

SLVSG10D - NOVEMBER 2021 - REVISED JULY 2022

TLC6984 48 Current Sources, 64 Scans, Common Cathode Matrix LED Display Driver

1 Features

- Separated V_{CC} and $V_{R/G/B}$ power supply
 - V_{CC} voltage range: 2.5 V 5.5 V
 - V_{R/G/B} voltage range: 2.5 V 5.5 V
- 48 current source channels from 0.2 mA to 20 mA
 - Channel-to-channel accuracy: ±0.5% (typ.), ±2% (max.); device-to-device accuracy: ±0.5% (typ.), ±2% (max.)
 - Low knee voltage: 0.26 V (max.) when I_{OUT} = 5
 - 3-bits (8 steps) global brightness control
 - 8-bits (256 steps) color brightness control
 - Maximum 16-bits (65536 steps) PWM grayscale control
- 16 scan line switches with 190-mΩ R_{DS(ON)}
- Ultra low power consumption
 - Independent V_{CC} down to 2.5 V
 - Lowest I_{CC} down to 3.6 mA with 50-MHz GCLK
 - Intelligent power saving mode with I_{CC} down to 0.9mA
- Built-in SRAM to support 1 64 multiplexing
 - Single device with 16 multiplexing to support 48 × 16 LEDs or 16 × 16 RGB pixels
 - Dual devices stackable with 32 multiplexing to support 96 × 32 LEDs or 32 × 32 RGB pixels
 - Three devices stackable with 48 multiplexing to support 144 × 48 LEDs or 48 × 48 RGB pixels
 - Four devices stackable with 64 multiplexing to support 192 × 64 LEDs or 64 × 64 RGB pixels
- High speed and low EMI Continuous Clock Series Interface (CCSI)
 - Only three wires: SCLK / SIN / SOUT
 - External 25-MHz (max.) SCLK with dual-edge transmission mechanism (internal 50 MHz)

- Internal frequency multiplier to support high GCLK frequency
- Optimized display performance
 - Programmable scan line sequence
 - Upside and downside ghosting removal
 - Low grayscale enhancement
 - LED open, short, and weak short detection and removal

2 Applications

- Narrow Pixel Pitch (NPP) LED display
- Mini and micro-LED products

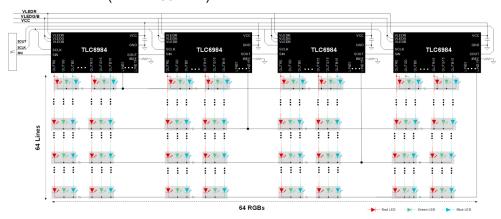
3 Description

With the pixel density getting higher in narrow pixel pitch LED display or mini and micro-LED products, there are urgent demands for LED drivers to address those critical challenges. These challenges include ultra high integration to meet the strict board space limitation, ultra low power to minimize the system level power dissipation, new interface to enable high data refresh rate with low EMI impact, and excellent display performance to serve the growing needs of higher display quality.

Device Information

| PART NUMBER | PACKAGE ⁽¹⁾ | BODY SIZE (NOM) |
|-------------|------------------------|-------------------|
| TLC6984 | VQFN (76) | 9.00 mm × 9.00 mm |
| | BGA (96) | 6.00 mm × 6.00 mm |

For all available packages, see the orderable addendum at the end of the data sheet.



TLC6984 with Four Devices Stackable Connection



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4 Revision History

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

| Changes from Revision C (March 2022) to Revision D (July 2022) | Page |
|--|------|
| Updated the BGA package information throughout the document | 1 |
| Changed the description of FREQ_MOD | 37 |
| Changed the name of register field | |
| Changes from Revision B (March 2022) to Revision C (March 2022) | Page |
| Updated the GCLK descriptions in the Features and Description (continued) sections | 1 |
| Changes from Revision A (December 2021) to Revision B (March 2022) | Page |
| Changed data sheet status from "Advance Information" to "Production Data" | 1 |
| Changes from Revision * (November 2021) to Revision A (December 2021) | Page |
| First public release of data sheet | 1 |

5 Description (continued)

The TLC6984 is a highly-integrated, common cathode matrix LED display driver with 48 constant current sources and 16 scanning FETs. Besides driving 16 × 16 and 32 × 32 RGB LED pixels as TLC6983, three TLC6984s are capable of driving 48 × 48 RGB LED pixels and stacking four TLC6984s can drive 64 × 64 RGB LED pixels. To achieve low-power consumption, the device supports separated power supplies for the red, green, and blue LEDs by its common cathode structure. Furthermore, the operation power of the TLC6984 is significantly reduced by ultra-low operation voltage range (Vcc down to 2.5 V) and ultra-low operation current (Icc down to 3.6 mA).

The TLC6984 implements a high-speed, dual-edge transmission interface to support high device count daisy-chained and high-refresh rate while minimizing electrical-magnetic interference (EMI). The device supports up to 25-MHz SCLK (external) and 40-MHz to 160-MHz GCLK (internal, typical values) with different GCLK multiplier modes and frequencies. Meanwhile, the device integrates enhanced circuits and intelligent algorithms to solve the various display challenges in Narrow Pixel Pitch (NPP) LED display applications and mini and micro-LED products. These challenges include dim at the first scan line, upper and downside ghosting, non-uniformity in low grayscale, coupling, and caterpillar caused by open or short LEDs, which make the TLC6984 a perfect choice in such applications.

The TLC6984 also implements LED open, weak-short, short detections and removals during operations and can also report this information out to the accompanying digital processor.



6 Pin Configuration and Functions

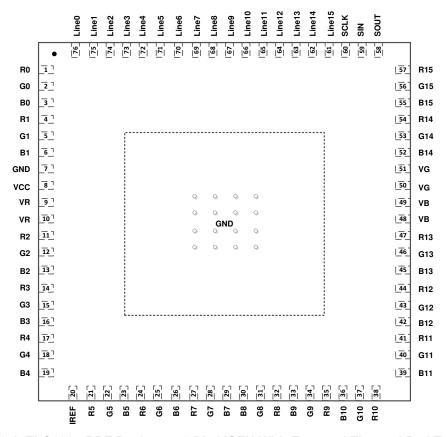


Figure 6-1. TLC6984 RRF Package 76-Pin VQFN With Exposed Thermal Pad Top View

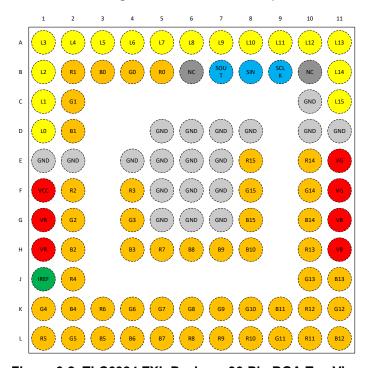


Figure 6-2. TLC6984 ZXL Package 96-Pin BGA Top View

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Table 6-1. Pin Functions

| | PIN | | | |
|------------------|---|---|-----|---|
| NAME | RRF NO. | ZXL NO. | I/O | DESCRIPTION |
| IREF | 20 | J1 | I | Pin for setting the maximum constant-current value. Connecting an external resistor between IREF and GND sets the maximum current for each constant-current output channel. When this pin is connected directly to GND, all outputs are forced off. The external resistor must be placed close to the device. |
| VCC | 8 | F1 | I | Device power supply |
| VR | 9, 10 | G1, H1 | I | Red LED power supply |
| VG | 51, 50 | E11, F11 | I | Green LED power supply |
| VB | 49, 48 | G11, H11 | I | Blue LED power supply |
| R0-R15 | 1, 4, 11, 14, 17, 21, 24, 27, 32, 35, 38, 41, 44, 47, 54, 57 | B5, B2,F2, F4, J2, L1, K3, H5, L6, L7, L8, L10, K10, H10, E10, E8 | 0 | Red LED constant-current output |
| G0-G15 | 2, 5, 12, 15, 18, 22, 25, 28, 31, 34, 37, 40, 43, 46, 53, 56 | B4, C2, G2, G4, K1, L2, K4, K5, K6, K7, K8, L9, K11, J10, F10, F8 | 0 | Green LED constant-current output |
| B0-B15 | 3, 6, 13, 16, 19, 23, 26, 29, 30, 33, 36, 39, 42, 45, 52, 55 | B3, D2, H2, H4, K2, L3, L4, L5, H6, H7, H8, K9, L11, J11, G10, G8 | 0 | Blue LED constant-current output |
| LINE0- LINE15 | 76, 75, 74, 73, 72, 71, 70, 69, 68, 67, 66, 65, 64, 63, 62, 61 | D1, C1, B1, A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, B11, C11 | 0 | Scan lines |
| SCLK | 60 | В9 | I | Clock-signal input pin |
| SIN | 59 | B8 | I | Serial-data input pin |
| SOUT | 58 | В7 | 0 | Serial data output pin |
| GND | 7 | C10, E1, E2, D5, D6, D7, D8, D10, D11, E1,E2, E4, E5, E6,E7, F5, F6, F7,G5, G6, G7 | _ | Power-ground reference |
| Thermal pad | _ | _ | _ | The thermal pad and the GND pin must be connected together on the board. |



7 Specifications

7.1 Absolute Maximum Ratings

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

| | | MIN | MAX | UNIT |
|--|------------------------------|------|-----|------|
| | VCC | -0.3 | 6 | V |
| | VR/G/B | -0.3 | 6 | V |
| Voltage | IREF, SCLK, SIN, SOUT, VSYNC | -0.3 | 6 | V |
| | RX/GX/BX | -0.3 | 6 | V |
| | LINE0 to LINE15 | -0.3 | 6 | V |
| Operating junction temperature, T _J | | -40 | 150 | °C |
| Storage temperature, T _{stg} | | -55 | 150 | °C |

⁽¹⁾ Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

7.2 ESD Ratings

| | | | VALUE | UNIT |
|--|---|---|-------|---------------------------------------|
| V | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾ | ±4000 | \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ |
| V _(ESD) Electrostatic discharge | Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002 ⁽²⁾ | ±1000 | V | |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

| | | MIN | NOM MAX | UNIT |
|-------------------|---|-----------|-----------|------|
| VCC | Device supply voltage | 2.5 | 5.5 | V |
| VLEDR/G/B | LED supply voltage | 2.5 | 5.5 | V |
| V _{IH} | High level logic input voltage (SCLK, SIN, VSYNC) | 0.7 × VCC | | V |
| V _{IL} | Low level logic input voltage (SCLK, SIN, VSYNC) | | 0.3 × VCC | V |
| I _{OH} | High level logic output current (SOUT) | | -2 | mA |
| I _{OL} | Low level logic output current (SOUT) | | 2 | mA |
| I _{CH} | Constant output source current | 0.2 | 20 | mA |
| I _{LINE} | Line scan switch load current | 0 | 2 | А |
| T _A | Ambient operating temperature | -40 | 85 | °C |

7.4 Thermal Information

| | | TLC | | |
|-----------------------|--|------------|-----------|------|
| | THERMAL METRIC ⁽¹⁾ | RRF (VQFN) | ZXL (BGA) | UNIT |
| | | 76 PINS | 96 PINS | |
| R _{0JA} | Junction-to-ambient thermal resistance | 22.2 | 33.5 | °C/W |
| R _{θJC(top)} | Junction-to-case (top) thermal resistance | 10.7 | 18.6 | °C/W |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 7.2 | 11.7 | °C/W |
| Ψ_{JT} | Junction-to-top characterization parameter | 0.1 | 0.3 | °C/W |
| ΨЈВ | Junction-to-board characterization parameter | 7.1 | 11.6 | °C/W |
| R _{0JC(bot)} | Junction-to-case (bottom) thermal resistance | 1.7 | | °C/W |

