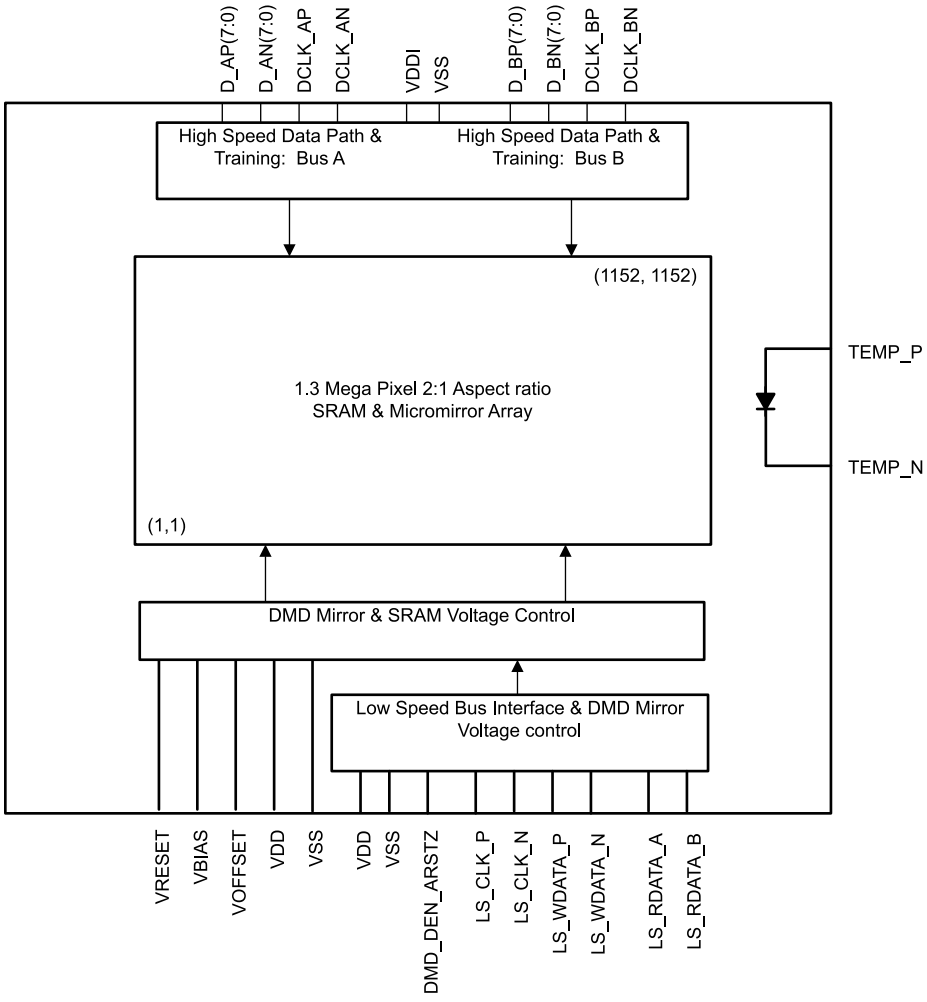
The DLP5531A-Q1 Automotive DMD consists of 1,327,104 highly reflective, digitally switchable, micrometer-sized mirrors organized in a two-dimensional array. As shown in Figure 6-13, the micromirror array consists of 1152 micromirror columns × 1152 micromirror rows in a diamond pixel configuration with a 2:1 aspect ratio.

Around the perimeter of the 1152 × 1152 array of micromirrors is a uniform band of border micromirrors called the Pond of Micromirrors (POM). The border micromirrors are not user-addressable. The border micromirrors land in the –12° position once power has been applied to the device. There are 10 border micromirrors on each side of the 1152 × 1152 active array.

Due to the diamond pixel configuration, the columns of each odd row are offset by half a pixel from the columns of the even row. Each mirror is switchable between two discrete angular positions: –12° and +12°. The mirrors are illuminated from the bottom which allows for compact and efficient system optical design.

Although the native resolution of the DLP5531A-Q1 is 1152 × 1152, when paired with the DLPC230-Q1 controller, the DLP5531A-Q1 can be driven with different resolutions to utilize the 2:1 aspect ratio. For example, Headlight applications typically use a resolution of 1152 × 576. Please see the DLPC230-Q1 automotive DMD controller data sheet (DLPS054) for a list of supported resolutions.

## 7.2 Functional Block Diagram





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## 7.3 Feature Description

The DLP5531A-Q1 consists of a two-dimensional array of 1-bit CMOS memory cells driven by a sub-LVDS bus from the DLPC230-Q1 and powered by the TPS99001-Q1. The temperature sensing diode is used to continuously monitor the DMD array temperature.

To ensure reliable operation the DLP5531A-Q1 must be used with the DLPC230-Q1 DMD display controller and the TPS99001-Q1 system management and illumination controller.

### 7.3.1 Sub-LVDS Data Interface

The Sub-LVDS signaling protocol was designed to enable very fast DMD data refresh rates while simultaneously maintaining low power and low emission.

Data is loaded into the SRAM under each micromirror using the sub-LVDS interface from the DLPC230-Q1. This interface consists of 16 pairs of differential data signals plus two clock pairs into two separate buses A and B loading the left and right half of the SRAM array. The data is latched on both transitions creating a double data rate (DDR) interface. The sub-LVDS interface also implements a continuous training algorithm to optimize the data and clock timing to allow for a more robust interface.

The entire DMD array of 1.3 million pixels can be updated at a rate of less than 100 µs as a result of the high speed sub-LVDS interface.

### 7.3.2 Low Speed Interface for Control

The purpose of the low speed interface is to configure the DMD at power up and power down and to control the micromirror reset voltage levels that are synchronized with the data loading. The micromirror reset voltage controls the time when the mirrors are mechanically switched. The low speed differential interface includes 2 pairs of signals for write data and clock, and 2 single-ended signals for output (A and B).

### 7.3.3 DMD Voltage Supplies

The micromirrors require unique voltage levels to control the mechanical switching from –12° to +12°. These voltage levels are nominally 16 V, 8.5 V, and –10 V (VBIAS, VOFFSET, and VRESET), and are generated by the TPS99001-Q1.

### 7.3.4 Asynchronous Reset

Reset of the DMD is required and controlled by the DLPC230-Q1 via the signal DMD_DEN_ARSTZ.

### 7.3.5 Temperature Sensing Diode

The DMD includes a temperature sensing diode designed to be used with the TMP411 temperature monitoring device. The DLPC230-Q1 monitors the temperature sense diode via the TMP411. The DLPC230-Q1 operation of the DMD timing can be adjusted based on the DMD array temperature, therefore this connection is essential to ensure reliable operation of the DMD.

Figure 7-1 shows the typical connection between the DLPC230-Q1, TMP411, and the DMD.

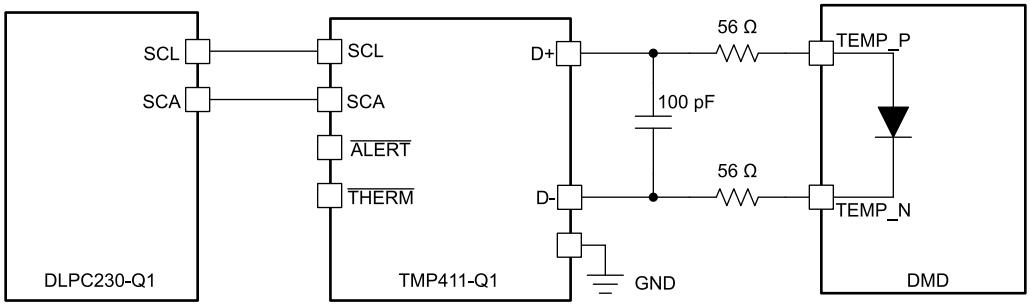


**Figure 7-1. Temperature Sense Diode Typical Circuit Configuration**

#### 7.3.5.1 Temperature Sense Diode Theory

A temperature sensing diode is based on the fundamental current and temperature characteristics of a transistor. The diode is formed by connecting the transistor base to the collector. Three different known currents flow through the diode and the resulting diode voltage is measured in each case. The difference in their base–emitter voltages is proportional to the absolute temperature of the transistor.

Refer to the TMP411-Q1 data sheet for detailed information about temperature diode theory and measurement. Figure 7-2 and Figure 7-3 illustrate the relationships between the current and voltage through the diode.

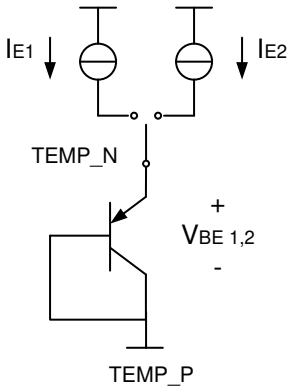


**Figure 7-2. Temperature Measurement Theory**

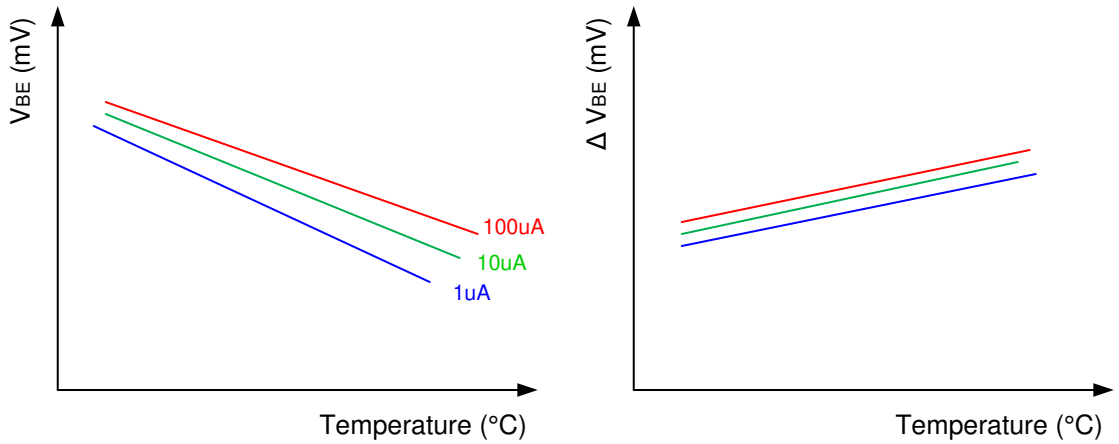


**Figure 7-3. Example of Delta VBE Versus Temperature**

## 7.4 System Optical Considerations

Optimizing system optical performance and image performance strongly relates to optical system design parameter trades. Although it is not possible to anticipate every conceivable application, projector image and optical performance is contingent on compliance to the optical system operating conditions described in the following sections.

### 7.4.1 Numerical Aperture and Stray Light Control

The numerical aperture of the illumination and projection optics at the DMD optical area should be the same. This cone angle defined by the numerical aperture should not exceed the nominal device mirror tilt angle unless appropriate apertures are added in the illumination and/or projection pupils to block out flat-state and stray light from the projection lens. The mirror tilt angle defines the DMD's capability to separate the "On" optical path from any other light path, including undesirable flat-state specular reflections from the DMD window, DMD border structures, or other system surfaces near the DMD such as prism or lens surfaces.


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### 7.4.2 Pupil Match

TI's optical and image performance specifications assume that the exit pupil of the illumination optics is nominally centered and located at the entrance pupil position of the projection optics. Misalignment of pupils between the illumination and projection optics can degrade screen image uniformity and cause objectionable artifacts in the display's border and/or active area. These artifacts may require additional system apertures to control, especially if the numerical aperture of the system exceeds the pixel tilt angle.