For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

Product Folder Links: TLC6984



7.5 Electrical Characteristics

At VCC = VR = 2.8 V, VG/B = 3.8 V and $T_A = -40$ °C to +85°C; Typical values are at $T_A = 25$ °C (unless otherwise specified)

| | PARAMETER | TEST CONDITIONS | MIN | TYP MAX | UNIT |
|---------------------------|---|---|-----------|-----------|------|
| VCC | Device supply voltage | | 2.5 | 5.5 | V |
| V _{UVR} | Undervoltage restart | VCC rising | | 2.3 | V |
| V _{UVF} | Undervoltage shutdown | VCC falling | 2.0 | | V |
| / _{UV(HYS)} | Undervoltage shutdown hysteresis | | | 0.1 | V |
| ICC Device supply current | | SCLK/SIN = 10 MHz, MPSM_EN = 1bit, Matrix PSM enable, internal GCLK off, GSn = 0000h, BC = 2h, CCR/G/B = 63h, PS_EN= 1h, VOUTn = floating, R _{IREF} = 7.8 kΩ (In intelligent power save mode) | | 0.9 | mA |
| | SCLK/SIN = 10 MHz, Standby enable, internal GCLK off, GSn = 0000h, BC = 2h, CCR/G/B = 63h, PS_EN= 1h, VOUTn = floating, R _{IREF} = 7.8 kΩ (In intelligent power save mode) | | 0.9 | mA | |
| | Device supply current | SCLK/SIN = 10 MHz, PSP_MOD = 1bit, internal GCLK=50MHz, GSn = 0000h, BC = 2h, CCR/G/B = 63h, PS_EN= 1h, VOUTn = floating, R _{IREF} = 7.8 kΩ (In power save mode) | | 3.6 | mA |
| | | SCLK = 10 MHz, internal GCLK = 50 MHz, GSn = 1FFFh, BC = 2h, CCR/G/B = 63h,VOUTn = floating, R_{IREF} = 7.8 k Ω , I_{CH} = 2 mA | | 3.6 | mA |
| | | SCLK = 10 MHz, internal GCLK = 100 MHz, GSn = 1FFFh, BC = 2h, CCR/G/B = 63h, VOUTn = floating, R_{IREF} = 7.8 k Ω , I_{CH} = 2 mA | | 4.9 | mA |
| /R/G/B | LED supply voltage | | 2.5 | 5.5 | V |
| / _{IH} | High level input voltage (SCLK, SIN) | | 0.7 × VCC | | V |
| / _{IL} | Low level input voltage (SCLK, SIN) | | | 0.3 × VCC | V |
| /он | High level output voltage (SOUT) | IOH = -2 mA at SOUT | VCC-0.4 | VCC | V |
| / _{OL} | Low level output voltage (SOUT) | IOL = 2 mA at SOUT | | 0.4 | V |
| LOGIC | Logic pin current (SCLK, SIN) | SCLK/SIN = VCC or GND | -1 | 1 | uA |
| R _{DS(ON)} | Scan switches' on-state resistance (LINE0 to LINE15) | VCC = 2.8 V, T _A = 25°C | | 190 | mΩ |
| / _{IREF} | Reference voltage | SCLK/SIN = GND, internal GCLK= 0MHz, GSn = 0000h, BC = 2h, CCR/G/B = 63h, VOUTn = floating, R_{IREF} = 7.8 k Ω | | 0.8 | V |



7.5 Electrical Characteristics (continued)

At VCC = VR = 2.8 V, VG/B = 3.8 V and $T_{\Delta} = -40^{\circ}$ C to +85°C; Typical values are at $T_{\Delta} = 25^{\circ}$ C (unless otherwise specified)

| | PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|--|---|------|------|------|------|
| | | VLEDR/G/B ≥ 2.8 V, all channel outputs on, output current at 1 mA | | | 0.25 | V |
| | | VLEDR/G/B ≥ 2.8 V, all channel outputs on, output current at 5 mA | | | 0.26 | V |
| Channel knee voltage (R0-R15 / G0-G15 / B0-B15) Channel leakage current (R0- | | VLEDR/G/B ≥ 2.8 V, all channel outputs on, output current at 10 mA | | | 0.3 | V |
| | VLEDR/G/B ≥ 2.8 V, IMAX = 1b, all channel outputs on, output current at 15 mA | | | 0.37 | V | |
| | VLEDR/G/B ≥ 2.8 V, IMAX=1b, all channel outputs on, output current at 20 mA | | | 0.41 | V | |
| CH(LKG) | Channel leakage current (R0- R15 / G0-G15 / B0-B15) | Channel voltage at 0 V | | | 1 | uA |
| | All CHn = on, BC = 00h, CC = 31h, VOUTn = (VLED-1)V, R_{IREF} = 19.05 k Ω (I_{CH} = 0.2-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±1 | ±2.5 | % | |
| | | All CHn = on, BC = 00h, CC = 7Dh, VOUTn = (VLED-1)V, R_{IREF} = 19.05 k Ω (I_{CH} = 0.5-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±0.5 | ±1.5 | % |
| | Constant-current channel to | All CHn = on, BC = 00h, CC = FBh, VOUTn = (VLED-1)V, R _{IREF} = 19.05 k Ω (I _{CH} = 1-mA target), T _A = 25°C, includes the V _{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±0.5 | ±1.5 | % |
| channel deviation (R0-R15 / G0-G15 / B0-B15) ⁽¹⁾ | All CHn = on, BC = 2h, CC = FBh, VOUTn = (VLED-1)V, R_{IREF} = 7.8 k Ω (I_{CH} = 5-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±0.5 | ±2 | % | |
| | All CHn = on, BC = 6h, CC = A7h, VOUTn = (VLED-1)V, R_{IREF} = 7.8 k Ω (I_{CH} = 10-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±0.5 | ±2 | % | |
| | | All CHn = on, BC = 7h, CC = FBh, IMAX=1b, VOUTn = (VLED-1)V, RIREF = 6.8 k Ω (I _{CH} = 20-mA target), T _A = 25°C, includes the V _{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±0.5 | ±2.5 | % |

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7.5 Electrical Characteristics (continued)

At VCC = VR = 2.8 V, VG/B = 3.8 V and $T_A = -40$ °C to +85°C; Typical values are at $T_A = 25$ °C (unless otherwise specified)

| | PARAMETER | TEST CONDITIONS | MIN TYP | MAX | UNIT |
|------------------------|--|---|---------|------|------|
| | | All CHn = on, BC = 00h, CC = 31h, VOUTn = (VLED-1)V, R_{IREF} = 19.05 k Ω (I_{CH} = 0.2-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±1 | ±2.5 | % |
| | | All CHn = on, BC = 00h, CC = 7Dh, VOUTn = (VLED-1)V, R _{IREF} = 19.05 k Ω (I _{CH} = 0.5-mA target), T _A = 25°C, includes the V _{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±0.5 | ±1.5 | % |
| | Constant-current device to | All CHn = on, BC = 00h, CC = FBh, VOUTn = (VLED-1)V, R_{IREF} = 19.05 k Ω (I_{CH} = 1-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±0.5 | ±1 | % |
| ΔI _{ERR(DD)} | device deviation (R0-R15 / G0-G15 / B0-B15) ⁽²⁾ | All CHn = on, BC = 2h, CC = FBh, VOUTn = (VLED-1)V, R_{IREF} = 7.8 k Ω (I_{CH} = 5-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±0.5 | ±1.5 | % |
| | | All CHn = on, BC = 6h, CC = A7h, VOUTn = (VLED-1)V, R_{IREF} = 7.8 k Ω (I_{CH} = 10-mA target), T_A = 25°C, includes the V_{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±0.5 | ±2 | % |
| | | All CHn = on, BC = 7h, CC = FBh, IMAX=1b, VOUTn = (VLED-1)V, R_{IREF} = 6.8 k Ω (I _{CH} = 20-mA target), T_A = 25°C, includes the V _{IREF} tolerance, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | ±0.5 | ±2 | % |
| $\Delta I_{REG(LINE)}$ | Line regulation (R0-R15 / G0-G15 / B0-B15) ⁽³⁾ | VLED = 2.5 to 5.5 V, All CHn = on, VOUTn = (VLED-1)V, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±1 | %/V |
| $\Delta I_{REG(LOAD)}$ | Load regulation (R0-R15 / G0-G15 / B0-B15) ⁽⁴⁾ | VOUTn = (VLED-1)V to (VLED-3)V, VR=VG/B=VLED = 3.8 V, All CHn = on, at same color grouped outputs of R0-R15 / G0-G15 / B0-B15 | | ±1 | %/V |
| T _{TSD} | Thermal shutdown threshold | | 170 | | °C |
| T _{HYS} | Thermal shutdown hysteresis | | 15 | | °C |

(1) The deviation of each output in same color group (OUTR0-15 or OUTG0-15 or OUTB0-15) from the average of same color group

$$\Delta(\%) = \left[\frac{I_{Xn}}{\frac{I_{X0} + I_{X1} + \dots + I_{X14} + I_{X15}}{16}} - 1\right] \times 100$$
constant current. The deviation is calculated by the formula. (X = R or G or B, n = 0-15)

(2) The deviation of the average of constant-current in each color group from the ideal constant-current value. (X = R or G or B):

$$\Delta(\%) = \begin{bmatrix} \frac{I_{X0} + I_{X1} + \dots + I_{X14} + I_{X15}}{16} - \text{Ideal Output Current} \\ \hline Ideal Output Current} \end{bmatrix} \times 100$$

$$I_{IDEAL_R(or\ G\ or\ B)} = \frac{V_{IREF}}{R_{IREF}} \times GAIN_{(BC)} \times \frac{1 + CC_R(or\ CC_G\ or\ CC_B)}{256}$$



Line regulation is calculated by the following equation. (X = R or G or B, n = 0-15):

Line regulation is calculated by the following equation:
$$(X - R \text{ or } G \text{ or } B, R - 0 - 15)$$
:
$$\Delta (\%V) = \left[\frac{(I_{Xn} \text{ at } V_{LED} = 5.5 \text{ V}) - (I_{Xn} \text{ at } V_{LED} = 2.5 \text{ V})}{(I_{Xn} \text{ at } V_{LED} = 2.5 \text{ V})} \right] \times \frac{100}{5.5 \text{ V} - 2.5 \text{ V}}$$
Load regulation is calculated by the following equation. $(X = R \text{ or } G \text{ or } B, n = 0 - 15)$:
$$\Delta (\%V) = \left[\frac{(I_{Xn} \text{ at } V_{Xn} = 1 \text{ V}) - (I_{Xn} \text{ at } V_{Xn} = 3 \text{ V})}{(I_{Xn} \text{ at } V_{Xn} = 3 \text{ V})} \right] \times \frac{100}{3 \text{ V} - 1 \text{ V}}$$

$$\Delta (\%V) = \left| \frac{(I_{Xn} at V_{Xn} = 1 V) - (I_{Xn} at V_{Xn} = 3 V)}{(I_{Xn} at V_{Xn} = 3 V)} \right| \times \frac{100}{3 V - 1 V}$$

7.6 Timing Requirements

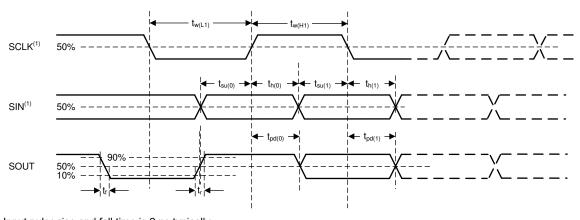
At VCC = VR = 2.8 V, VG/B = 3.8 V and $T_A = -40$ °C to +85°C; Typical values are at $T_A = 25$ °C (unless otherwise specified)

| | PARAMETER | TEST CONDITIONS | MIN | TYP MA | X UNIT |
|--------------------|----------------------------------|-----------------|-----|--------|--------|
| f _{SCLK} | Clock frequency (SCLK) | | | 2 | 5 MHz |
| t _{w(H1)} | High level pulse duration (SCLK) | | 18 | | ns |
| t _{w(L1)} | Low level pulse duration (SCLK) | | 18 | | ns |
| t _{su(0)} | Setup time | SIN to SCLK↑ | 10 | | ns |
| t _{su(1)} | Setup time | SIN to SCLK↓ | 10 | | ns |
| t _{h(0)} | Hold time | SCLK↑ to SIN↑↓ | 2 | | ns |
| t _{h(1)} | Hold time | SCLK↓ to SIN↑↓ | 2 | | ns |

7.7 Switching Characteristics

At VCC = VR = 2.8 V, VG/B = 3.8 V and T_A = -40°C to +85°C; Typical values are at T_A = 25°C (unless otherwise specified)

| | PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--------------------|-------------------|--|-----|-----|------|------|
| t _r | Rise time (SOUT) | VCC = 3.3 V, C _{SOUT} = 30 pF | | 2 | 10 | ns |
| t _f | Fall time (SOUT) | VCC = 3.3 V, C _{SOUT} = 30 pF | | 2 | 10 | ns |
| t _{pd(0)} | Propagation delay | $\begin{array}{c} \text{SCLK}\uparrow \text{ to SOUT}\uparrow\downarrow, \text{ full temperature,} \\ C_{\text{SOUT}} = 30 \text{ pF} \end{array}$ | 3.5 | | 14.2 | ns |
| t _{pd(1)} | Propagation delay | SCLK \downarrow to SOUT $\uparrow\downarrow$, full temperature, $C_{SOUT} = 30 \text{ pF}$ | 3.5 | | 14.2 | ns |

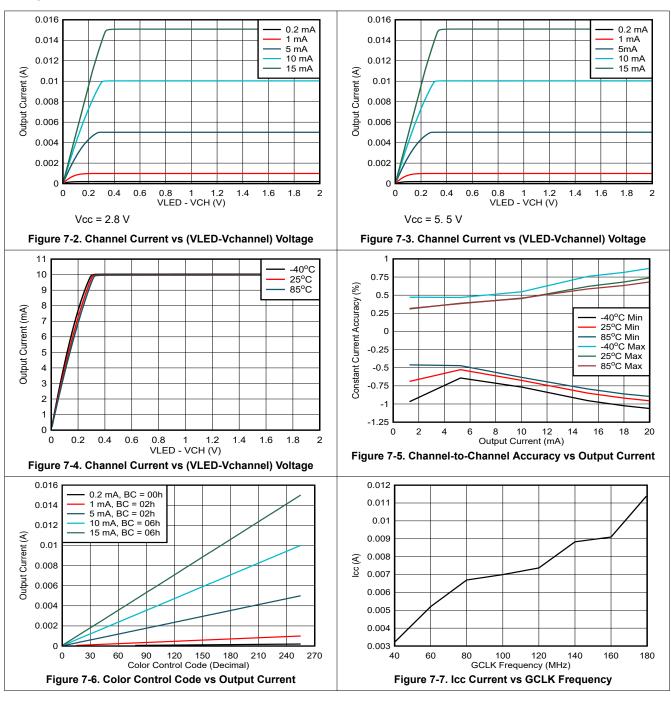


(1). Input pulse rise and fall time is 2 ns typically.

Figure 7-1. Timing and Switching Diagram (Dual Edge)

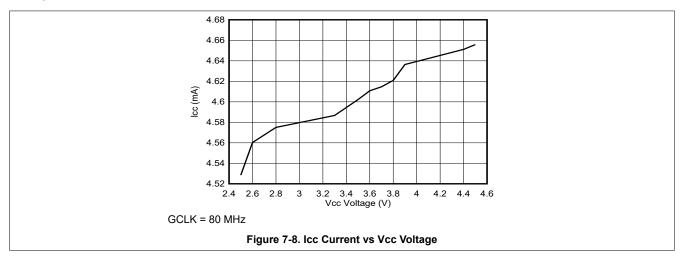


7.8 Typical Characteristics





7.8 Typical Characteristics (continued)



8 Detailed Description

8.1 Overview

The TLC6984 is a highly-integrated, common cathode LED-display driver with 48 constant current sources and 16 scanning FETs. A single TLC6984 is capable of driving 16 \times 16 RGB LED pixels while stacking four TLC6984s can drive 64 \times 64 RGB LED pixels. To achieve low-power consumption, the device supports separated power supplies for the red, green, and blue LEDs by its common cathode structure. Furthermore, the operation power of the TLC6984 is significantly reduced by ultra-low operation voltage range (V_{CC} down to 2.5 V) and ultra-low operation current (I_{CC} down to 3.6 mA).

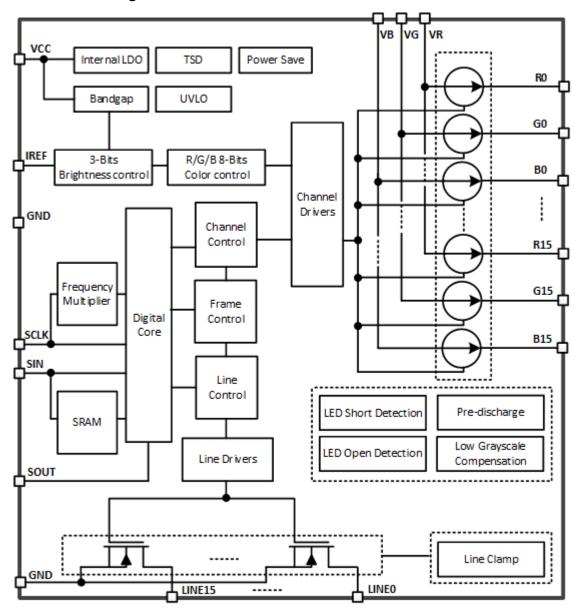
The TLC6984 supports per channel current from 0.2 mA to 20 mA, with typical 0.5% channel-to-channel current deviation and typical 0.5% device-to-device current deviation. The DC current value of all 48 channels is set by an external IREF resistor and can be adjusted by the 8-step global brightness control (BC) and the 256-step per-color group brightness control (CC_R/CC_G/CC_B).

The TLC6984 implements a high-speed, dual-edge transmission interface to support high device count daisy-chained and high-refresh rate while minimizing electrical-magnetic interference (EMI). The TLC6984 supports up to 25-MHz SCLK (external) and up to 160-MHz GCLK (internal). Meanwhile, the device integrates enhanced circuits and intelligent algorithms to solve the various display challenges in Narrow Pixel Pitch (NPP) LED display applications and mini and micro-LED products: dim at the fist scan line, upper and downside ghosting, non-uniformity in low grayscale, coupling, caterpillar caused by open or short LEDs, which make the TLC6984 a perfect choice in such applications.

The TLC6984 also implements LED open, weak-short, short detections and removals during operations and can also report this information out to the accompanying digital processor.



8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Independent and Stackable Mode

The TLC6984 can operate in two different modes: independent or stackable. In independent mode, a single TLC6984 can drive a 16×16 RGB LED matrix, while in stackable mode, up to four TLC6984s can be stacked together, which means the line switches of one device can be shared to the others. Stacking three TLC6984s can drive a 48×48 RGB LED matrix while stacking four TLC6984s can drive a 64×64 RGB matrix. The mode can be configured by the MOD_SIZE (see FC2 for more details).

8.3.1.1 Independent Mode

Figure 8-1 shows an implementation of a 16 × 32 RGB LED matrix using two TLC6984s in independent mode. Each device is responsible for its own 16 ×16 RGB LED matrix which means that all the data for section A is stored in device 1 and the data for section B is stored in device 2.

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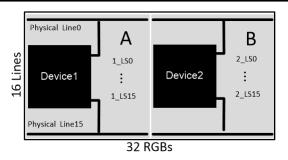


Figure 8-1. Two Devices in Independent Mode

The unused line must be assigned to the last several lines of the device. For example, if there are only 14 scanning lines, then the two unused lines must be assigned to 1 LS14 and 1 LS15.

8.3.1.2 Stackable Mode

Table 8-1 shows operating the TLC6984 in stackable mode.

| Table 8-1. Stackable Mode | | | | | |
|---------------------------|-------------|----------------|--------------------|--|--|
| Mode | Matrix Size | Register Value | Scan Sequence | | |
| Mode1 | 16 × 32 | 000b | D1, D2 independent | | |
| Mode2 | 32 × 32 | 001b | D1->D2 | | |
| Mode3 | 48 × 48 | 010b | D1->D2->D3 | | |
| Mode4 | 48 × 48 | 011b | D1->D3->D2 | | |
| Mode5 | 48 × 64 | 100b | D1->D2->D3 | | |
| Mode6 | 48 × 64 | 101b | D1->D3->D2 | | |
| Mode7 | 64 × 64 | 110b | D1->D2->D3->D4 | | |
| Mode8 | 64 × 64 | 111b | D1->D4->D2->D3 | | |

Table 8-1. Stackable Mode

Figure 8-2 shows that device 2 must be rotated 180° relative to device 1. This action allows the position of line switches to be near the center column of the LED matrix for better routing. For device 1, the lines are connected sequentially (line switch 0 connected to scan line 1). However on device 2, it is connected in reverse order, with the 16th scan line is connected to line switch 15 and the 32th scan line is connected to line switch 0.

Figure 8-2 shows the connection between two TLC6984 devices in stackable mode driving a 32 × 32 RGB LED pixels. The MOD_SIZE must be configured to 001b. Device1 supplies 16 line switches for the first 16 scan line, and device 2 supplies 16 line switches for scan line 17-32. The data for matrix sections A and C are stored in device 1, while matrix sections B and D data are stored in device 2.

To make sure the scanning sequence is still from 1st line to 32nd line, the scan line switching order of the second device must be reversed, This configuration can be completed by the SCAN_REV (see FC4 for more details).



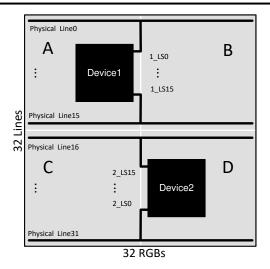


Figure 8-2. Mode2 Diagram

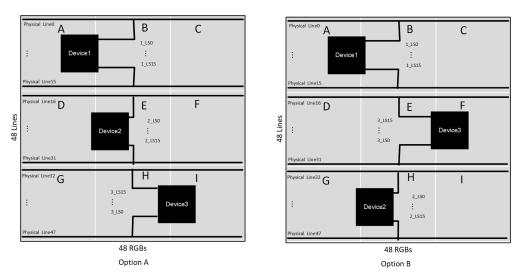


Figure 8-3. Mode3 and Mode4 Diagram

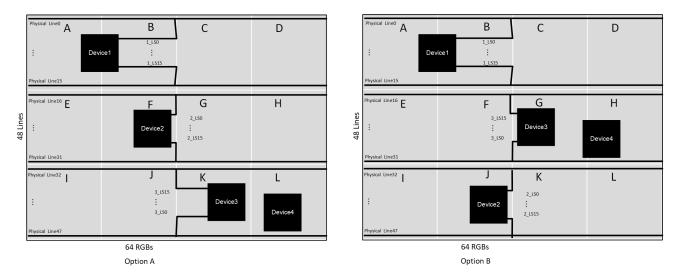
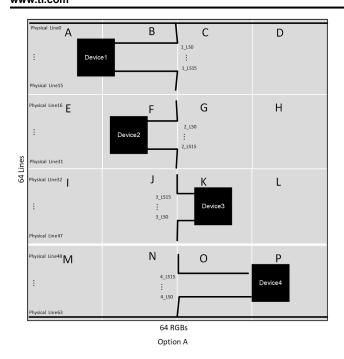


Figure 8-4. Mode5 and Mode6 Diagram

Product Folder Links: TLC6984



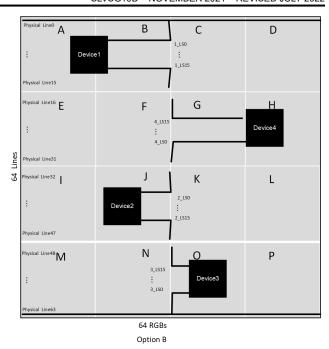


Figure 8-5. Mode7 and Mode8 Diagram

When two TLC6984 devices are used in stackable mode, if there are unused line switches, these unused line switches must be the last line switches of the first or the second device. For example, if there are only 30 scanning lines, and if,

SCAN REV = '0'b, the unused line switches can be either of below,

- 1 LS14, 1 LS15
- 2 LS14, 2 LS15

SCAN REV = '1'b, the unused line switches can be either of below,

- 1_LS14, 1_LS15
- 2 LS1, 2 LS0

If the unused line switches are 1_LS14, 1_LS15, the FC6-FC13 registers must be configured. If the unused line switches are 2_LS14, 2_LS15 when SCAN_REV = '0' or 2_LS1, 2_LS0 when SCAN_REV = '1', there is no need to configure FC6-FC13 registers.

8.3.2 Current Setting

8.3.2.1 Brightness Control (BC) Function

The TLC6984 device is able to adjust the output current of all constant-current outputs simultaneously. This function is called global brightness control (BC). The global BC for all outputs is programmed with a 3-bit register, thus all output currents can be adjusted in 8 steps for a given current-programming resistor, R_{IREF} . When the 3-bit BC register changes, the gain of output current, $GAIN_{BC}$ changes as Table 8-2 below.



Table 8-2. Current Gain Versus BC Code

| BC Register (BC) | Current Gain (GAIN _{BC}) | |
|------------------|------------------------------------|--|
| 000b | 24.17 | |
| 001b | 30.57 | |
| 010b | 49.49 | |
| 011b (default) | 86.61 | |
| 100b | 103.94 | |
| 101b | 129.92 | |
| 110b | 148.48 | |
| 111b | 173.23 | |

The maximum output current per channel, I_{OUTSET} , is determined by resistor R_{IREF} , and the GAIN_{BC}. The voltage on IREF is typically 0.8 V. Use Equation 1 to calculate R_{IREF} . For noise immunity purpose, suggest R_{IREF} < 40 k Ω .

$$R_{IREF}(k\Omega) = \frac{V_{IREF}(V)}{I_{IREF}(mA)} = \frac{V_{IREF}(V)}{I_{OUTSET}(mA)} \times GAIN_{(BC)}$$
(1)

8.3.2.2 Color Brightness Control (CC) Function

The TLC6984 device is able to adjust the output current of each of the three color groups R0-R15, G0-G15, and B0-B15 separately. This function is called color brightness control (CC). For each color, it has 8-bit data register, CC_R, CC_G, or CC_B. Thus, all color group output currents can be adjusted in 256 steps from 0% to 100% of the maximum output current, I_{OUTSET} . Use Equation 2 to calculate the output current of each color, $I_{OUT_R \text{ (or } G \text{ or } B)}$.

$$I_{OUT_R(or\ G\ or\ B)} = I_{OUTSET} \times \frac{1 + CC_R(or\ CC_G\ or\ CC_B)}{256}$$
(2)

Table Table 8-3 shows the CC data versus the constant-current against I_{OUTSET}.