### 7.4.3 Illumination Overfill

Overfill light illuminating the area outside the active array can create artifacts from the mechanical features and other surfaces that surround the active array. These artifacts may be visible in the projected image. The illumination optical system should be designed to minimize light flux incident outside the active array and on the window aperture. Depending on the particular system's optical architecture and assembly tolerances, this amount of overfill light on the area outside of the active array may still cause artifacts to be visible.

Illumination light and overfill can also induce undesirable thermal conditions on the DMD, especially if illumination light impinges directly on the DMD window aperture or near the edge of the DMD window. Heat load on the aperture in the areas shown in Figure 6-1 should not exceed the values listed in *Recommended Operating Conditions*. This area is a 0.5-mm wide area the length of the aperture opening. The values listed in *Recommended Operating Conditions* assume a uniform distribution. For a non-uniform distribution please contact TI for additional information.

**Note**

TI ASSUMES NO RESPONSIBILITY FOR IMAGE QUALITY ARTIFACTS OR DMD FAILURES CAUSED BY OPTICAL SYSTEM OPERATING CONDITIONS EXCEEDING LIMITS DESCRIBED PREVIOUSLY.

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## 7.5 DMD Image Performance Specification

**Table 7-1. DMD Image Performance**

| PARAMETER(1) (2) | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|
| Dark Blemishes - Viewed on a linear blue 60 screen.(3) | | | 4 | |
| Light Blemishes - Viewed on a linear gray 10 screen. | | | 4 | |
| Bright Pixels - Viewed on a linear gray 10 screen. | | | 0 | micromirrors |
| Dark Pixels - Viewed on a white screen. | | | 4 | micromirrors |

(1) See the *System Optical Considerations* section.
(2) Blemish counts do not include reflections or shadows of the same artifact. Any artifact that is not specifically called out in this table is acceptable. Viewing distance must be > 60 in. Screen size should be similar to application image size. All values referenced are in linear gamma. Non-linear gamma curves may be running by default, and it should be ensured with a TI applications engineer that the equivalent linear gamma value as specified is used to judge artifacts.
(3) Linear gray 5 may be substituted in monochrome applications.

## 7.6 Micromirror Array Temperature Calculation

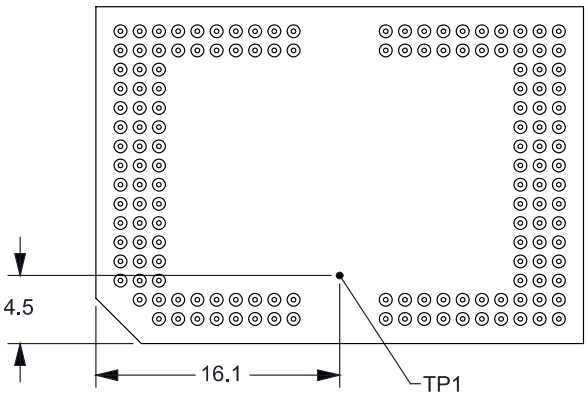


**Figure 7-4. DMD Thermal Test Points**

### 7.6.1 Temperature Rise Through the Package for Heatsink Design

When designing the DMD heatsink solution, the package thermal resistance from array to reference ceramic temperature (thermocouple location TP1 in Figure 7-4) can be used to determine the temperature rise through the package as given by the following equations:

$$T_{ARRAY\text{-}TO\text{-}CERAMIC} = Q_{ARRAY} \times R_{ARRAY–TO–CERAMIC} \quad (1)$$

$$Q_{ILLUMINATION} = (Q_{INCIDENT} \times \text{DMD Absorption Constant}) \quad (2)$$

$$Q_{ARRAY} = Q_{ELECTRICAL} + Q_{ILLUMINATION} \quad (3)$$

where

- $T_{ARRAY\text{-}TO\text{-}CERAMIC}$ = temperature rise from array to thermal test point TP1 (°C/W)
- $T_{CERAMIC}$ = measured ceramic temperature, at the TP1 location in Figure 7-4 (°C)
- $R_{ARRAY–TO–CERAMIC}$ = DMD package thermal resistance from array to thermal test point TP1 (°C/W), see Section 6.5
- $Q_{ARRAY}$ = total power, electrical plus absorbed, on the DMD array (W)
- $Q_{ELECTRICAL}$ = nominal electrical power dissipation by the DMD (W)
- $Q_{ILLUMINATION}$ = absorbed illumination heat load (W)
- $Q_{INCIDENT}$ = incident power on the DMD (W)

The DMD package thermal resistance from array to ceramic ($R_{ARRAY–TO–CERAMIC}$) assumes a non-uniform illumination distribution on the DMD as shown in Figure 7-5. For illumination profiles more uniform than the one highlighted in Figure 7-5, the value provided here is valid. However, for more non-uniform profiles (e.g.


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Gaussian distribution) the thermal resistance will be higher. Please contact TI to determine an accurate value for this case.

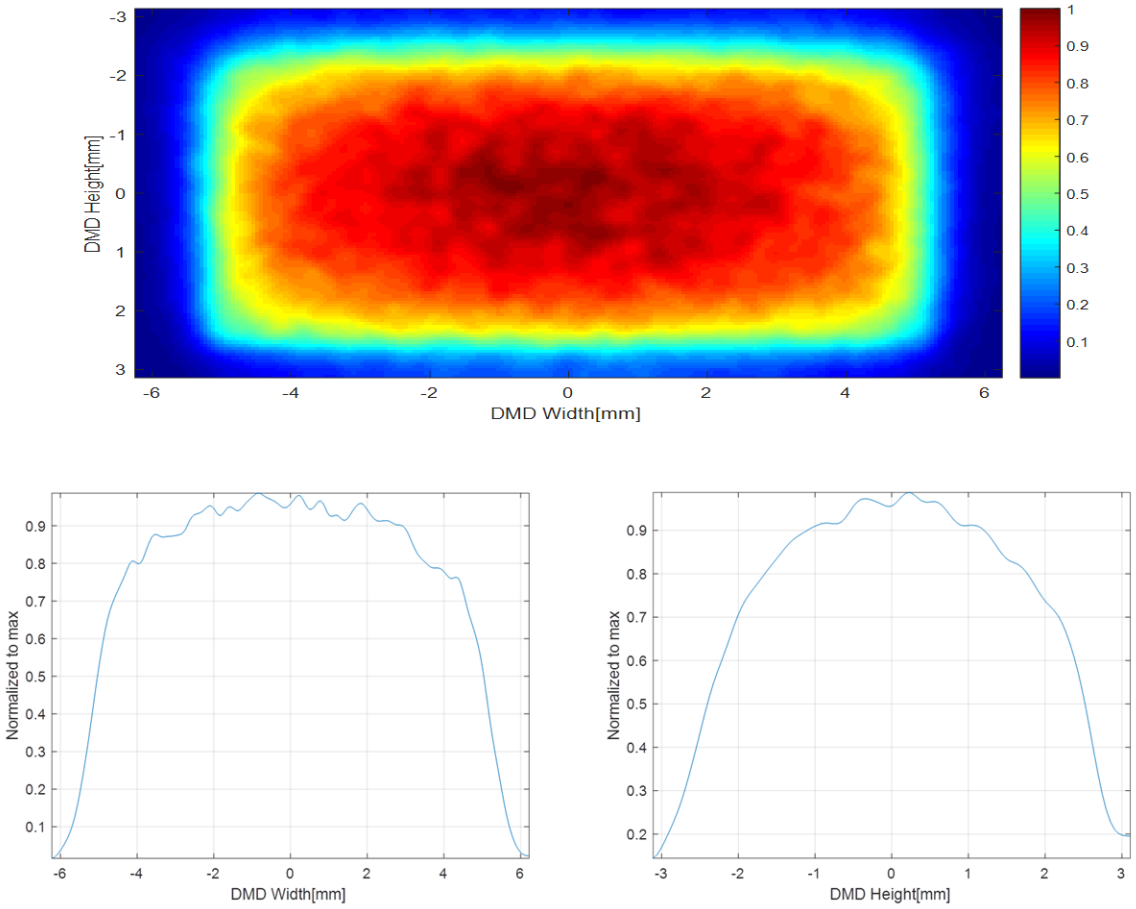


**Figure 7-5. Non-Uniform Illumination Profile**

The DMD absorption constant is a function of illumination distribution on the active array and the array border, angle of incidence (AOI), f number of the system, and operating state of the mirrors. The absorption constant is higher in the OFF state than in the ON state. Equations to calculate the absorption constant are provided for both ON and OFF mirror states. They assume an AOI of 34 degrees, an f/1.7 system, and they account for the distribution of light on the active array, POM, and array border.

$$\text{DMD Absorption Constant (OFF state)} = 0.895 - 0.004783 \times (\%\ \text{of light on ActiveArray + POM}) \quad (4)$$

$$\text{DMD Absorption Constant (ON state)} = 0.895 - 0.007208 \times (\%\ \text{of light on ActiveArray + POM}) \quad (5)$$

Electrical power dissipation of the DMD is variable and depends on the voltages, data rates, and operating frequencies.

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The following sample calculations assume 10% of the total incident light falls outside of the active array and POM, and the mirrors are in the OFF state.

1. DMD Absorption Constant = 0.895 – 0.004783 × 90 = 0.46
2. $Q_{ELECTRICAL}$ = 0.4 W
3. $R_{ARRAY–TO–CERAMIC}$ = 1.3°C/W
4. $Q_{INCIDENT}$ = 10 W
5. $Q_{ARRAY}$ = 0.4 W + (0.46 × 10 W) = 5 W
6. $T_{ARRAY-TO-CERAMIC}$ = 5 W × 1.3°C/W = 6.5°C

### 7.6.2 Monitoring Array Temperature Using the Temperature Sense Diode

The active array temperature can be computed analytically from the temperature sense diode measurement, the thermal resistance from array to diode, the electrical power, and the illumination heat load. The relationship between array temperature and the temperature sense diode is provided by the following equations:

$$T_{ARRAY} = T_{DIODE} + Q_{ARRAY} \times R_{ARRAY–TO–DIODE} \quad (6)$$

$$Q_{ILLUMINATION} = (Q_{INCIDENT} \times \text{DMD Absorption Constant}) \quad (7)$$

$$Q_{ARRAY} = Q_{ELECTRICAL} + Q_{ILLUMINATION} \quad (8)$$

where

- $T_{ARRAY}$ = computed array temperature (°C)
- $T_{DIODE}$ = measured temperature sense diode temperature (°C)
- $R_{ARRAY–TO–DIODE}$ = package thermal resistance from array to diode (°C/W)
- $Q_{ARRAY}$ = total power, electrical plus absorbed, on the DMD array (W)
  Refer to Section 7.6.1 for details
- $Q_{ELECTRICAL}$ = nominal electrical power dissipation by the DMD (W)
- $Q_{ILLUMINATION}$ = absorbed illumination heat load (W)
- $Q_{INCIDENT}$ = incident power on the DMD (W)

The temperature sense diode to array thermal resistance ($R_{ARRAY–TO–DIODE}$) assumes a non-uniform illumination distribution on the DMD as shown in Figure 7-5. For illumination profiles more uniform than the one highlighted in Figure 7-5, the value provided here is valid. However, for more non-uniform profiles (e.g. Gaussian distribution), the thermal resistance will be higher. Please contact TI to determine an accurate value for this case.