Table 8-3. CC Data vs Current Ratio

| CC Register (CC_R or CC_G or CC_B) | Ratio of I _{OUTSET} | | |
|------------------------------------|------------------------------|--------|--|
| 0000 0000b | 1/256 | 0.39% | |
| 0000 0001b | 2/256 | 0.78% | |
| | | | |
| 0111 1111b (default) | 128/256 | 50% | |
| | | | |
| 1111 1110b | 255/256 | 99.61% | |
| 1111 1111b | 256/256 | 100% | |

8.3.2.3 Choosing BC/CC for a Different Application

BC is mainly used for global brightness adjustment to adapt to ambient brightness, such as between day and night, indoor and outdoor.

- Suggested BC is 3h or 4h, which is in the middle of the range, allowing flexible changes in brightness up and down.
- If the current of one color group (usually R LEDs) is close to the output maximum current (10 mA or 20 mA), to prevent the constant output current from exceeding the upper limit in case a larger BC code is input accidentally, choose the maximum BC value, 7h.

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If the current of one color group (usually B LEDs) is close to the output minimum current (0.2 mA), to prevent the constant output current from exceeding the lower limit in case a lower BC code is input accidentally. choose the minimum BC code. 0h.

CC can be used to fine tune the brightness in 256 steps. This action is suitable for white balance adjustment between RGB color group. To get a pure white color, the general requirement for the luminous intensity ratio of R, G, B LED is 5:3:2. Depending on the characteristics of the LED (Electro-Optical conversion efficiency), the current ratio of R. G. B LED is much different from this ratio. Usually, the Red LED needs the largest current. Choose 255d (the maximum value) CC code for the color group that needs the largest initial current, then choose proper CC code for the other two color groups according to the current ratio requirement of the LED used.

8.3.3 Frequency Multiplier

The TLC6984 has an internal frequency multiplier to generate the GCLK by SCLK. The GCLK frequency can be configured by FREQ MOD (See FC0 for more details) and FREQ MUL (see FC0 for more details) from 40 MHz to 160 MHz. As Figure 8-6 shows, if the GCLK frequency is not higher than 80 MHz, the GCLK_MOD is set to 0 to disable the bypass switch (enable the ½ divider), while the GCLK frequency is higher than 80 MHz, the GCLK_MOD is set to 1 to enable the bypass switch (disable the ½ divider).

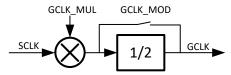


Figure 8-6. Frequency Multiplier Block Diagram

8.3.4 Line Transitioning Sequence

The TLC6984 defines a timing sequence of scan line transition, shown as Figure 8-7. T SW is the total transitioning time. T SW is broken up into four intervals: T0 is the time interval between the end of PWM time in current segment and the beginning of channel pre-discharge, T1 is the time interval between the beginning of the channel pre-discharge and the beginning of current line OFF, T2 is the time interval that the beginning of current line OFF and the beginning of next line ON, T3 is the time interval of the beginning of next line ON and the beginning of PWM time in next segment.

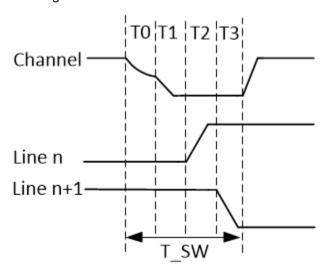


Figure 8-7. Line Transitioning Sequence

The line switch time T_SW equals to T0 + T1 + T2 + T3. T_SW can be configured by the LINE_SWT (see FC1 register bit 40-37 in FC1).

Table 8-4 is the relation between LINE_SWT bits and the line switch time (GCLK numbers) with different internal GCLK frequency.



Table 8-4. Line Switch Time

| LINE_SW T | GCLK Numbers | T_SW (us, 40- MHZ GCLK) | T_SW (us, 60-MHZ GCLK) | T_SW (us, 100-MHZ GCLK) | T_SW (us, 120-MHZ GCLK) | T_SW (us, 160- MHZ GCLK) |
|--------------|-----------------|----------------------------|---------------------------|----------------------------|----------------------------|-----------------------------|
| 0000b | 45 | 1.125 | 0.7515 | 0.45 | 0.3735 | 0.2835 |
| 0001b | 60 | 1.5 | 1.002 | 0.6 | 0.498 | 0.378 |
| 0010b | 90 | 2.25 | 1.503 | 0.9 | 0.747 | 0.567 |
| 0011b | 120 | 3 | 2.004 | 1.2 | 0.996 | 0.756 |
| 0100b | 150 | 3.75 | 2.505 | 1.5 | 1.245 | 0.945 |
| 0101b | 180 | 4.5 | 3.006 | 1.8 | 1.494 | 1.134 |
| 0110b | 210 | 5.25 | 3.507 | 2.1 | 1.743 | 1.323 |
| 0111b | 240 | 6 | 4.008 | 2.4 | 1.992 | 1.512 |
| 1000b | 270 | 6.75 | 4.509 | 2.7 | 2.241 | 1.701 |
| 1001b | 300 | 7.5 | 5.01 | 3 | 2.49 | 1.89 |
| 1010b | 330 | 8.25 | 5.511 | 3.3 | 2.739 | 2.079 |
| 1011b | 360 | 9 | 6.012 | 3.6 | 2.988 | 2.268 |
| 1100b | 390 | 9.75 | 6.513 | 3.9 | 3.237 | 2.457 |
| 1101b | 420 | 10.5 | 7.014 | 4.2 | 3.486 | 2.646 |
| 1110b | 450 | 11.25 | 7.515 | 4.5 | 3.735 | 2.835 |
| 1111b | 480 | 12 | 8.016 | 4.8 | 3.984 | 3.024 |

8.3.5 Protections and Diagnostics

8.3.5.1 Thermal Shutdown Protection

The thermal shutdown (TSD) function turns off all IC constant-current outputs when the junction temperature (T_J) exceeds 170°C (typical). The function resumes normal operation when T_J falls below 155°C (typical).

8.3.5.2 IREF Resistor Short Protection

The IREF resistor short protection (ISP) function prevents unwanted large currents from flowing through the constant-current output when the IREF resistor is shorted accidently. The TLC6984 device turns off all output channels when the IREF pin voltage is lower than 0.19 V (typical). When the IREF pin voltage goes higher than 0.325 V (typical), the TLC6984 device resumes normal operation.

8.3.5.3 LED Open Load Detection and Removal

8.3.5.3.1 LED Open Detection

The LED open detection (LOD) function detects faults caused by an open circuit in any LED, or a short from OUTn to VLED with low impedance. This function was realized by comparing the OUTn voltage to the LOD detection threshold voltage level set by LODVTH_R/LODVTH_G/LODVTH_B (See FC3 for more details). If the OUTn voltage is higher than the programmed voltage, the corresponding output LOD bit is set to 1 to indicate an open LED. Otherwise, the output of that LOD bit is 0. LOD data output by the detection circuit are valid only during the OUTn turning on period.

Figure 8-8 shows the equivalent circuit of LED open detection.

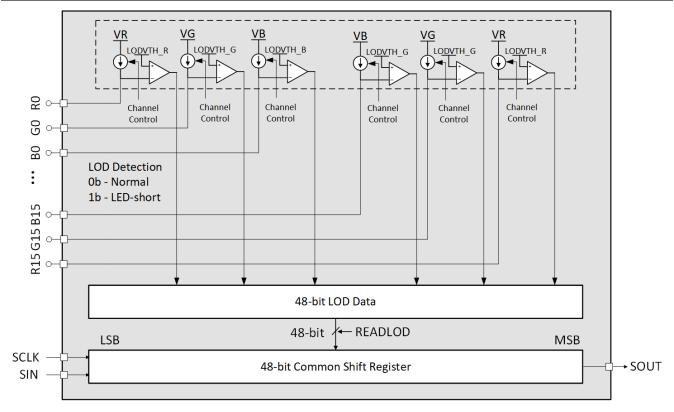


Figure 8-8. LED Open Detection Circuit

The LED open detection function records the position of the open LED, which contains the scan line number and relevant channel number. The scan line order is stored LOD_LINE_WARN register (see FC16, FC17 for more details), and the channel number is latched into the internal 48-bit LOD data register (see FC20 for more details) at the end of each segment. Figure 8-9 shows the bit arrangement of the LOD data register.

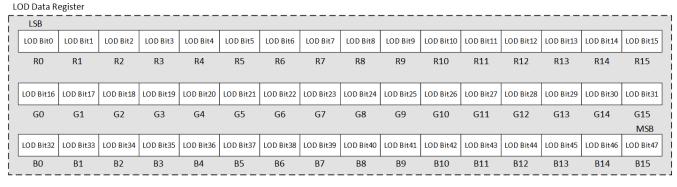


Figure 8-9. Bit Arrangement in LOD Data Register

8.3.5.3.2 Read LED Open Information

The LOD readback function must be enabled before read LED open information. This function is enabled by LOD_LSD_RB (see FC3 for more details).

Figure 8-10 shows the steps to read LED open information. Wait at least one sub-period time between Step2 and Step3 command.



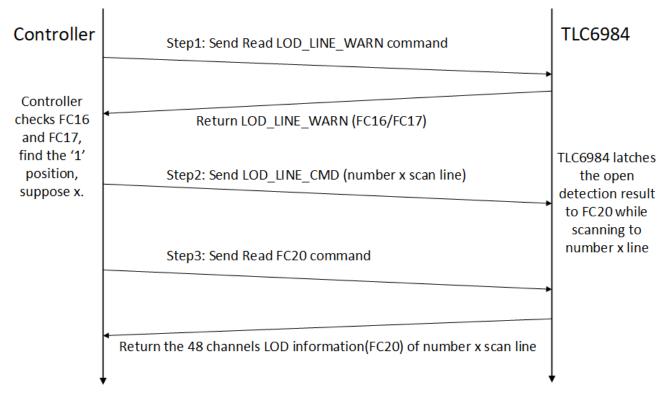


Figure 8-10. Steps to Read LED Open Information

8.3.5.3.3 LED Open Caterpillar Removal

Figure 8-11 shows the caterpillar issue caused by open LED. Suppose the LED0-1 is an open LED. When line0 is chosen and the OUT1 is turned on, the OUT1 voltage is forced to approach to VLED because of the broken path of the current source. However, the voltage of the un-chosen lines are below the Vclamp which is much lower than VLED, causing all LEDs which connect to the channel OUT1, light unwanted.

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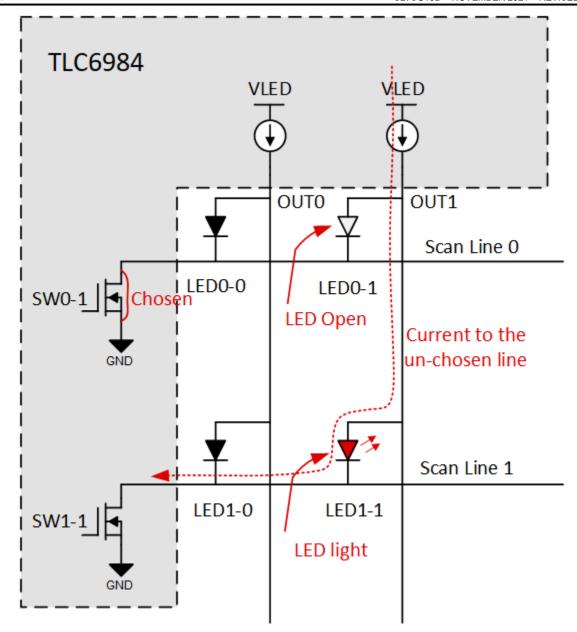


Figure 8-11. LED Open Caterpillar

The TLC6984 implements circuits that can eliminate the caterpillar issue caused by open LEDs. The LED open caterpillar removal function is configured by LOD_RM_EN (see FC0 for more details). When LOD_RM_EN is set to 1b, the caterpillar removal function is enabled. The corresponding channel OUTn is turned off when scanning to line with open LED, The caterpillar issue is eliminated until device resets or LOD_RM_EN is set to 0b.

The internal caterpillar elimination circuit can handle a maximum of three lines that have open LEDs fault condition. If there are open LEDs located in three or fewer lines, the TLC6984 is able to handle the open LEDs all in these lines. If there are open LEDs in more than three lines, the caterpillar issue is solved for the lines where the first three open LEDs were detected, but the open LEDs in the fourth and subsequent lines still cause the caterpillar issue.

8.3.5.4 LED Short and Weak Short Circuitry Detection and Removal

8.3.5.4.1 LED Short and Weak Short Detection

The LED short detection (LSD) function detects faults caused by a short circuit in any LED. This function was realized by comparing the OUTn voltage to the LSD threshold voltage. If the OUTn voltage is lower than the

threshold voltage, the corresponding output LSD bit is set to 1 to indicate an short LED, otherwise, the output of that LSD bit is 0. LSD data output by the detection circuit are valid only during the OUTn turning on period.

LSD weak short can be detected by adjusting threshold voltage, which level is set by LSDVTH_R/LSDVTH_G/LSDVTH_B (See FC3 for more details).

Figure 8-12 shows the equivalent circuit of LED short detection.

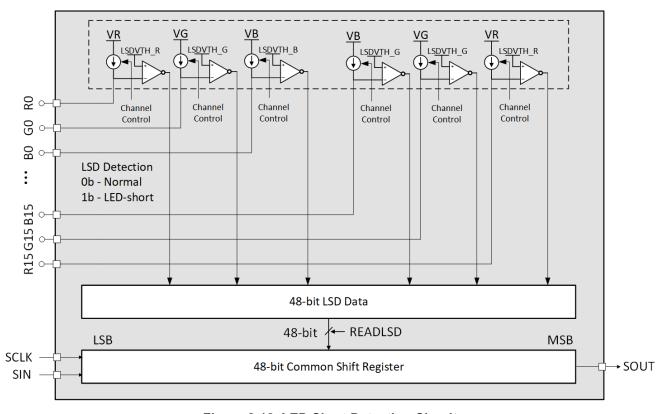


Figure 8-12. LED Short Detection Circuit

The LED short detection function records the position of the short LED, which contains the scan line order and relevant channel number. The scan line order is stored LSD_LINE_WARN register (see FC18 and FC19 for more details), and the channel number is latched into the internal 48-bit LSD data register (see FC21 for more details) at the end of each segment. Figure 8-13 shows the bit arrangement of the LSD data register.

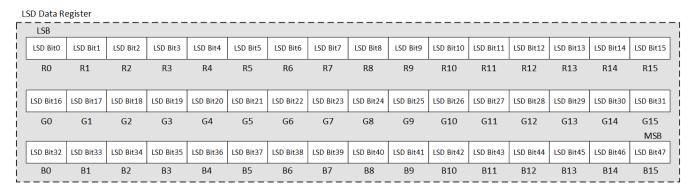


Figure 8-13. Bit Arrangement in the LSD Data Register

8.3.5.4.2 Read LED Short Information

The LSD readback function must be enabled before reading LED Short information. This function is enabled by LOD_LSD_RB (see FC3 for more details).

Product Folder Links: TLC6984

Figure 8-14 shows the steps to read LED Short information. Wait at least one sub-period time between Step2 and Step3 command.

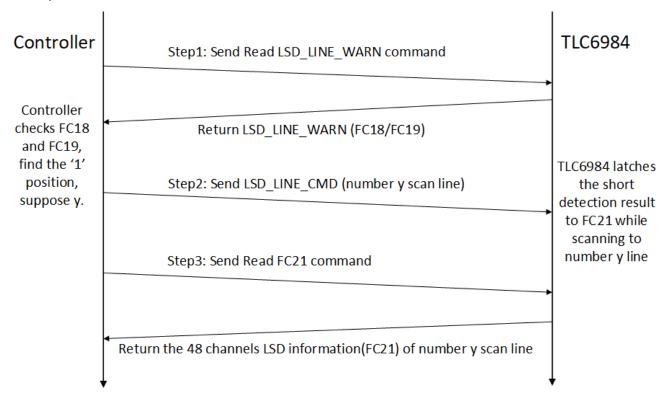


Figure 8-14. Steps to Read LED Short Information

8.3.5.4.3 LSD Caterpillar Removal

Figure 8-15 shows the LSD caterpillar issue caused by short LED. Suppose the LED0-1 is a short LED. When it scans to the line1 and the OUT1 is turned off, the OUT1 voltage is the same with scan line0 voltage because of the short path of the LED0-1. At this time, there is a current path from the line0 to the GND through the LED1-1 and SW1-1, which causes LED1-1 light unwanted.



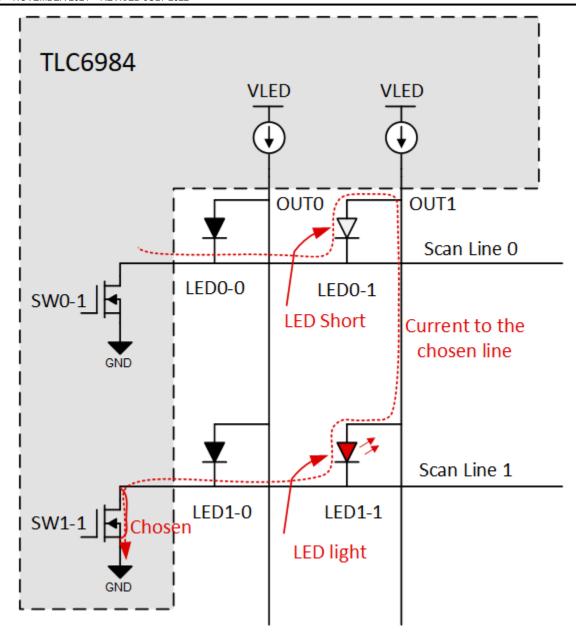


Figure 8-15. LED Short Caterpillar

The TLC6984 device implements internal circuits that can eliminate the caterpillar issue by short LEDs. As is shown in Figure 8-15, the LED short caterpillar is caused by the voltage of the Vclamp on the line. So it can be solved by adjusting the LSD_RM_EN (see FC3 for more details) to let the voltage drop of the LED1-1 be smaller than LED forward voltage.

8.4 Device Functional Modes

The device functional modes are shown in Figure 8-16.

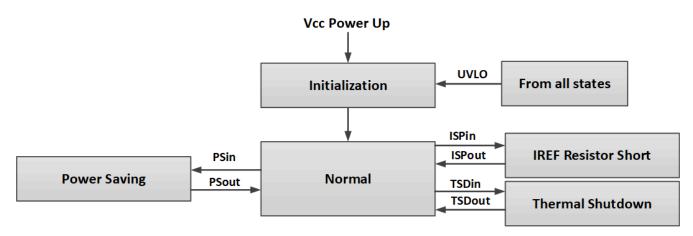


Figure 8-16. Functional Modes

- **Initialization:** the device enters into Initialization when Vcc goes down to UVLO voltage. In this mode, all the registers are reset. Entry can also be from any state.
- **Normal:** the device enters the normal mode when Vcc is higher than UVLO threshold. The display process is shown as below in normal mode.
- Power saving: the device automatically enters and gets out from the power save mode when it detects the
 condition PSin and PSout. In this mode, all channels turn off. PSin: after the device detects that the display
 data of the next frame all equal to zero, it enters to power save mode when the VSYNC comes. PSout: after
 the device detects that there is non-zero display data of the next frame, it gets out from power save mode
 immediately.
- **IREF Resistor Short Protection:** the device automatically enters and gets out from the IREF resistor short protection mode when it detects the condition ISPin and ISPout. In this mode, all channels turn off. ISPin: the device detects that the reference voltage is smaller than 0.195 V ISPout: the device detects that the reference voltage is larger than 0.325 V.
- Thermal Shutdown: the device automatically enters and gets out from the thermal shutdown mode when it
 detects the condition TSDin and TSDout. In this mode, all channels turn off. TSDin: the device detects that
 the junction temperature exceeds 170° C TSDout: the device detects that the junction temperature is below
 155° C.

8.5 Continuous Clock Series Interface

The continuous clock series interface (CCSI) provides access to the programmable functions and registers, SRAM data of the device. The interface contains two input digital pins. the pins are the serial data input (SIN) and serial clock (SCLK). Moreover, there is an another wire called serial data output (SOUT) as the output digital signal of the device. The SIN is set to HIGH when device is in idle status and the SCLK must be existent and continuous all the time considering as the clock source of internal Frequency Multiplier, the SOUT is used to transmit the data or read the data of internal registers.

This protocol can support up to 32 devices cascaded in a data chain. The devices receive the chip index command after power up. The chip index command configures addresses of the devices from 0x00 up to 0x1F according to the sequence that receives the command. Then the controller can communicate with all the devices through the broadcast way or particular device through non-broadcast way.

The broadcast is mainly used to transmit function control commands. All the devices in a data chain receive the same data in this way. The non-broadcast is mainly used to transmit function control commands or display data, and each device receives its own data in this way. These two ways are distinguished by the command identification.

Dual-edge is designed to support more devices cascaded in a data chain.

8.5.1 Data Validity

The data on DIN wire must be stable at rising and falling edges of the SCLK in dual-edge transmission.



8.5.2 CCSI Frame Format

Figure 8-17 defines the format of the command and data transimission. There are four states in one frame.

- IDLE: SCLK is always existent and continuous, and DIN is always HIGH.
- START: DIN changes from HIGH to LOW after the IDLE states.
- DATA:
 - Head_bytes: command identifier that contains one 16-bit data and one check bit. It can be WRITE COMMAND ID or READ COMMAND ID (see Register Maps for more details).
 - Data_bytes_N: The Nth data-bytes, contains 3 × 17-bit data, each 17-bit data contains one 16-bit data and one check bit. N is the number of devices cascaded in a data chain.
- END: the device recognizes continuous 18-bit HIGH on DIN, then returns to IDLE state.
- **CHECK BIT:** the check bit (17th bit) value is the **NOT** of 16th bit value, to avoid continuous 18-bit HIGH (to distinguish with END).

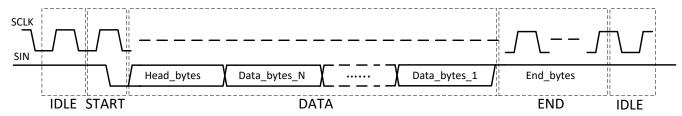


Figure 8-17. CCSI Frame

The IDLE state is not the necessary, that means the START state of next frame can connect to the END state of current frame.

8.5.3 Write Command

Take m devices cascaded in a data chain for example.

8.5.3.1 Chip Index Write Command

The chip index is used to set the identification of the device cascaded in a data chain. When the first device receives the chip index command Head_bytes1, it sets the current address to 00h and meanwhile change the chip index command Head_bytes2, then sends to the next device. When the device receives the Head_bytes2, it sets the address to 01h and meanwhile changes the chip index command Head_bytes3, then sends to the next device, likewise, all the cascaded devices get their unique identifications.

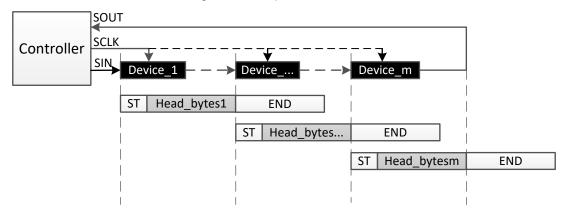


Figure 8-18. Chip Index Write Command

8.5.3.2 VSYNC Write Command

The VSYNC is used to sync the display of each frame for the devices in a cascaded chain. The VSYNC is a write-only command. The devices receive VSYNC command one time from the controller in each frame, and the VSYNC command must be active for all devices at the same time.

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Because some devices receive the command earlier in the data chain, they must wait until the last device receives the command, then all the devices are active at that time. To realize such function, each device must know its delay time from receiving VSYNC command to enabling VSYNC. The device uses some register bits to restore the device number in a data chain. This number minuses the device identification, and the result is the delay time of the device.

Because the sync function has been done by the device, the controller must only send the VSYNC command to the first device in a data chain.

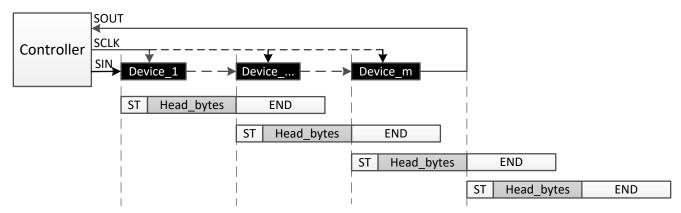


Figure 8-19. VSYNC Write Command

8.5.3.3 MPSM Write Command

The MPSM command is used to control the intelligent power save mode of devices in the same matrix. The device detects all zero data in a stackable module and receives MPSM command in current frame, then when VSYNC command comes, all devices in the same matrix turn off. After the device detects that there is non-zero display data of the next frame, it gets out from intelligent power save mode until MSPM command comes in current frame.