The following sample calculations assume 10% of the total incident light falls outside of the active array and POM, and the mirrors are in the OFF state.

1. DMD Absorption Constant = 0.895 – 0.004783 × 90 = 0.46
2. $Q_{ELECTRICAL}$ = 0.4 W
3. $R_{ARRAY–TO–DIODE}$ = 0.8°C/W
4. $Q_{INCIDENT}$ = 10 W
5. $T_{DIODE}$ = 50°C
6. $Q_{ARRAY}$ = 0.4 W + (0.46 × 10 W) = 5 W
7. $T_{ARRAY}$ = 50°C + (5 W × 0.8°C/W) = 54.0°C


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## 7.7 Micromirror Landed-On/Landed-Off Duty Cycle

### 7.7.1 Definition of Micromirror Landed-On/Landed-Off Duty Cycle

The micromirror landed-on/landed-off duty cycle (landed duty cycle) denotes the amount of time (as a percentage) that an individual micromirror is landed in the ON state versus the amount of time the same micromirror is landed in the OFF state.

As an example, a landed duty cycle of 90/10 indicates that the referenced pixel is in the ON state 90% of the time (and in the OFF state 10% of the time), whereas 10/90 would indicate that the pixel is in the OFF state 90% of the time. Likewise, 50/50 indicates that the pixel is ON 50% of the time and OFF 50% of the time.

Note that when assessing landed duty cycle, the time spent switching from one state (ON or OFF) to the other state (OFF or ON) is considered negligible and is thus ignored.

Since a micromirror can only be landed in one state or the other (ON or OFF), the two numbers (percentages) always add to 100.

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# 8 Application and Implementation

**Note**

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

## 8.1 Application Information

The DLP5531A-Q1 chipset is designed to support projection-based automotive applications such as high resolution adaptive driving beam (ADB) headlights.

## 8.2 Typical Application

The chipset consists of three components—the DLP5531A-Q1 automotive DMD, the DLPC230-Q1, and the TPS99001-Q1. The DMD is a light modulator consisting of tiny mirrors that are used to form and project images. The DLPC230-Q1 is a controller for the DMD; it formats incoming video and controls the timing of the DMD illumination sources and the DMD in order to display the incoming video. The TPS99001-Q1 is a high performance voltage regulator for the DMD and a management IC for the entire chipset. In conjunction, the DLPC230-Q1 and the TPS99001-Q1 can be used for system-level monitoring, diagnostics, and failure detection features. Figure 8-1 is a system level block diagram with these devices in the DLP headlight module configuration and displays the primary features and functions of each device.


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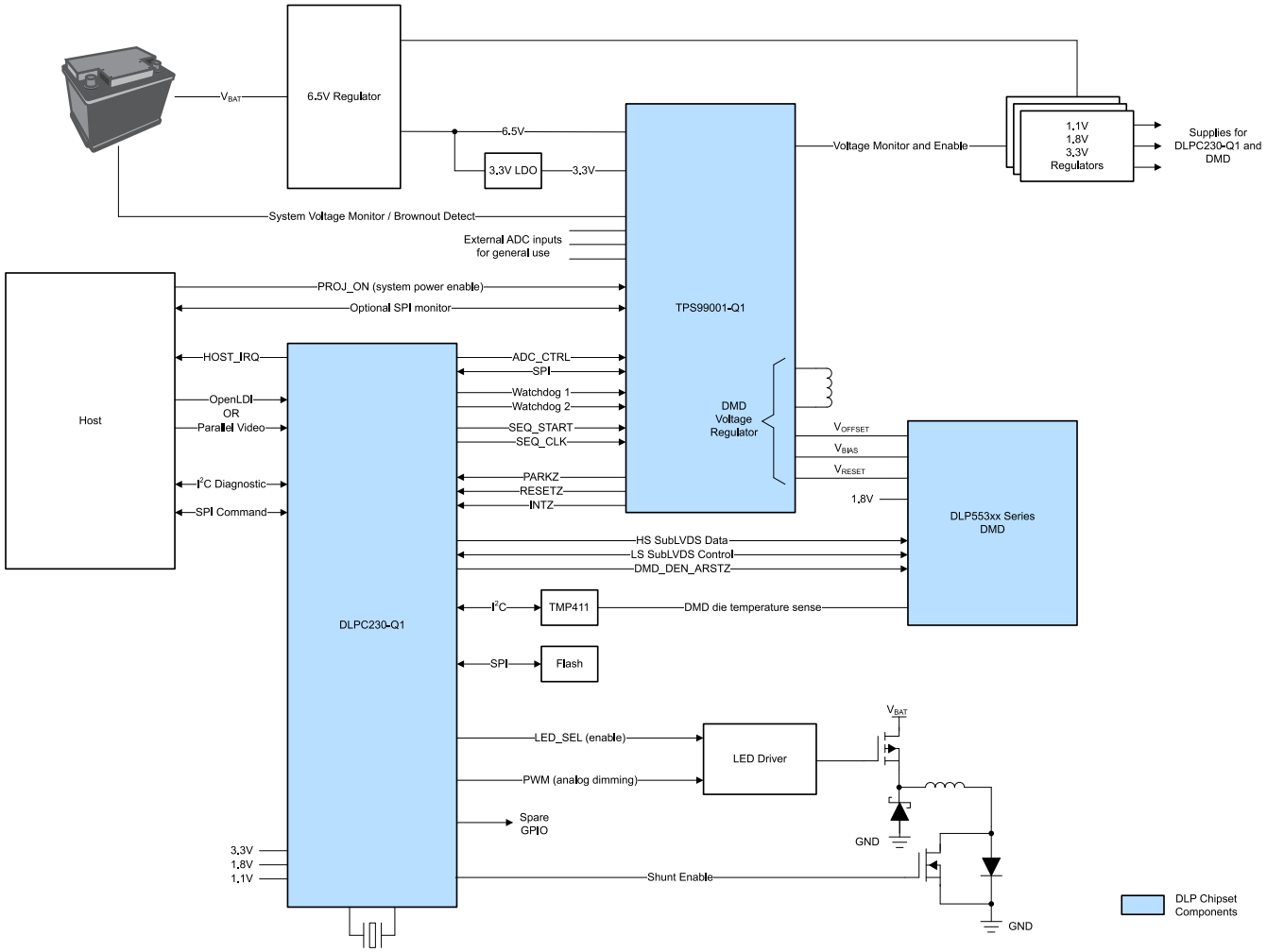


**Figure 8-1. Headlight System Block Diagram**

### 8.2.1 Application Overview

Figure 8-1 shows the system block diagram for a DLP headlight module. The system uses the DLPC230-Q1, TPS99001-Q1, and the DLP5531A-Q1 automotive DMD to enable a headlight projection system with unprecedented resolution and grayscale light control. The combination of the DLPC230-Q1 and TPS99001-Q1 removes the need for external SDRAM and a dedicated microprocessor. The chipset manages the illumination control of LED sources, power sequencing functions, and system management functions. Additionally, the chipset supports numerous system diagnostic and built-in self test (BIST) features. The following paragraphs describe the functionality of the chipset used for a headlight projection system in more detail.

The DLPC230-Q1 is a controller for the DMD and the light sources in the DLP headlight module. It receives input video from the host and synchronizes DMD and light source timing in order to achieve the desired video. The DLPC230-Q1 formats input video data that is displayed on the DMD. It synchronizes these video segments with light source timing in order to create a video with grayscale shading.

The DLPC230-Q1 receives inputs from a host processor in the vehicle. The host provides commands and input video data. Host commands can be sent using either the $I^2C$ bus or SPI bus. The bus that is not being used for host commands can be used as a read-only bus for diagnostic purposes. Input video can be sent over an OpenLDI bus or a parallel 24-bit bus. The 24-bit bus can be limited to only 8-bits of data for single light source systems such as headlights. The SPI flash memory provides the embedded software for the DLPC230-Q1's ARM core, any calibration data, and default settings. The TPS99001-Q1 provides diagnostic and monitoring information to the DLPC230-Q1 using an SPI bus and several other control signals such as PARKZ, INTZ, and RESETZ to manage power-up and power-down sequencing. The TMP411 uses an $I^2C$ interface to provide the DMD array temperature to the DLPC230-Q1.

The outputs of the DLPC230-Q1 are configuration and monitoring commands to the TPS99001-Q1, timing controls to the LED or laser driver, control and data signals to the DMD, and monitoring and diagnostics information to the host processor. The DLPC230-Q1 communicates with the TPS99001-Q1 over an SPI bus. It uses this to configure the TPS99001-Q1 and to read monitoring and diagnostics information from the TPS99001-Q1. The DLPC230-Q1 sends drive enable signals to the LED or laser driver, and synchronizes this with the DMD mirror timing. The control signals to the DMD are sent using a sub-LVDS interface.

The TPS99001-Q1 is a highly integrated mixed-signal IC that controls DMD power, the timing and amplitude of the LEDs or lasers, and provides monitoring and diagnostics information for the DLP headlight module. The power sequencing and monitoring blocks of the TPS99001-Q1 properly power up the DMD and provide accurate DMD voltage rails (–16 V, 8.5 V, and 10 V), and then monitor the system's power rails during operation. The integration of these functions into one IC significantly reduces design time and complexity. The TPS99001-Q1 also has several output signals that can be used to control a variety of LED or laser driver topologies. The TPS99001-Q1 has several general-purpose ADCs that designers can use for system level monitoring, such as over-brightness detection.

The TPS99001-Q1 receives inputs from the DLPC230-Q1, the power rails it monitors, the host processor, and potentially several other ADC ports. The DLPC230-Q1 sends configuration and control commands to the TPS99001-Q1 over an SPI bus and several other control signals. The DLPC230-Q1's clocks are also monitored by the watchdogs in the TPS99001-Q1 to detect any errors. The power rails are monitored by the TPS99001-Q1 in order to detect power failures or glitches and request a proper power down of the DMD in case of an error. The host processor can read diagnostics information from the TPS99001-Q1 using a dedicated SPI bus, which enables independent monitoring. Additionally the host can request the image to be turned on or off using a PROJ_ON signal. Lastly, the TPS99001-Q1 has several general-purpose ADCs that can be used to implement system level monitoring functions.

The outputs of the TPS99001-Q1 are diagnostic information and error alerts to the DLPC230-Q1, and control signals to the LED or laser driver. The TPS99001-Q1 can output diagnostic information to the host and the DLPC230-Q1 over two SPI buses. In case of critical system errors, such as power loss, it outputs signals to the DLPC230-Q1 that trigger power down or reset sequences. It also has output signals that can be used to implement various LED or laser driver topologies.

The DMD is a micro-electro-mechanical system (MEMS) device that receives electrical signals as an input (video data), and produces a mechanical output (mirror position). The electrical interface to the DMD is a sub-LVDS


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interface with the DLPC230-Q1. The mechanical output is the state of more than 1.3 million mirrors in the DMD array that can be tilted ±12°. In a projection system the mirrors are used as pixels in order to display an image.

### 8.2.2 Reference Design

For information about connecting together the DLP5531A-Q1 DMD, DLPC230-Q1 controller, and TPS99001-Q1, please see the DLP5531A-Q1 evaluation module. For optomechanical reference designs see DLP5531LEQ1EVM.

### 8.2.3 Application Mission Profile Consideration

Each application is anticipated to have different mission profiles, or number of operating hours at different temperatures. To assist in evaluation the Application Report *Reliability Lifetime Estimates for DLP3030-Q1 and DLP553x-Q1 DMDs in Automotive Applications* may be provided. See the TI Application team for more information.