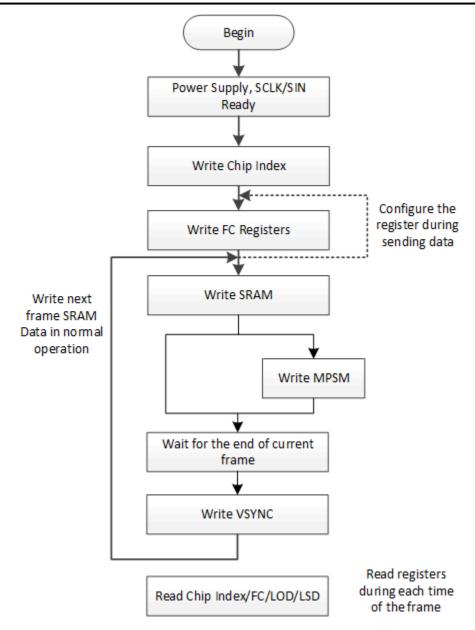


Figure 8-20. Design Procedure for MPSM Command

8.5.3.4 Standby Clear and Enable Command

Standby clear command and standby enable command are used to control intelligent power save mode of devices in the same daisy chain. When the device receives standby enable command, it enters to intelligent power save mode right away and does not have to wait for other devices in a module or daisy chain. After the device receives standby enable command, it exits from intelligent power save mode immediately and does not wait for other devices in a module or daisy chain.

8.5.3.5 Soft Reset Command

The Soft_Reset Command is used to reset all the function registers to the default value, except for SRAM data. The format of this command is the same with VSYNC shown as VYSNC Write Command. The difference is the headbytes.

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8.5.3.6 Data Write Command

The device can receive the function control with broadcast and non-broadcast way, which depends on the configuration of the devices. If the cascaded devices have the same configuration, broadcast is used, if the cascaded devices have the different configurations, non-broadcast is used. The MSB is always transmitted first and the LSB transmitted last. For 48-bits RGB data, the Blue data must be transmitted first, then the Green, and last the Red data.

For broadcast, the devices receive the same data. When devices recognize the broadcast command, they copy the data to the internal registers. Generally, broadcast is used for write FC0-FC13 command, LOD/LSD.

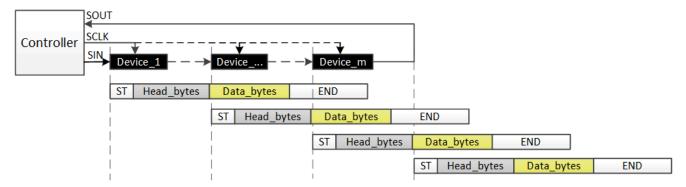


Figure 8-21. Data Write Command with Broadcast

Figure 8-22 shows the time diagram of the data write command with broadcast.

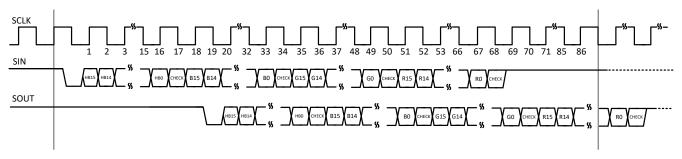


Figure 8-22. Data Write Command with Broadcast (Timing Diagram)

For non-broadcast, the devices receive the different data, the controller prepares the data as the figure shows. One pixel data is written to the corresponding device in each command. When the first device receives the END, it cuts off the last 51-bit (3 × 17 bit) data before the END, and the left are shifted out from SDO to the second device. Similarly, when the second device receives the END bytes from the former device, it cuts off the last 51-bit (3×17 bit) data before the END, and the left are shifted out to the next device. Generally, non-broadcast is used for write SRAM command (WRTGS), Details for how to write a frame data into memory bank can be found in *Write a Frame Data into Memory Book*.

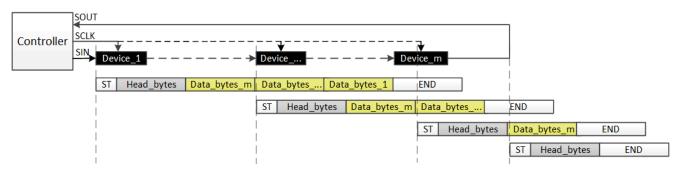


Figure 8-23. Data Write Command with Non-Broadcast



Figure 8-24 shows the time diagram of the data write command with non-broadcast.

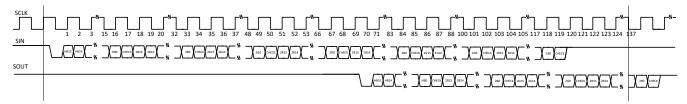


Figure 8-24. Data Write Command with Non-Broadcast (Timing Diagram)

8.5.4 Read Command

The controller sends the read command. When the first device receives this command, it inserts its 48-bit data before End_bytes, and meanwhile shifts out to the second device. When the second device receives this command, it inserts its 48-bit data before End_bytes and meanwhile shifts out to the third device. The data of all the device shifts out from the last device SOUT with this flow. It is always the MSB transmitted first and the LSB transmitted last.

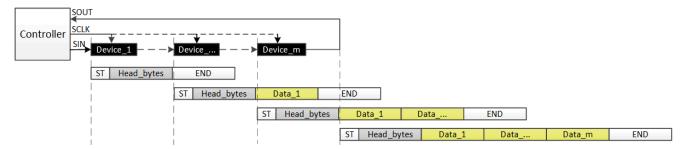


Figure 8-25. Data Read Command

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8.6 PWM Grayscale Control

8.6.1 Grayscale Data Storage and Display

8.6.1.1 Memory Structure Overview

The TLC6984 implements a display memory unit to achieve high refresh rate and high contrast ratio in an LED display products. The internal display memory unit is divided into two BANKs: BANK A and BANK B. During the normal operation, one BANK is selected to display the data of current frame, another is used to restore the data of next frame. The BANK switcher is controlled by the BANK SEL bit, which is an internal flag register bit.

After power on, BANK_SEL is initialized to 0, and BANK A is selected to restore the data of next frame. Meanwhile, the data in BANK B is read out for display. When one frame has elapsed, the controller sends the vertical synchronization (VSYNC) command to start the next frame, the BANK_SEL bit value is toggled and the selection of the two BANKs reverses. Repeat this operation until all the frame images are displayed.

With this method, the TLC6984 device can display the current frame image at a very high refresh rate. See Figure 8-26 for more details about the BANK-selection exchange operation.

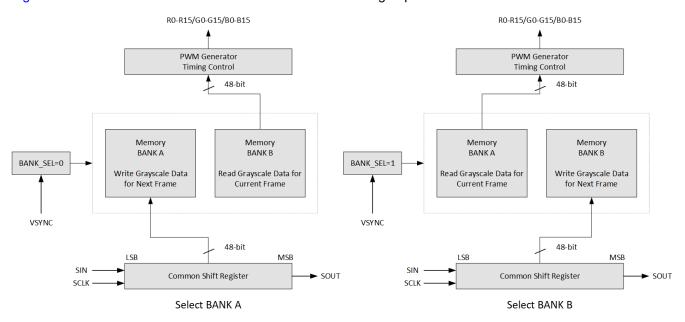


Figure 8-26. Bank Selection Exchange Operation

8.6.1.2 Details of Memory Bank

Each memory BANK contains the frame-image grayscale data of all the 64 lines. Each line comprises 16 48-bit-width memory units. Each memory unit contains the grayscale data of the corresponding R/G/B channels.

Depending on the number of scan lines set in SCAN_NUM (FC0 bit 21 to bit 16), the total number of memory units that must be written in one BANK is: 48×10^{-5} the number of scan lines. For example, if the number of scan lines is set to 64, then 3072 ($64 \times 48 = 3072$) memory units must be written during each frame period.

Figure 8-27 shows the detailed memory structure of the TLC6984 device.



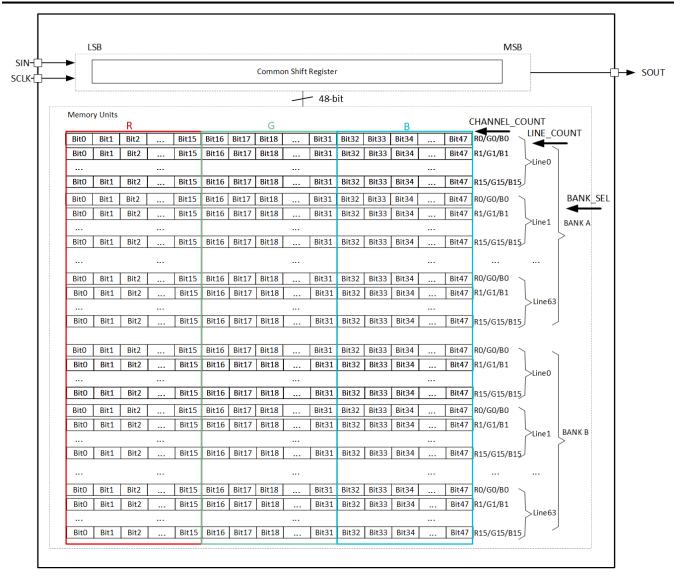


Figure 8-27. TLC6984 Memory-unit Structure

8.6.1.3 Write a Frame Data into Memory Bank

After power on, the TLC6984 internal flag BANK_SEL, and counters LINE_COUNT, CHANNEL_COUNT, are all initialized to 0. Thus, the memory unit of channel R0/G0/B0, locating in line 0 of BANK A, is selected to restore the data transimitted the first time after VSYNC command.

When the first WRTGS command is received, all the data in the common shift register is latched into the memory unit of channel R0/G0/B0, locating in line 0 of BANK A. Then CHANNEL_COUNT increases by 1 and LINE_COUNT stays the same. Thus, the memory unit of channel R1/G1/B1, locating in line 0 of BANK A, is selected to restore the data transimitted the second time after VSYNC command.

When the second WRTGS command is received, all the data in the common shift register is latched into the memory unit of channel R1/G1/B1, locating in line 0 of BANK A. Then CHANNEL_COUNT increases by 1 and LINE_COUNT stays the same. Thus, the memory unit of channel R2/G2/B2, locating in line 0 of BANK A, is selected to restore the data transimitted the third time after VSYNC command.

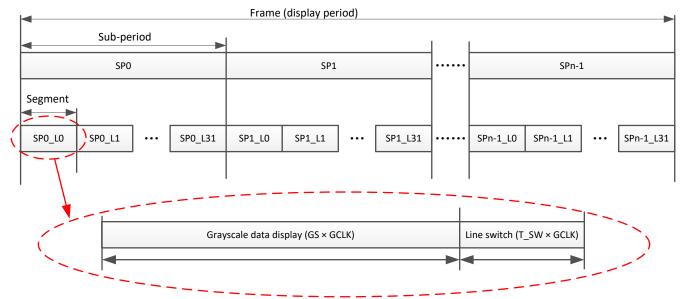
Repeat the grayscale-data-write operation until the 16th WRTGS command is received. Then CHANNEL_COUNT is reset to 0 and LINE_COUNT increases by 1. Thus, the memory unit of channel R0/G0/B0, locating in line 1 of BANK A, is selected to restore the data transimitted the 17th time after VSYNC command.

Repeat this operation for each line until the LINE_COUNT exceeds the number of scan lines set in the SCAN_NUM (See FC0 register bit21-16) and all scan lines have been updated with new GS data, which means one frame of GS data is restored into the memory BANK. Then the LINE COUNT is reset to 0.

8.6.2 PWM Control for Display

To increase the refresh rate in time-multiplexing display system, an DS-PWM (Dynamic Spectrum- Pulse Width Modulation) algorithm is proposed in this device. One frame is divided into many segments shown as below. Note that one frame is divided into n sub-periods, n is set by SUBP_NUM (FC0 register bit24-22), and each sub-period is divided into 32 segments for 32 scan lines. Each segment contains GS GCLKs time for grayscale data display and T_SW GCLKs time for switching lines. GS is configured by the SEG_LENGTH (FC1 register bit9-0 in Table 8-8), and T_SW is the line switch time, which is configured by the LINE_SWT (see FC1 register bit 40-37 in Table 8-8).





Note that, SPO: Sub-period 0, LO: Scan line 0

Figure 8-28. DS-PWM Algorithm with 32 Scan Lines

The DS-PWM can not only increase the refresh rate meanwhile keep the same frame rate, but also decrease the brightness loss in low grayscale, which can smoothly increase the sub-period number when the grayscale data increases.

To achieve ultra-low luminance, the LED driver must have the ability to output a very short current pulse (1 GCLK time). However, because of the parasitic capacitor of the LEDs, such pulse can not turn on the LEDs. And the larger GCLK frequency is, the harder to turn on LEDs.

The DS-PWM algorithm has a parameter called sub-period threshold, which is used to calculate when to change sub-period number according to the giving grayscale data. Sub-period threshold defines the LED minimum turn-on time, so as to conquer the current loss caused by LED parasitic capacitor. Sub-period threshold is configured by the SUBP_TH_R/G/B (FC1 register bit24-10 in Table 8-8).

With DS-PWM algorithm, the brightness has smoothly increased with the gradient grayscale data.

8.7 Register Maps

Table 8-5. Register Maps

| Tuble 6 6. Register maps | | | | | |
|--------------------------|------|---------------------|--------------------|--|--|
| REGISTER NAME | TYPE | WRITE COMMAND ID | READ COMMAND ID | DESCRIPTION | |
| FC0 | R/W | AA00h | AA60h | Common configuration | |
| FC1 | R/W | AA01h | AA61h | Common configuration | |
| FC2 | R/W | AA02h | AA62h | Common configuration | |
| FC3 | R/W | AA03h | AA63h | Common configuration | |
| FC4 | R/W | AA04h | AA64h | Common configuration | |
| FC14 | R/W | AA0Eh | AA6Eh | Locate the line for LOD | |
| FC15 | R/W | AA0Fh | AA6Fh | Locate the line for LSD | |
| FC16 | R | | AAA0h | Read the lines' warning of LOD from 64th ~ 49th line | |
| FC17 | R | | AAA1h | Read the lines' warning of LOD from 48th~1st line | |
| FC18 | R | | AAA2h | Read the lines' warning of LSD from 64th ~ 49th line | |
| FC19 | R | | AAA3h | Read the lines' warning of LSD from 48th~1st line | |
| FC20 | R | | AAA4h | Read the channel's warning of LOD | |

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Table 8-5. Register Maps (continued)

| | issue of the groups (commisses) | | | | | | | | | |
|---------------|---------------------------------|---------------------|--------------------|---|--|--|--|--|--|--|
| REGISTER NAME | TYPE | WRITE COMMAND ID | READ COMMAND ID | DESCRIPTION | | | | | | |
| FC21 | R | | AAA5h | Read the channel's warning of LSD | | | | | | |
| Chip Index | R/W | AA10h | AA70h | Read/Write chip index | | | | | | |
| VSYNC | W | AAF0h | | Write VSYNC command | | | | | | |
| MPSM | W | AA90h | | Write matrix PSM command | | | | | | |
| SBY_CLR | W | AAB0h | | Write standby clear command | | | | | | |
| SBY_EN | W | AAB1h | | Write standby enable command | | | | | | |
| Soft_Reset | W | AA80h | | Reset the all the registers expect the SRAM | | | | | | |
| SRAM | W | AA30h | | Write or read the SRAM data | | | | | | |

Table 8-6. Access Type Codes

| Table 6 6. Addeds Type Godes | | | | | | | | |
|------------------------------|-------|--|--|--|--|--|--|--|
| Access Type | Code | Description | | | | | | |
| Read Type | | | | | | | | |
| R | R | Read | | | | | | |
| Write Type | | | | | | | | |
| W | W | Write | | | | | | |
| Reset or Default | Value | | | | | | | |
| -n | | Value after reset or the default value | | | | | | |

8.7.1 FC0

FC0 is shown in Figure 8-29 and described in Table 8-7.

Figure 8-29. FC0 Register

| | | | | i igule 0-23. i Ob ikegistei | | | | | | | | | | | |
|---------------|----------|------|--------------|------------------------------|------------|------------|------------|------------|------------|----------------|----|----------|----------|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| LSD_R M_EN | RESE | RVED | G | RP_DLY_ | _B | G | GRP_DLY_G | | | RP_DLY_ | _R | RESERVED | | | |
| R/ W-0b | R/W | -01b | F | R/W-0001 |) | I | R/W-000b | | F | R/W-000b | | | R/W-00b | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| FI | REQ_MU | JL | FREQ_ MOD | R | RESERVED | | SUBP_NUM | | | SCAN_NUM | | | | | |
| F | R/W-0111 | b | R/ W-0b | F | R/W-000b |) | R/W-000b | | | R/W-000000b | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| LODR M_EN | PSP_ | MOD | PS_EN | R | ESERVE | D | PDC_E N | R | ESERVE | ERVED CHIP_NUM | | | М | | |
| R/ W-0b | R/W | -00b | R/ W-0b | R/ W-0b | R/ W-0b | R/ W-0b | R/ W-1b | R/ W-0b | R/ W-0b | R/ W-0b | | R | /W-00111 | lb | |

Table 8-7. FC0 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|-----|----------|------|--------|---|
| 4-0 | CHIP_NUM | R/W | 00111b | Set the device number 00000b: 1 device 01111b: 16 devices |
| | | | | UTITID: 16 devices |
| | | | | 11111b: 32 devices |
| 7-5 | RESERVED | R/W | 000b | |
| 8 | PDC_EN | R/W | 1b | Enable or disable pre-discharge function 0b: disable 1b: enable |

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Table 8-7. FC0 Register Field Descriptions (continued)

| Bit | Field | Type | Reset | Descriptions (continued) |
|-------|-----------|------|---------|--|
| 11-9 | RESERVED | R/W | 000b | |
| 12 | PS_EN | R/W | 0b | Enable or disable the power saving mode 0b: disable 1b: enable |
| 14-13 | PSP_MOD | R/W | 00b | Set the powering saving plus mode 00b: disable 01b: enable, when GSn(including the extending) ≤ 1/4 segment_length, power saving during the off cycle. 10b: enable, when GSn(including the extending) ≤ 1/2 segment_length, power saving during the off cycle. 11b: enable, when GSn(including the extending) ≤ 7/8 segment_length, power saving during the off cycle. |
| 15 | LODRM_EN | R/W | 0b | Enable or disable the LED open load removal function 0b: disable 1b: enable |
| 21-16 | SCAN_NUM | R/W | 000000b | Set the scan line number 000000b: 1 line 001111b: 16 lines |
| | | | | 011111b: 32 lines |
| | | | | 111111b: 64 lines |
| 24-22 | SUBP_NUM | R/W | 000b | Set the subperiod number 000b: 16 001b: 32 010b: 48 011b: 64 100b: 80 101b: 96 110b: 112 111b: 128 |
| 27-25 | RESERVED | R/W | 000b | |
| 28 | FREQ_MOD | R/W | 0b | Set the GCLK multiplier mode 0b: high frequency mode, 80MHz to 160MHz 1b:low frequency mode, 40MHz to 80MHz |
| 32-29 | FREQ_MUL | R/W | 0111b | Set the GCLK multiplier frequency 0000b: 1 x SCLK frequency 0111b: 8 x SCLK frequency 1111b: 16 x SCLK frequency |
| 35-33 | LINE_CHRG | R/W | 000b | |
| 38-36 | GRP_DLY_R | R/W | 000b | Set the Red group delay, forward PWM mode only 000b: no delay 001b: 1 GCLK 010b: 2 GCLK 011b: 3 GCLK 100b: 4 GCLK 101b: 5 GCLK 111b: 7 GCLK |
| 41-39 | GRP_DLY_G | R/W | 000b | Set the Green group delay, forward PWM mode only 000b: no delay 001b: 1 GCLK 010b: 2 GCLK 011b: 3 GCLK 100b: 4 GCLK 101b: 5 GCLK 111b: 7 GCLK 111b: 7 GCLK |

Table 8-7. FC0 Register Field Descriptions (continued)

| Bit | Field | Туре | Reset | Description |
|-------|-----------|------|-------|---|
| 44-42 | GRP_DLY_B | R/W | 000Ь | Set the Blue group delay, forward PWM mode only 000b: no delay 001b: 1 GCLK 010b: 2 GCLK 011b: 3 GCLK 100b: 4 GCLK 101b: 5 GCLK 110b: 6 GCLK 111b: 7 GCLK |
| 46-45 | RESERVED | R/W | 01b | |
| 47 | LSD_RM_EN | R/W | 0b | Enable or disable short LED caterpillar 0b: disable 1b: enable |



8.7.2 FC1

FC1 is shown in Figure 8-30 and described in Table 8-8.

Figure 8-30. FC1 Register

| | | <u></u> | | | | | | <u> </u> | | | | | | | |
|---------------|------------------|-----------|----------------------|------|-------|----|---------------------|----------|-------|----|----|------------|-------|--------------|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| RESE RVED | BLK_ADJ | | | | | | LINE_SWT LG_ENH_B | | | | | | | LG_EN H_G | |
| R-0b | R/W-000000b | | | | | | | R/W- | 0111b | | | R/W- | 0000b | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| L | G_ENH_G LG_ENH_R | | | | | | LG_STEP_B LG_STEP_G | | | | | | ΓEP_G | | |
| R | R/W-0000 | b | | R/W- | 0000b | | R/W-01001b | | | | | R/W-01001b | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| LG_ST EP_G | | LG_STEP_R | | | | | SEG_LENGTH | | | | | | | | |
| | | R | /W-0100 ⁻ | 1b | | | R/W-0'000'000'000b | | | | | | | | |

Table 8-8. FC1 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|-------|------------|------|--------------------|--|
| 9-0 | SEG_LENGTH | R/W | 00P 0,000,000,0 | Set the GCLK number in each segment 127d: 128 GCLK 1023d: 1024 GCLK others: 128 GCLK |
| 14-10 | LG_ENH_B | R/W | 01001Ь | Adjust the smooth of the brightness in low grayscale 00000b: level 1 01111b: level 16 11111b: level 32 |
| 19-15 | LG_ENH_G | R/W | 01001ь | Adjust the smooth of the brightness in low grayscale 00000b: level 1 01111b: level 16 11111b: level 32 |
| 24-20 | LG_ENH_B | R/W | 01001ь | Adjust the smooth of the brightness in low grayscale 00000b: level 1 01111b: level 16 11111b: level 32 |
| 28-25 | LG_STEP_R | R/W | 0000Ь | Adjust low grayscale enhancement of red channels 0000b: level 0 0111b: level 7 1111b: level 15 |
| 32-29 | LG_STEP_G | R/W | 0000Ь | Adjust low grayscale enhancement of green channels 0000b: level 0 0111b: level 7 1111b: level 15 |
| 36-33 | LG_STEP_B | R/W | 0000Ь | Adjust low grayscale enhancement of blue channels 0000b: level 0 0111b: level 7 1111b: level 15 |

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Table 8-8. FC1 Register Field Descriptions (continued)

| Bit | Field | Туре | Reset | Description Description |
|-------|----------|------|---------|---|
| 40-37 | LINE_SWT | R/W | 0111b | Set the scan line switch time. 0000b: 45 GCLK 0001b: 2x30 GCLK 0111b: 8x30 GCLK 1111b: 16x30 GCLK |
| 46-41 | BLK_ADJ | R/W | 000000Ь | Set the black field adjustment 000000b: 0 GCLK 011111b: 31 GCLK 111111b: 63 GCLK |
| 47 | RESERVED | R | 0b | Reserved bit. |

8.7.3 FC2

FC2 is shown in Figure 8-31 and described in Table 8-9.

Figure 8-31. FC2 Register

| | | | | | | . igaic | | 1 02 Kegistei | | | | | | | |
|-------------|--------------|---------|----------|---------|------------|-----------------------|-----------------------|-----------------------|----|-----------------|---------|--------------|-------|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| MPSM _EN | RESE RVED | N | MOD_SIZE | | | CH_B_ IMMU NITY | CH_G_ IMMU NITY | CH_R_ IMMU NITY | R | ESERVE | D | LG_COLOR_B | | | |
| R/ W-0b | R/ R/W-111b | | |) | R/ W-0b | R/ W-1b | R/ W-1b | R/ W-1b | F | R/W-000b R/W-00 | | | 0000b | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | LG_CO | LOR_G | | | LG_CO | LOR_R | | DE_COUPLE1_B | | | | DE_COUPLE1_G | | | |
| | R/W-0 | 0000b | | | R/W-0 | 0000b | | R/W-0000b | | | | R/W-0000b | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | DE_COL | JPLE1_R | 1 | V_PDC_B | | | | V_PDC_G | | | V_PDC_R | | | | |
| | R/W-0 | 0000b | | | R/W-0 | 0110b | | R/W-0110b | | | | R/W-0110b | | | |

Table 8-9. FC2 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|-----|---------|------|-------|---|
| 3-0 | V_PDC_R | R/W | 0110b | Set the Red pre_discharge voltage (typical), the voltage value must not be higher than (VR-1.3 V). 0000b: 0.1 V 0001b: 0.2 V 0010b: 0.3 V 0011b: 0.4 V 0100b: 0.5 V 0101b: 0.6 V 0111b: 0.8 V 1000b: 0.9 V 1001b: 1.0 V 1011b: 1.3 V 1100b: 1.5 V 1111b: 1.3 V 1110b: 1.7 V 1111b: 1.9 V 1111b: 2.1 V |