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# 9 Power Supply Recommendations

The following power supplies are all required to operate the DMD: VDD, VDDI, VOFFSET, VBIAS, and VRESET. All VSS connections are also required. DMD power-up and power-down sequencing is strictly controlled by the TPS99001-Q1 device.

**CAUTION**

For reliable operation of the DMD, the following power supply sequencing requirements must be followed. Failure to adhere to the prescribed power-up and power-down procedures may affect device reliability.

VDD, VDDI, VOFFSET, VBIAS, and VRESET power supplies have to be coordinated during power-up and power-down operations. Failure to meet any of the below requirements will result in a significant reduction in the DMD's reliability and lifetime. VSS must also be connected.

## 9.1 Power Supply Power-Up Procedure

- During power-up, VDD and VDDI must always start and settle before VOFFSET, VBIAS, and VRESET voltages are applied to the DMD.
- During power-up, it is a strict requirement that the delta between VBIAS and VOFFSET must be within the specified limit shown in the *Recommended Operating Conditions*.
- During power-up, the DMD's LPSDR input pins shall not be driven high until after VDD and VDDI have settled at operating voltage.
- During power-up, there is no requirement for the relative timing of VRESET with respect to VOFFSET and VBIAS. Power supply slew rates during power-up are flexible, provided that the transient voltage levels follow the requirements listed previously and in Figure 9-1.

## 9.2 Power Supply Power-Down Procedure

- The power-down sequence is the reverse order of the previous power-up sequence. VDD and VDDI must be supplied until after VBIAS, VRESET, and VOFFSET are discharged to within 4 V of ground.
- During power-down, it is not mandatory to stop driving VBIAS prior to VOFFSET, but it is a strict requirement that the delta between VBIAS and VOFFSET must be within the specified limit shown in the *Recommended Operating Conditions* (Refer to Note 2 in Section 9.3).
- During power-down, the DMD's LPSDR input pins must be less than VDDI, the specified limit shown in the *Recommended Operating Conditions*.
- During power-down, there is no requirement for the relative timing of VRESET with respect to VOFFSET and VBIAS.
- Power supply slew rates during power-down are flexible, provided that the transient voltage levels follow the requirements listed previously and in Section 9.3.


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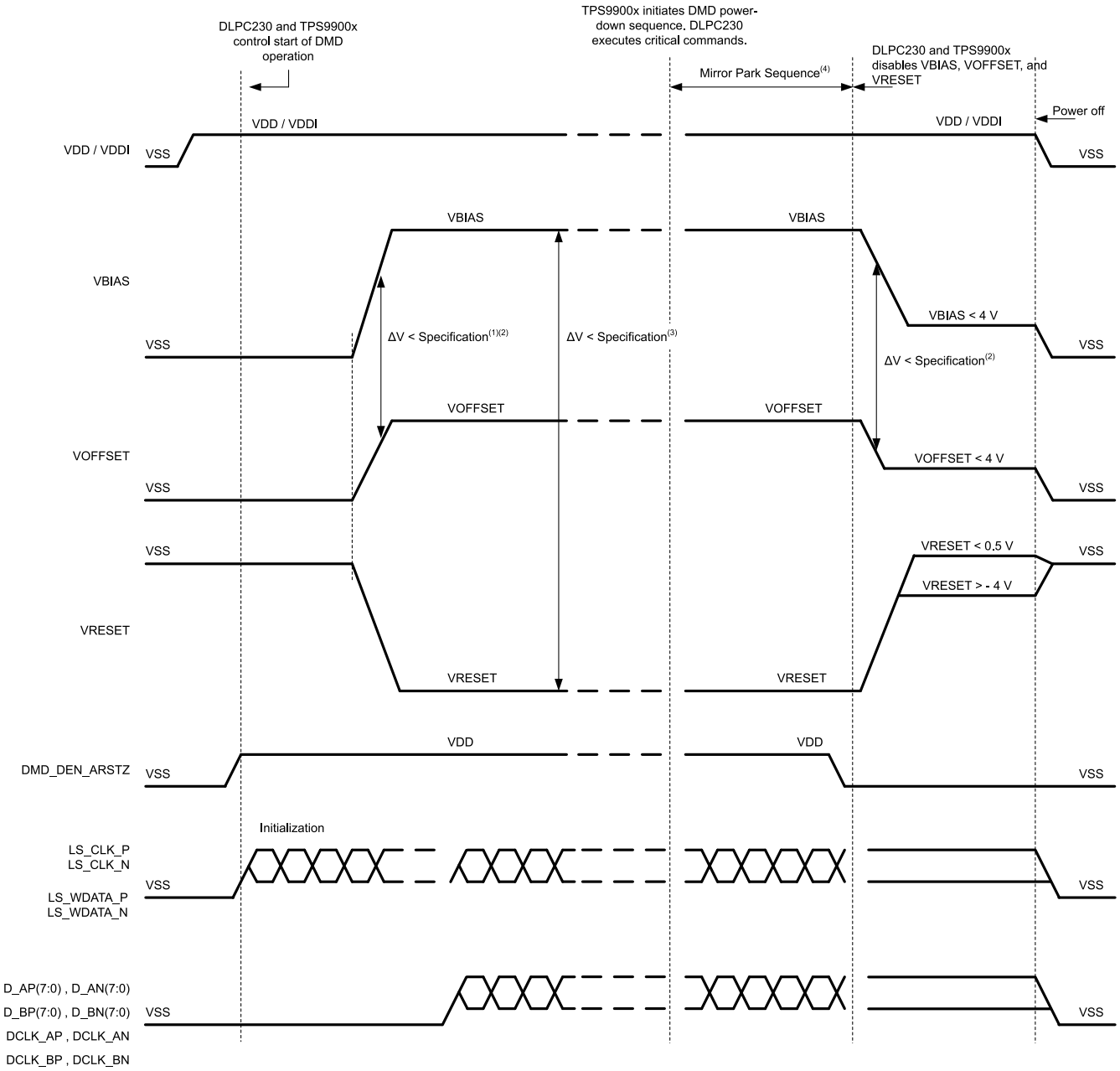
## 9.3 Power Supply Sequencing Requirements




A. To prevent excess current, the supply voltage delta |VBIAS – VOFFSET| must be less than specified in the Recommended Operating Conditions. OEMs may find that the most reliable way to ensure this is to power VOFFSET prior to VBIAS during power-up and to remove VBIAS prior to VOFFSET during power-down. Also, the TPS99001-Q1 is capable of managing the timing between VBIAS and VOFFSET.

B. To prevent excess current, the supply voltage delta |VBIAS – VRESET| must be less than specified than the limit shown in the Recommended Operating Conditions.

C. When system power is interrupted, the TPS99001-Q1 initiates hardware power-down that disables VBIAS, VRESET and VOFFSET after the Micromirror Park Sequence.

D. Drawing is not to scale and details are omitted for clarity.

**Figure 9-1. Power Supply Sequencing Requirements (Power Up and Power Down)**

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# 10 Layout

## 10.1 Layout Guidelines

Please refer to the DLPC230-Q1 and TPS99001-Q1 data sheets for specific PCB layout and routing guidelines. For specific DMD PCB guidelines, use the following:

- Match lengths for the LS_WDATA and LS_CLK signals.
- Minimize vias, layer changes, and turns for the HS bus signals.
- Minimum of two 220-nF decoupling capacitors close to VBIAS.
- Minimum of two 220-nF decoupling capacitors close to VRESET.
- Minimum of two 220-nF decoupling capacitors close to VOFFSET.
- Minimum of four 100-nF decoupling capacitors close to VDDI and VDD.
- Temperature diode pins

  The DMD has an internal diode (PN junction) that is intended to be used with an external TI TMP411 temperature sensing IC. PCB traces from the DMD's temperature diode pins to the TMP411 are sensitive to noise. Please see the TMP411 data sheet for specific routing recommendations.


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# 11 Device and Documentation Support

## 11.1 Device Support

### 11.1.1 Device Nomenclature

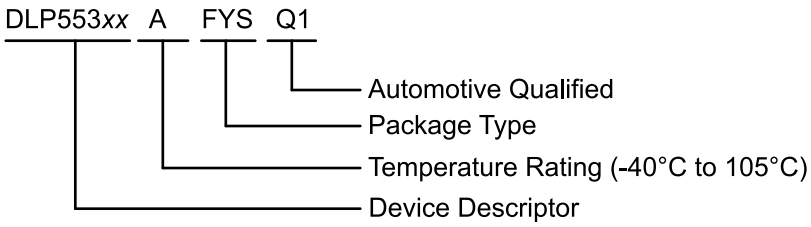


**Figure 11-1. Part Number Description**

### 11.1.2 Device Markings

The device marking includes the legible character string GHJJJJK DLP553xxAFYSQ1. GHJJJJK is the lot trace code. DLP553*xx*AFYSQ1 is the part number.

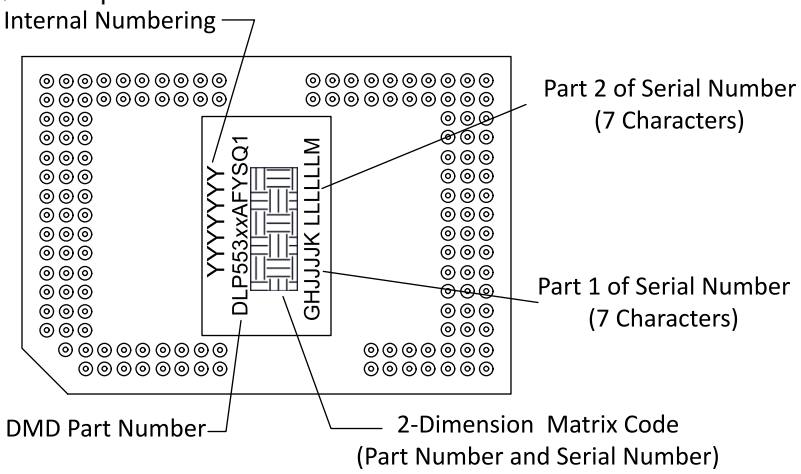


**Figure 11-2. DMD Marking**

## 11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Subscribe to updates* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

## 11.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

## 11.4 Trademarks

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DLP® is a registered trademark of Texas Instruments.
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### 11.5 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 11.6 DMD Handling

The DMD is an optical device so precautions should be taken to avoid damaging the glass window. Please see the application note DLPA019 DMD Handling for instructions on how to properly handle the DMD.

### 11.7 Glossary

| | |
|---|---|
| TI Glossary | This glossary lists and explains terms, acronyms, and definitions. |

## 12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.


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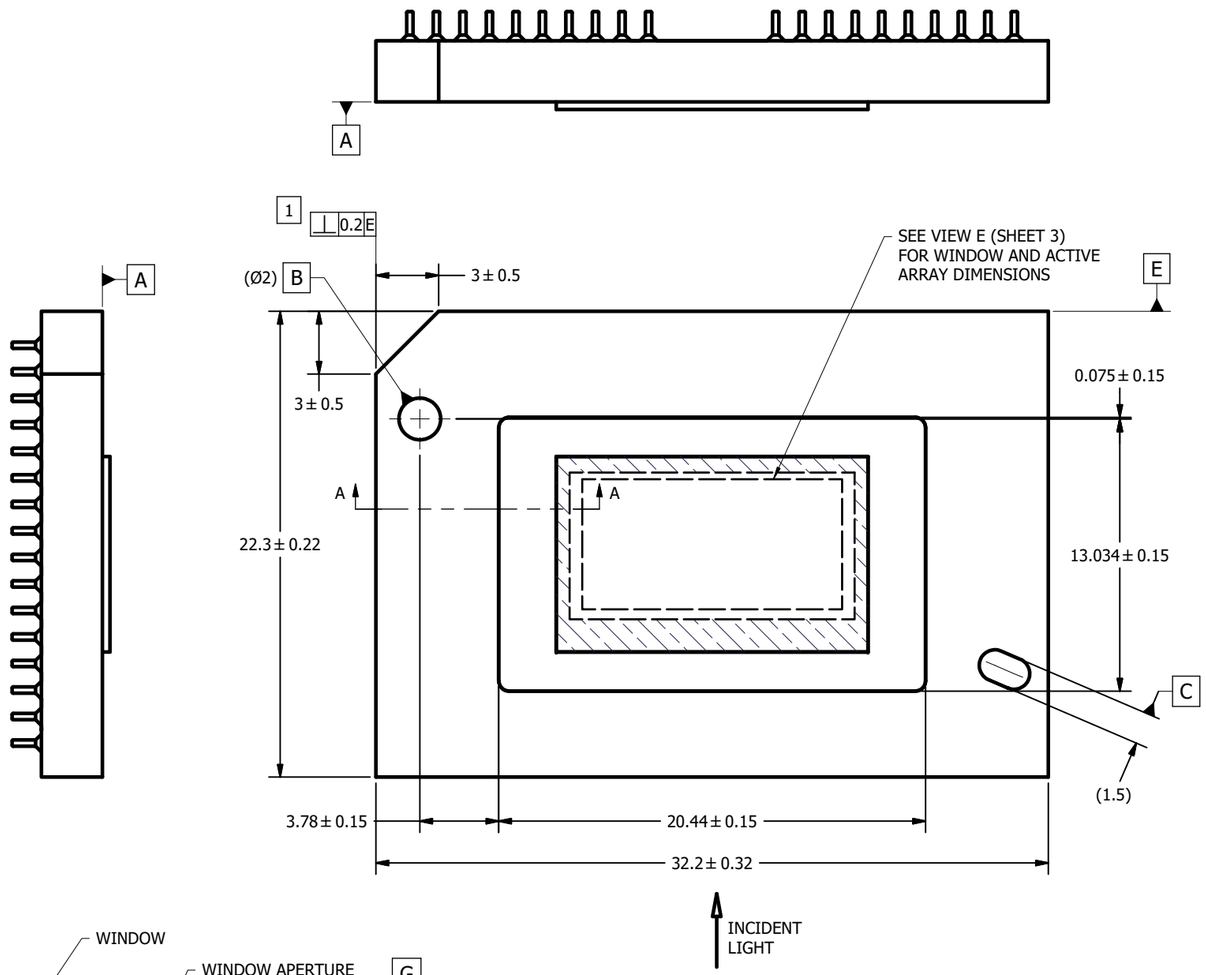
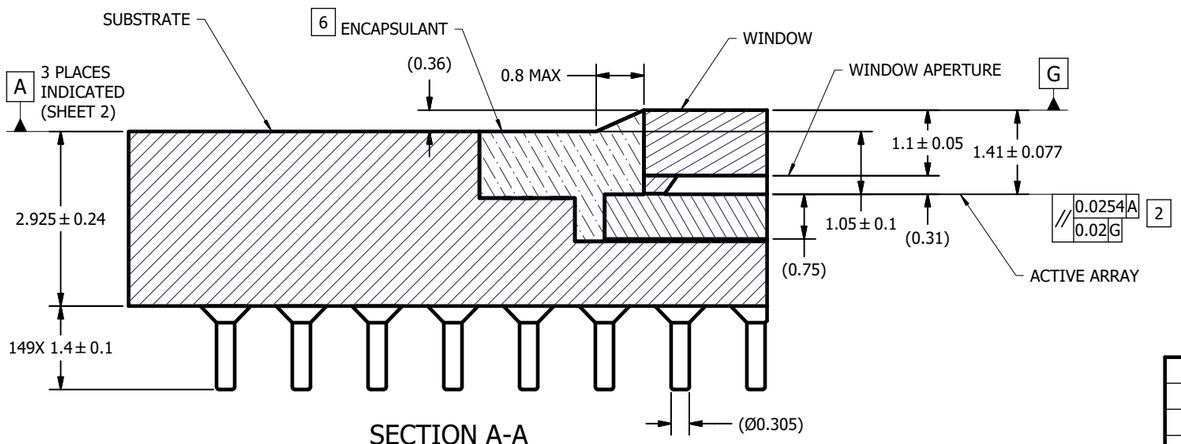
REVISIONS

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| A | ECO 2182382: INITIAL RELEASE | 7/17/2019 | BMH |
| B | ECO 2182408: CHANGE APERTURE TOP EDGE SHAPE | 7/26/2019 | BMH |
| C | ECO 2187769: CHG APER TOP EDGE SHAPE & LOCATION | 5/14/2020 | BMH |

NOTES UNLESS OTHERWISE SPECIFIED:

1. SUBSTRATE EDGE PERPENDICULARITY TOLERANCE APPLIES TO ENTIRE SURFACE.
2. DIE PARALLELISM TOLERANCE APPLIES TO DMD ACTIVE ARRAY ONLY.
3. ROTATION ANGLE OF DMD ACTIVE ARRAY IS A REFINEMENT OF THE LOCATION TOLERANCE AND HAS A MAXIMUM VALUE OF 0.8 DEGREES.
4. SUBSTRATE SYMBOLIZATION PAD AND PLATING AT BOTTOM OF DATUMS B AND C HOLES TO BE ELECTRICALLY CONNECTED TO VSS PLANE WITHIN THE SUBSTRATE.
5. BOUNDARY MIRRORS SURROUNDING THE ACTIVE ARRAY.
6. MAXIMUM ENCAPSULANT PROFILE SHOWN.
7. ENCAPSULANT ALLOWED ON THE SURFACE OF THE CERAMIC IN THE AREA SHOWN IN VIEW B (SHEET 2). ENCAPSULATION SHALL NOT EXCEED 0.2 THICKNESS MAXIMUM.
8. INDICATED CERAMIC SUBSTRATE FEATURES TO BE PLATED WITH 0.3 MICROMETERS MINIMUM ELECTROLYTIC GOLD OVER 0.1 MICROMETER MINIMUM PALLADIUM OVER 1.27-8.89 MICROMETERS ELECTROLYTIC NICKEL PER ASTM B488-01, ASTM B679-95(2009), AND AMS-QQ-N-290, RESPECTIVELY.
9. NOTE THAT THE LOCATION OF THE ACTIVE ARRAY CENTER FOR THIS DMD IS THE SAME AS THE AUTOMOTIVE DLP5530-Q1 AND DLP5531-Q1 DMD'S, BUT IS NOT CONSISTENT WITH ALL OTHER SERIES 450 DMD'S.




SECTION A-A
SCALE 20 : 1

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| NONE | 0314DA |
| NEXT ASSY | USED ON |
| APPLICATION | |

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED
- DIMENSIONS ARE IN MILLIMETERS
- TOLERANCES:
  - ANGLES ± 1°
  - 2 PLACE DECIMALS ± 0.25
  - 1 PLACE DECIMALS ± 0.50
- ~~DIMENSIONAL LIMITS APPLY BEFORE PROCESSES~~
- INTERPRET DIMENSIONS IN ACCORDANCE WITH ASME Y14.5M-1994
- ~~REMOVE ALL BURRS AND SHARP EDGES~~
- PARENTHETICAL INFORMATION FOR REFERENCE ONLY

| | | DATE |
|---|---|---|
| DRAWN | B. HASKETT | 7/17/2019 |
| ENGINEER | B. HASKETT | 7/17/2019 |
| QA/CE | P. KONRAD | 7/18/2019 |
| CM | M. LOPEZ | 7/18/2019 |
| | J. McKINLEY | 7/18/2019 |
| APPROVED | B. RAY | 7/17/2019 |

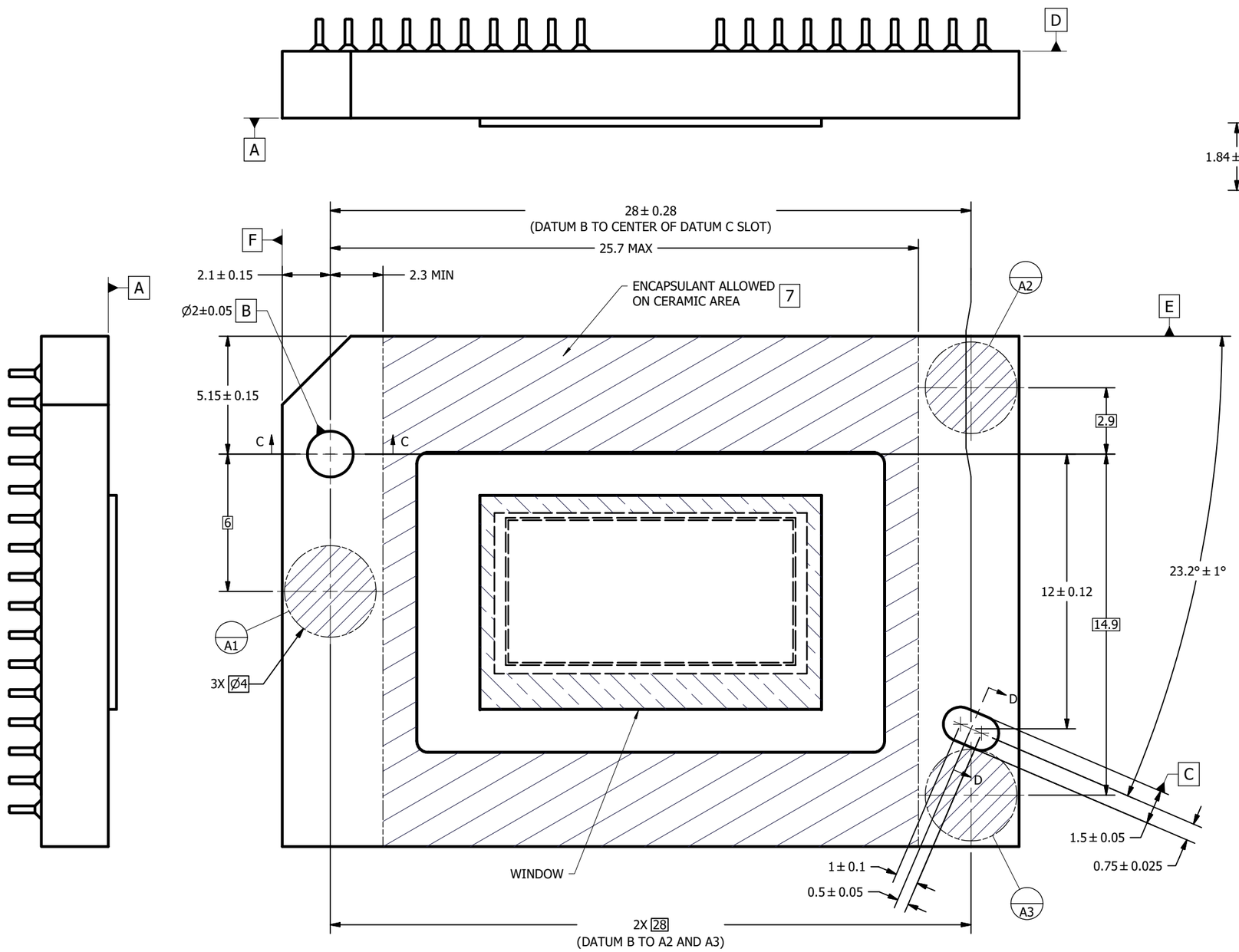
TEXAS INSTRUMENTS
Dallas Texas

TITLE: ICD, MECHANICAL, DMD .55 2:1 1.3MP SERIES 450 -A1 (FYS PACKAGE)

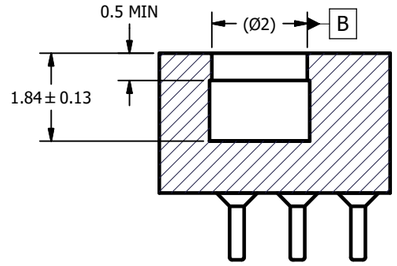
| SIZE | DWG NO | REV |
|---|---|---|
| D | 2516726 | C |

SCALE 4:1 SHEET 1 OF 4

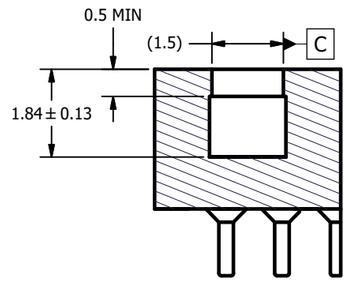
INV2013-DLPa




VIEW B
DATUMS AND ENCAPSULANT ALLOWABLE AREA
SCALE 10 : 1




SECTION C-C
DATUM B
SCALE 16 : 1




SECTION D-D
DATUM C
(VIEW ROTATED FOR CLARITY)
SCALE 16 : 1

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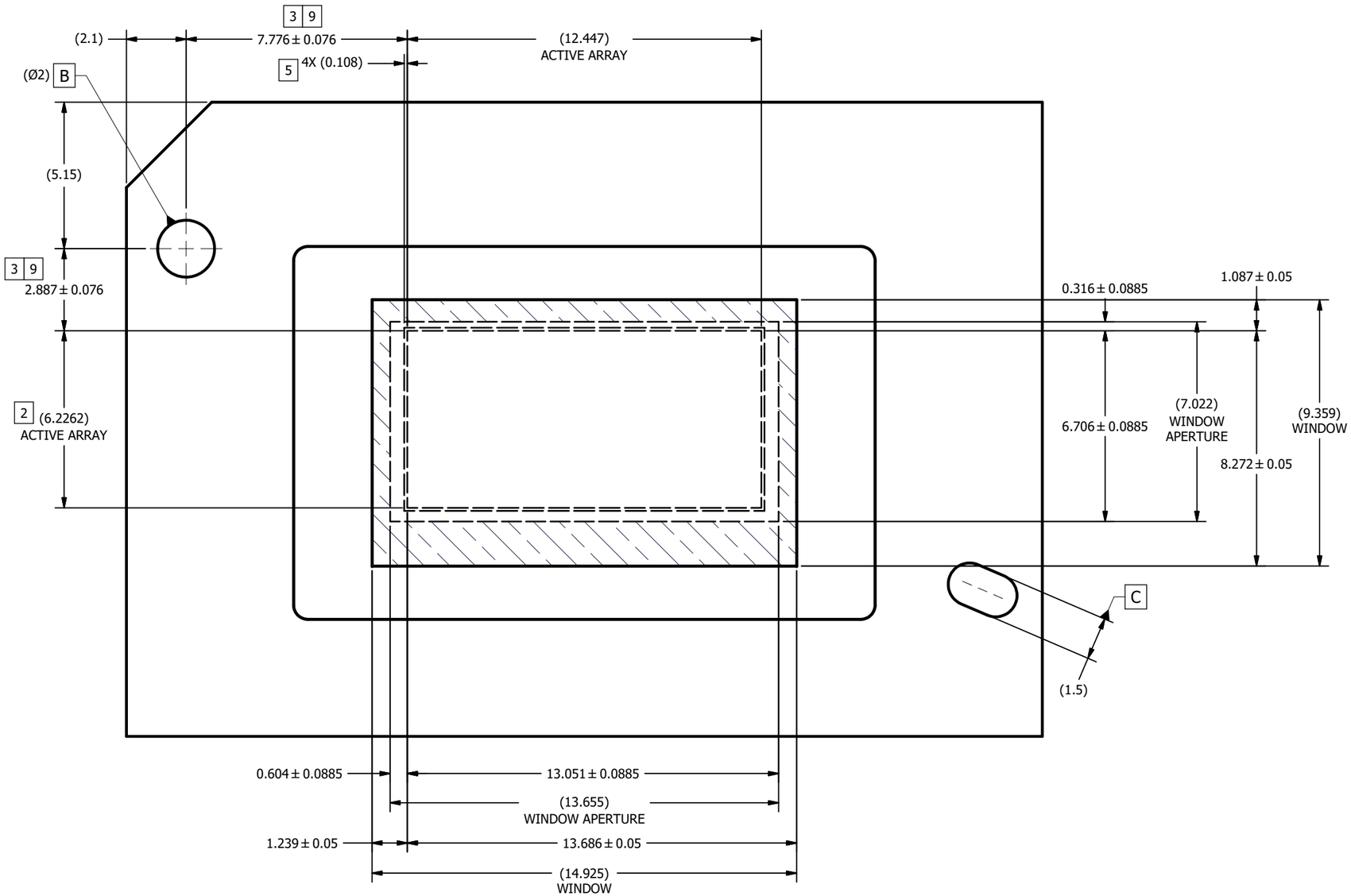
| TEXAS INSTRUMENTS Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | DWG NO 2516726 | REV C |
| | | | SCALE | SHEET 2 OF 4 | |

INV2013-DLPa




VIEW E
ACTIVE ARRAY AND WINDOW
SCALE 12 : 1

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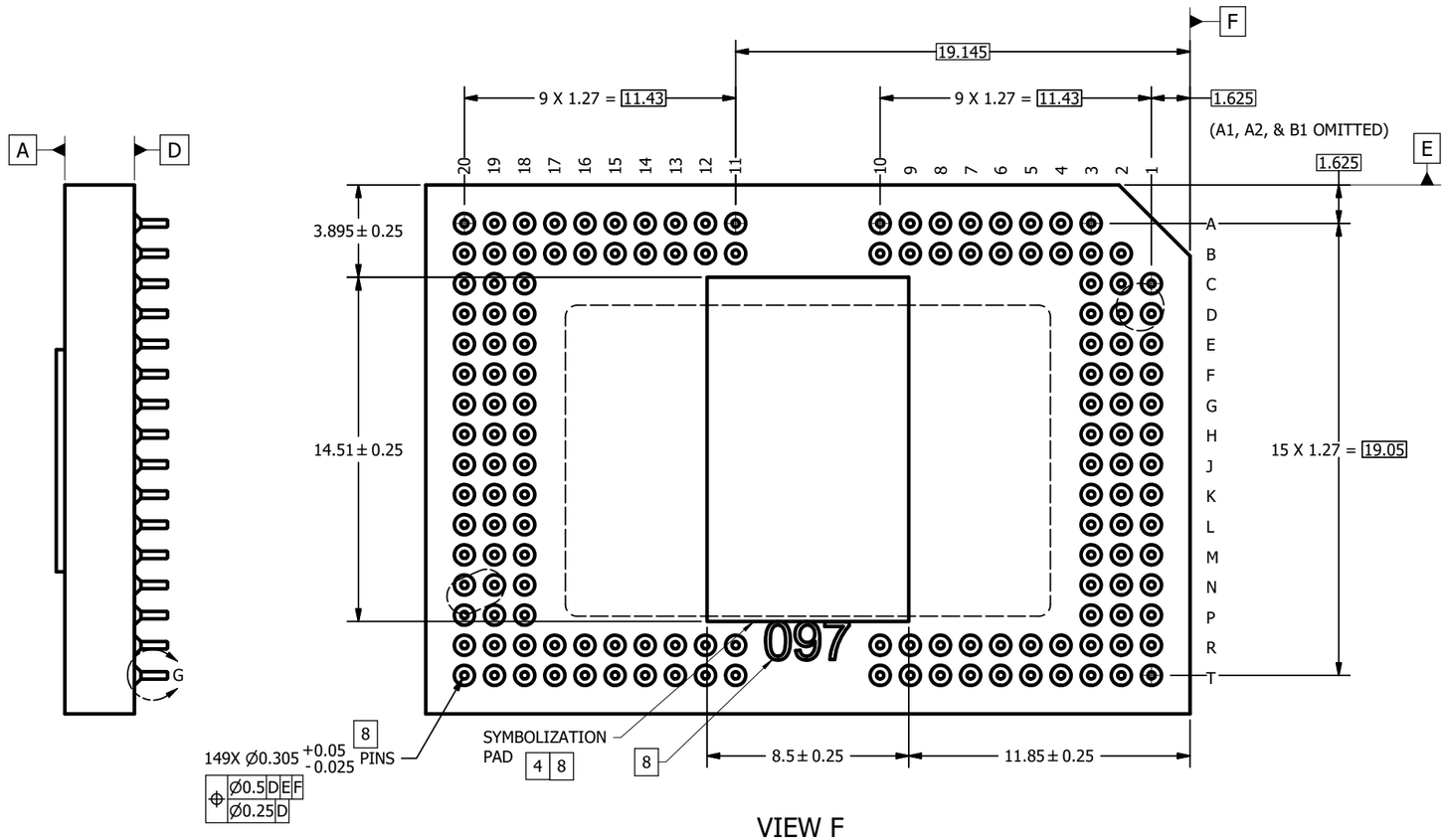
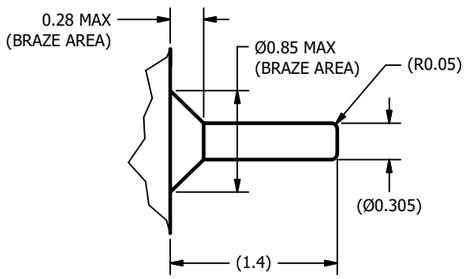
| Texas Instruments, Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | | DWG NO 2516726 | REV C |
| | | | SCALE | | SHEET 3 OF 4 | |

INV2013-DLPa




VIEW F
PINS AND SYMBOLIZATION PAD
SCALE 8 : 1




DETAIL G
PIN AND BRAZE DIMENSIONS
149 PLACES
SCALE 40 : 1

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| Texas Instruments, Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | DWG NO 2516726 | REV C |
| | | | SCALE | SHEET 4 OF 4 | |

INV2013-DLPa

## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| DLP5531AAFYSQ1 | Active | Production | CPGA (FYS) \| 149 | 33 \| JEDEC TRAY (5+1) | Yes | Call TI | N/A for Pkg Type | -40 to 105 | |
| DLP5531AAFYSQ1.A | Active | Production | CPGA (FYS) \| 149 | 33 \| JEDEC TRAY (5+1) | Yes | Call TI | N/A for Pkg Type | -40 to 105 | |
| DLP5531AAFYSQ1.B | Active | Production | CPGA (FYS) \| 149 | 33 \| JEDEC TRAY (5+1) | Yes | Call TI | N/A for Pkg Type | -40 to 105 | |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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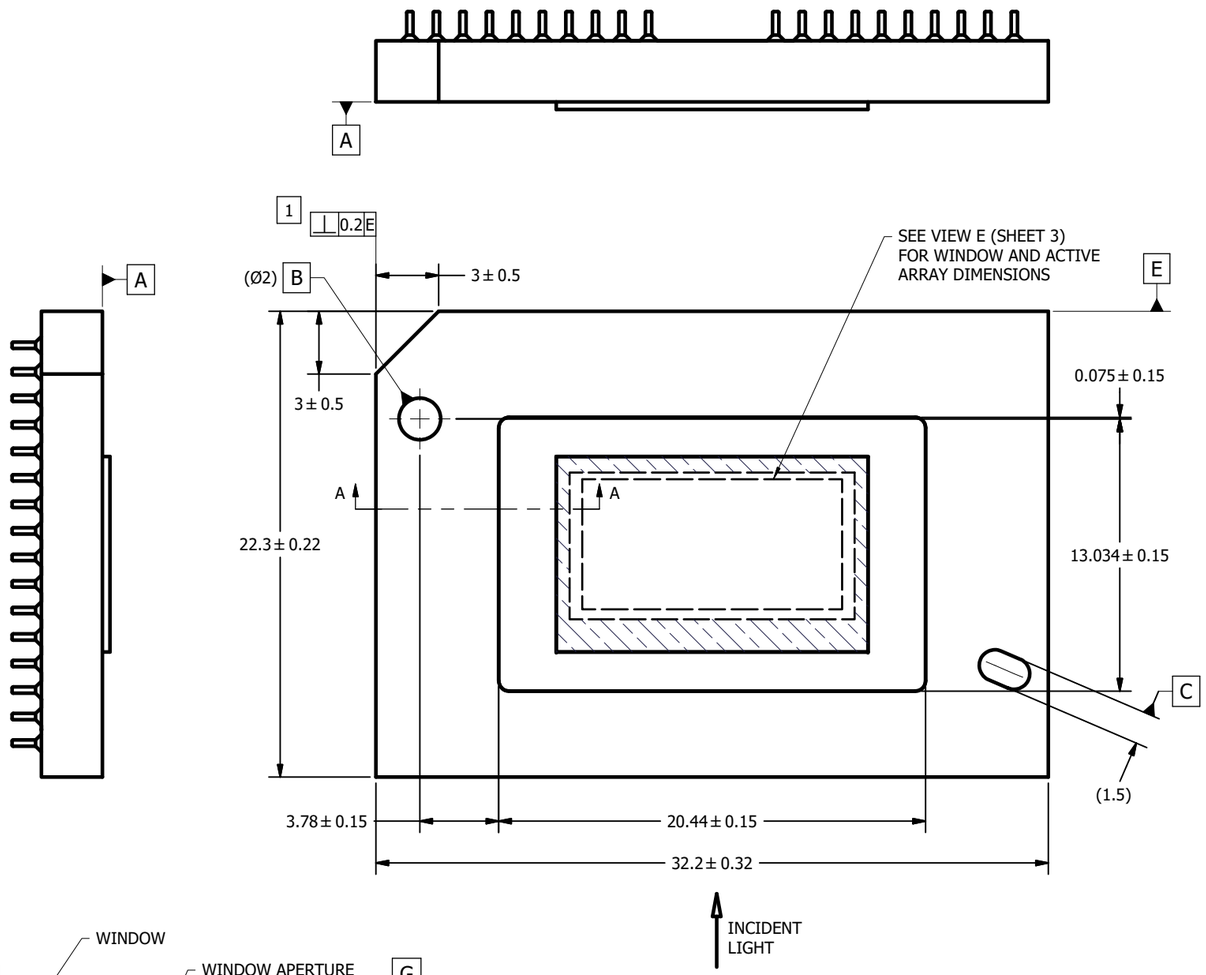
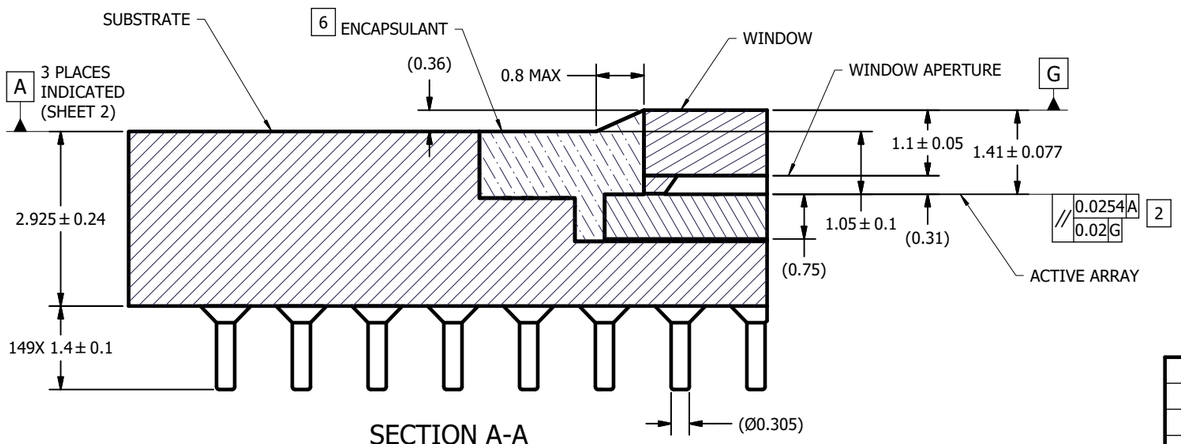
| A | ECO 2182382: INITIAL RELEASE | 7/17/2019 | BMH |
| B | ECO 2182408: CHANGE APERTURE TOP EDGE SHAPE | 7/26/2019 | BMH |
| C | ECO 2187769: CHG APER TOP EDGE SHAPE & LOCATION | 5/14/2020 | BMH |

NOTES UNLESS OTHERWISE SPECIFIED:

1. SUBSTRATE EDGE PERPENDICULARITY TOLERANCE APPLIES TO ENTIRE SURFACE.
2. DIE PARALLELISM TOLERANCE APPLIES TO DMD ACTIVE ARRAY ONLY.
3. ROTATION ANGLE OF DMD ACTIVE ARRAY IS A REFINEMENT OF THE LOCATION TOLERANCE AND HAS A MAXIMUM VALUE OF 0.8 DEGREES.
4. SUBSTRATE SYMBOLIZATION PAD AND PLATING AT BOTTOM OF DATUMS B AND C HOLES TO BE ELECTRICALLY CONNECTED TO VSS PLANE WITHIN THE SUBSTRATE.
5. BOUNDARY MIRRORS SURROUNDING THE ACTIVE ARRAY.
6. MAXIMUM ENCAPSULANT PROFILE SHOWN.
7. ENCAPSULANT ALLOWED ON THE SURFACE OF THE CERAMIC IN THE AREA SHOWN IN VIEW B (SHEET 2). ENCAPSULATION SHALL NOT EXCEED 0.2 THICKNESS MAXIMUM.
8. INDICATED CERAMIC SUBSTRATE FEATURES TO BE PLATED WITH 0.3 MICROMETERS MINIMUM ELECTROLYTIC GOLD OVER 0.1 MICROMETER MINIMUM PALLADIUM OVER 1.27-8.89 MICROMETERS ELECTROLYTIC NICKEL PER ASTM B488-01, ASTM B679-95(2009), AND AMS-QQ-N-290, RESPECTIVELY.
9. NOTE THAT THE LOCATION OF THE ACTIVE ARRAY CENTER FOR THIS DMD IS THE SAME AS THE AUTOMOTIVE DLP5530-Q1 AND DLP5531-Q1 DMD'S, BUT IS NOT CONSISTENT WITH ALL OTHER SERIES 450 DMD'S.




SECTION A-A
SCALE 20 : 1

| | |
|---|---|
| NONE | 0314DA |
| NEXT ASSY | USED ON |
| APPLICATION | |

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED
- DIMENSIONS ARE IN MILLIMETERS
- TOLERANCES:
  - ANGLES ± 1°
  - 2 PLACE DECIMALS ± 0.25
  - 1 PLACE DECIMALS ± 0.50
- ~~DIMENSIONAL LIMITS APPLY BEFORE PROCESSES~~
- INTERPRET DIMENSIONS IN ACCORDANCE WITH ASME Y14.5M-1994
- ~~REMOVE ALL BURRS AND SHARP EDGES~~
- PARENTHETICAL INFORMATION FOR REFERENCE ONLY

| | | DATE |
|---|---|---|
| DRAWN | B. HASKETT | 7/17/2019 |
| ENGINEER | B. HASKETT | 7/17/2019 |
| QA/CE | P. KONRAD | 7/18/2019 |
| CM | M. LOPEZ | 7/18/2019 |
| | J. McKINLEY | 7/18/2019 |
| APPROVED | B. RAY | 7/17/2019 |

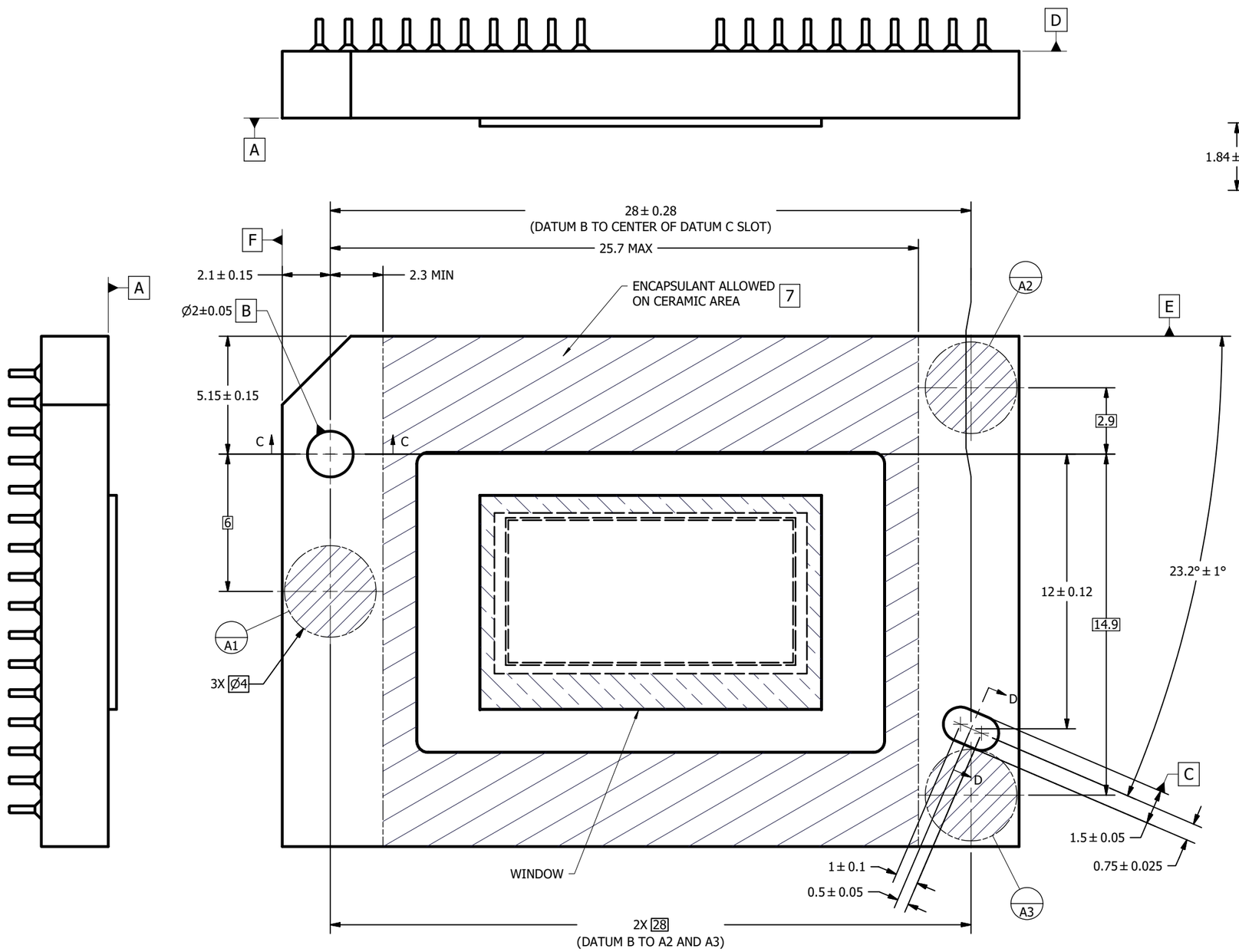
TEXAS INSTRUMENTS
Dallas Texas

TITLE: ICD, MECHANICAL, DMD .55 2:1 1.3MP SERIES 450 -A1 (FYS PACKAGE)

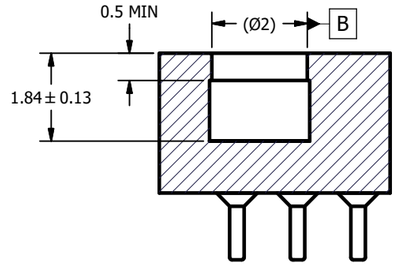
| SIZE | DWG NO | REV |
|---|---|---|
| D | 2516726 | C |

SCALE 4:1 SHEET 1 OF 4

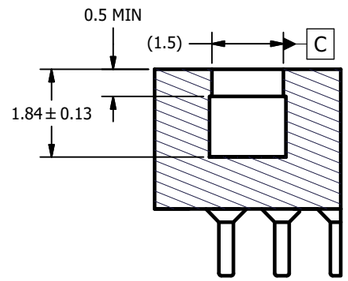
INV2013-DLPa




VIEW B
DATUMS AND ENCAPSULANT ALLOWABLE AREA
SCALE 10 : 1



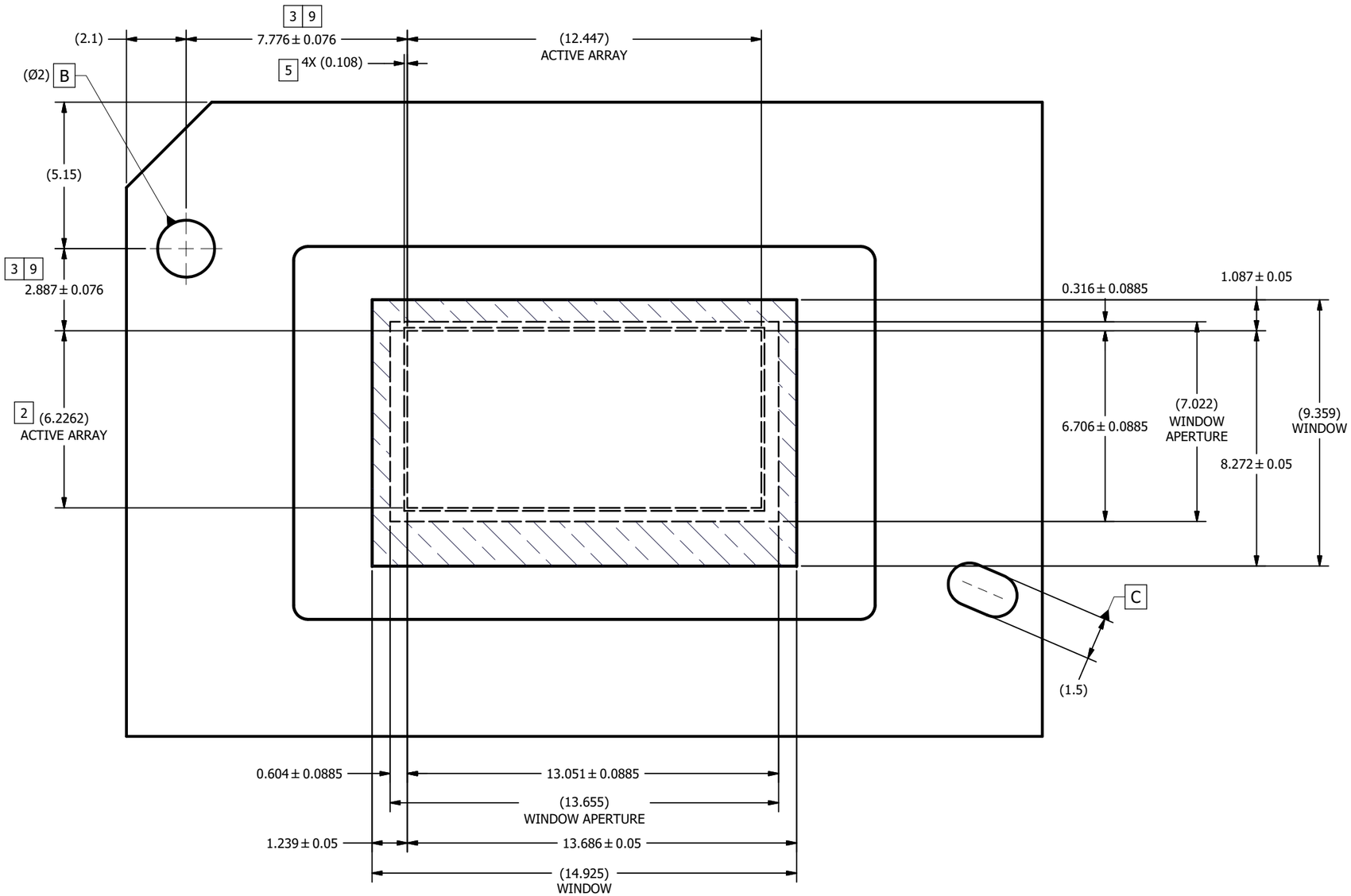

SECTION C-C
DATUM B
SCALE 16 : 1




SECTION D-D
DATUM C
(VIEW ROTATED FOR CLARITY)
SCALE 16 : 1

| | | | | | |
|---|---|---|---|---|---|
| TEXAS INSTRUMENTS Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | DWG NO 2516726 | REV C |
| | | | SCALE | SHEET 2 OF 4 | |

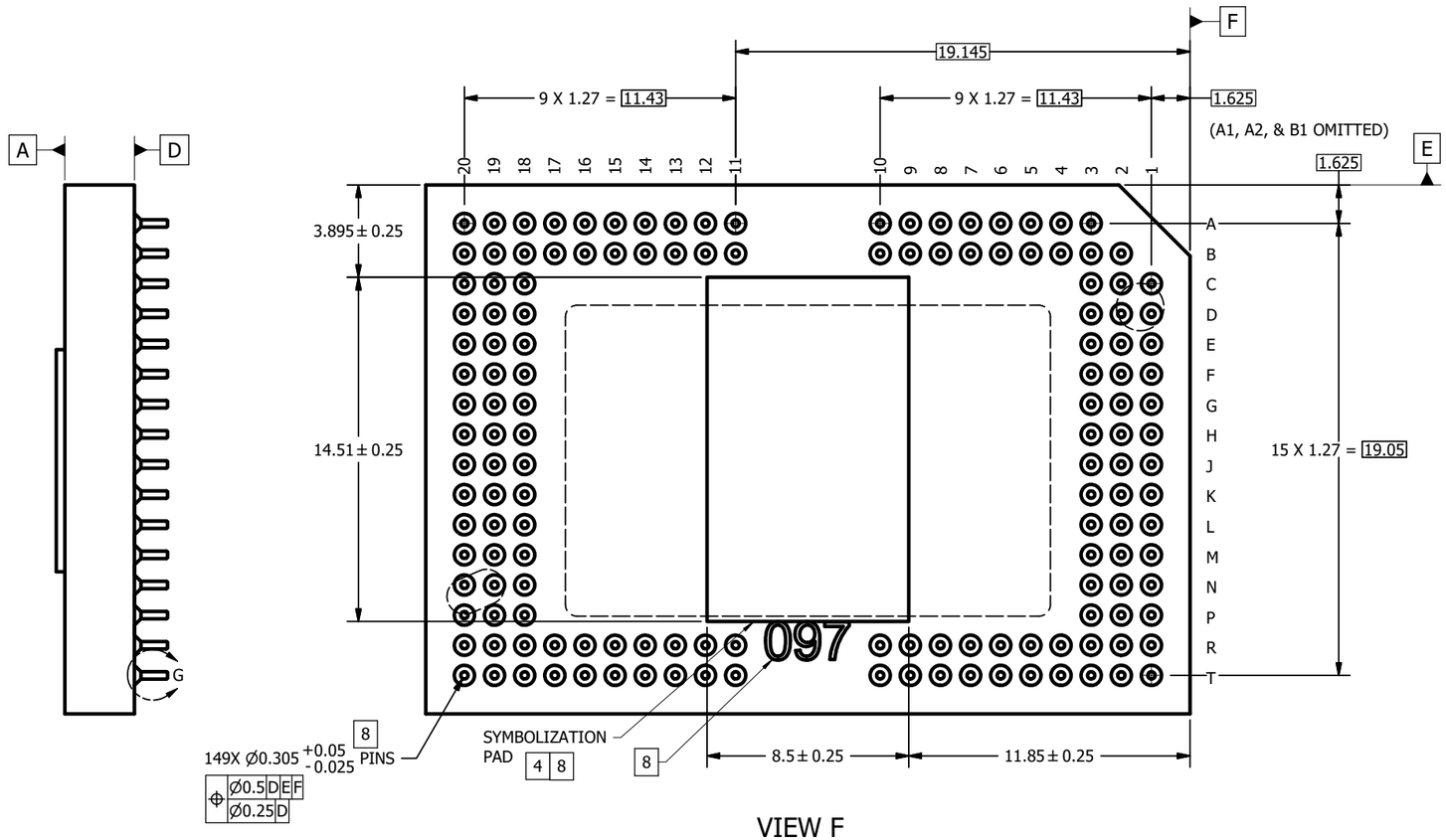
INV2013-DLPa



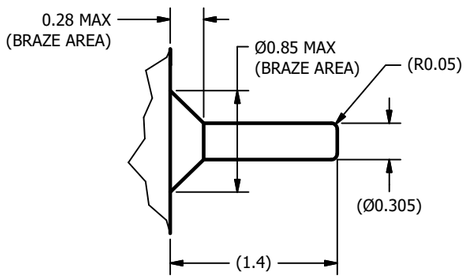

VIEW E
ACTIVE ARRAY AND WINDOW
SCALE 12 : 1

| | | | | | | |
|---|---|---|---|---|---|---|
| Texas Instruments, Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | | DWG NO 2516726 | REV C |
| | | | SCALE | | SHEET 3 OF 4 | |

INV2013-DLPa




VIEW F
PINS AND SYMBOLIZATION PAD
SCALE 8 : 1




DETAIL G
PIN AND BRAZE DIMENSIONS
149 PLACES
SCALE 40 : 1

| | | | | | |
|---|---|---|---|---|---|
| Texas Instruments, Dallas Texas | DRAWN B. HASKETT | DATE 7/17/2019 | SIZE D | DWG NO 2516726 | REV C |
| | | | SCALE | SHEET 4 OF 4 | |

INV2013-DLPa

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