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Table 8-9. FC2 Register Field Descriptions (continued)

| Bit | Field | Туре | Reset | Description (Continued) |
|-------|--------------|------|-------|---|
| 7-4 | V_PDC_G | R/W | 0110b | Set the Green pre_discharge voltage (typical), the voltage value must not be higher than (VG-1.3V). 0000b: 0.1 V 0001b: 0.2 V 0010b: 0.3 V 0011b: 0.4 V 0100b: 0.5 V 0101b: 0.6 V 0110b: 0.7 V 0111b: 0.8 V 1000b: 0.9 V 1001b: 1.0 V 1011b: 1.3 V 1100b: 1.5 V 1110b: 1.7 V 1110b: 1.9 V 1111b: 2.1 V |
| 11-8 | V_PDC_B | R/W | 0110b | Set the Blue pre_discharge voltage (typical), the voltage value must not be higher than (VB-1.3V). 0000b: 0.1V 0001b: 0.2 V 0010b: 0.3 V 0011b: 0.4 V 0100b: 0.5 V 0110b: 0.7 V 0111b: 0.8 V 1000b: 0.9 V 1001b: 1.0 V 1010b: 1.1 V 1011b: 1.3 V 1100b: 1.5 V 1110b: 1.7 V 1111b: 2.1 V |
| 15-12 | DE_COUPLE1_R | R/W | 0000b | Set the Red dummy rising one-shot level 0000b: level 1 (lowest) 0111b: level 8 (middle) 1111b: level 16(highest) |
| 19-16 | DE_COUPLE1_G | R/W | 0000Ь | Set the Green dummy rising one-shot level 0000b: level 1 (lowest) 0111b: level 8 (middle) 1111b: level 16(highest) |
| 23-20 | DE_COUPLE1_B | R/W | 0000Ь | Set the Blue dummy rising one-shot level 0000b: level 1 (lowest) 0111b: level 8 (middle) 1111b: level 16(highest) |
| 27-24 | LG_COLOR_R | R/W | 0000Ь | Set the Red rising one-shot level 0000b: level 1 (lowest) 0111b: level 8 (middle) 1111b: level 16(highest) |

Table 8-9. FC2 Register Field Descriptions (continued)

| Bit | Field | Type | Reset | Descriptions (continued) |
|-------|---------------|------|-------|---|
| | | | | • |
| 31-28 | LG_COLOR_G | R/W | 0000b | Set the Green rising one-shot level 0000b: level 1 (lowest) |
| | | | | 0111b: level 8 (middle) |
| | | | | 1111b: level 16(highest) |
| 35-32 | LG_COLOR_B | R/W | 0000b | Set the Blue rising one-shot level 0000b: level 1 (lowest) |
| | | | | 0111b: level 8 (middle) |
| | | | | 1111b: level 16(highest) |
| 38-36 | RESERVED | R/W | 000b | |
| 39 | CH_R_IMMUNITY | R/W | 1b | Set the immunity of the Red channels group 0b: high immunity 1b: low immunity |
| 40 | CH_G_IMMUNITY | R/W | 1b | Set the immunity of the Green channels group 0b: high immunity 1b: low immunity |
| 41 | CH_B_IMMUNITY | R/W | 1b | Set the immunity of the Blue channels group 0b: high immunity 1b: low immunity |
| 42 | SUBP_MAX_256 | R/W | 0b | Set the maximum subperiod to 256. 0b: disable 1b: enable |
| 45-43 | MOD_SIZE | R/W | 111b | Set the module size. 000b: 16x16 RGB pixels 001b:32x32 RGB pixels 010b:48x48 RGB pixels with D3 reverse, and scan sequence D1, D2, D3 48x48 RGB pixels with D3 reverse, and scan sequence D1, D3, D2 100b:48x64 RGB pixels with D3, D4 reverse, and scan sequence D1, D2, D3 101b:48x64 RGB pixels with D3,D4 reverse, and scan sequence D1, D3, D2 110b:64x64 RGB pixels with D3, D4 reverse, and scan sequence D1, D3, D2 110b:64x64 RGB pixels with D3, D4 reserve, and scan sequence D1, D2, D3, D4 111b:64x64 RGB pixels with D3, D4 reverse, and scan sequence D1, D4, D2, D3 |
| 46 | RESERVED | R/W | 0b | |
| 47 | MPSM_EN | R/W | 0b | Enable or disable matrix power saving mode. 0b: disable 1b: enable |

8.7.4 FC3

FC3 is shown in Figure 8-32 and described in Table 8-10.

Figure 8-32. FC3 Register

| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
|----------------|---------------------------|----|----|----------|--------|----------------|----------|------|----|------|-------|----|----|----------|----|
| L | LSDVTH_B LSDVTH_G LSDVTH_ | | | | SDVTH_ | R LSD_RM BC | | | | | | | | | |
| I | R/W-000k |) | F | R/W-000k |) | ı | R/W-000k |) | | R/W- | 0111b | | ı | R/W-011k | , |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | | | CC | B | | | | CC_G | | | | | | | |
| R/W-0111 1111b | | | | | | R/W-0111 1111b | | | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |



Figure 8-32. FC3 Register (continued)

| CC_R | LOD_L SD_RB | RESE RVED | LODVTH_B | LODVTH_G | LODVTH_R |
|----------------|----------------|--------------|----------|----------|----------|
| R/W-0111 1111b | R/ W-0b | R/ W-0b | R/W-00b | R/W-00b | R/W-00b |

Table 8-10. FC3 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|-------|------------|------|------------|---|
| 1-0 | LODVTH_R | R/W | 00b | Set the Red LED open load detection threshold 00b: (V _{LEDR} -0.2) V 01b: (V _{LEDR} -0.5) V 10b: (V _{LEDR} -0.9) V 11b: (V _{LEDR} -1.2) V |
| 3-2 | LODVTH_G | R/W | 00b | Set the Green LED open load detection threshold 00b: (V _{LEDG} -0.2) V 01b: (V _{LEDG} -0.5) V 10b: (V _{LEDG} -0.9) V 11b: (V _{LEDG} -1.2) V |
| 5-4 | LODVTH_B | R/W | 00b | Set the Blue LED open load detection threshold 00b: (V _{LEDB} -0.2) V 01b: (V _{LEDB} -0.5) V 10b: (V _{LEDB} -0.9) V 11b: (V _{LEDB} -1.2) V |
| 6 | RESERVED | R/W | 0b | |
| 7 | LOD_LSD_RB | R/W | 0b | Enable or disable the LOD and LSD readback function 0b: disabled 01b: enabled |
| 15-8 | CC_R | R/W | 0111 1111b | Set the Red color brightness level 0000 0000b: level 0 (lowest) 0111 1111b: level 127 (middle) 1111 1111b: level 255 (highest) |
| 23-16 | CC_G | R/W | 0111 1111b | Set the Green color brightness level 0000 0000b: level 0 (lowest) 0111 1111b: level 127 (middle) 1111 1111b: level 255 (highest) |
| 31-24 | CC_B | R/W | 0111 1111b | Set the Blue color brightness level 0000 0000b: level 0 (lowest) 0111 1111b: level 127 (middle) 1111 1111b: level 255 (highest) |
| 34-32 | BC | R/W | 011b | Set the global brightness level 000b: level 0 (lowest) 011b: level 3 (middle) 111b: level 7 (highest) |

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Table 8-10. FC3 Register Field Descriptions (continued)

| Bit | Field | Туре | Reset | Descriptions (continued) |
|-------|----------|------|-------|---|
| 38-35 | LSD_RM | R/W | 0111b | Set the LED short removal level 0000b: level 1 0001b: level 2 0010b: level 3 0011b: level 4 0100b: level 5 0101b: level 6 0110b: level 7 0111b: level 8 1000b: level 9 1001b: level 10 1010b: level 11 1011b: level 12 1100b: level 13 1101b: level 14 11110b: level 15 1111b: level 16 |
| 41-39 | LSDVTH_R | R/W | 000b | Set the Red LED short/weak short circuitry detection threshold (typical) 000b: 0.2 V 001b: 0.4 V 010b: 0.8 V 011b: 1.0 V 100b: 1.2 V 101b: 1.4 V 110b: 1.6 V 111b: 1.8 V |
| 44-42 | LSDVTH_G | R/W | 000b | Set the Green LED short/weak short circuitry detection threshold (typical) 000b: 0.2 V 001b: 0.4 V 010b: 0.8 V 011b: 1.2 V 100b: 1.6 V 101b: 2 V 110b: 2.4 V 111b: 2.8 V |
| 47-45 | LSDVTH_B | R/W | 000b | Set the Blue LED short/weak short circuitry detection threshold (typical) 000b: 0.2 V 001b: 0.4 V 010b: 0.8 V 011b: 1.2 V 100b: 1.6 V 101b: 2 V 110b: 2.4 V 111b: 2.8 V |

8.7.5 FC4

FC4 is shown in Figure 8-33 and described in Table 8-11.

Figure 8-33. FC4 Register

| | | | | | | rigure | · o-აა. | FC4 RE | gister | | | | | | |
|--------------------------|--------|------|-----------------------|--------------|--------------|--------------|------------|--------------------|------------|-----------|---------|----|--------------|--------------|--------------|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| R | ESERVE | D | DE_C OUPL E3_EN | | DE_CC | UPLE3 | | DE_C OUPL E2 | | FIRST_L | INE_DIM | ĺ | CAUR SE_B | CAUR SE_G | CAUR SE_R |
| | R-000b | | R/ W-0b | | R/W-1000b | | | R/ W-0b | | R/W-0000b | | | R/ W-0b | R/ W-0b | R/ W-0b |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| RESERVED SR_ON_B SR_ON_G | | SR_C | DN_R | SR_OF F_B | SR_OF F_G | SR_OF F_R | FINE_ B | FINE_ G | FINE_ R | | | | | | |



Figure 8-33. FC4 Register (continued)

| | | | | | 94. | 0 0 00. | . • | 09.00. | (00:::: | aoa, | | | | | |
|--------------|--------------|-------|----|-----|------|---------|--------|----------|---------|------------|------------|------------|------------|------------|---------------|
| | R/W-0 | 0000b | | R/W | -01b | R/W | '-01b | R/W | -01b | R/ W-0b | R/ W-0b | R/ W-0b | R/ W-0b | R/ W-0b | R/ W-0b |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| RESE RVED | SCAN_ REV | | | | | | RESE | RVED | | • | | | | IMAX | LAST_ SOUT |
| R/ W-0b | R/ W-1b | | | | | R/ | W-0000 | 0000 111 | 1b | | | | | R/ W-0b | R/ W-0b |

Table 8-11. FC4 Register Field Descriptions

| Bit | Field | Type | Reset | Description Description |
|-------|-----------|------|--------------------|---|
| 0 | LAST_SOUT | R/W | 0b | Enable or disable the last device's SOUT cut-off function 0b: disabled, last chip's SOUT shift out 1b: enabled, last chip's SOUT cut off, except for READ command |
| 1 | IMAX | R/W | 0b | Set the maximum current of each channel 0b: 10mA maximum 01b: 20 mA maximum |
| 13-2 | RESERVED | R/W | 0000 0000 1111b | |
| 14 | SCAN_REV | R/W | 1b | When 2 device stackable or 3 devices stackable, the scan lines PCB layout is reversed. For the proper scan and SRAM read sequence, SCAN_REV register is provided. 0b: the PCB layout sequence is L0-L15, L16-L31. 1b: the PCB layout sequence is L0-L15, L31-L16. |
| 15 | RESERVED | R/W | 0b | |
| 16 | FINE_R | R/W | 0b | Enable the Red brightness compensation level fine range 0b: disable. 1b: enable. |
| 17 | FINE_G | R/W | 0b | Enable the Green brightness compensation level fine range 0b: disable. 1b: enable. |
| 18 | FINE_B | R/W | 0b | Enable the Blue brightness compensation level fine range 0b: disable. 1b: enable. |
| 19 | SR_OFF_R | R/W | 0b | Slew rate control function when Red turns off operation 0b: slow slew rate. 1b: fast slew rate. |
| 20 | SR_OFF_G | R/W | 0b | Slew rate control function when Green turns off operation 0b: slow slew rate. 1b: fast slew rate. |
| 21 | SR_OFF_B | R/W | 0b | Slew rate control function when Blue turns off operation 0b: slow slew rate. 1b: fast slew rate. |
| 23-22 | SR_ON_R | R/W | 01b | Slew rate control function when Red turns on operation 00b: the slower slew rate. 01b: slow slew rate. 10b: fast slew rate. 11b: the faster slew rate. |
| 25-24 | SR_ON_G | R/W | 01b | Slew rate control function when Green turns on operation 00b: the slower slew rate. 01b: slow slew rate. 10b: fast slew rate. 11b: the faster slew rate. |
| 27-26 | SR_ON_B | R/W | 01b | Slew rate control function when Blue turns on operation 00b: the slower slew rate. 01b: slow slew rate. 10b: fast slew rate. 11b: the faster slew rate. |

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Table 8-11. FC4 Register Field Descriptions (continued)

| Bit | Field | Туре | Reset | Description |
|-------|----------------|------|-------|--|
| 31-28 | RESERVED | R/W | 0000b | |
| 32 | CAURSE_R | R/W | 0b | Enable the Red brightness compensation level caurse tange 0b: disabled 1b: enabled |
| 33 | CAURSE_G | R/W | 0b | Enable the Green brightness compensation level caurse tange 0b: disabled 1b: enabled |
| 34 | CAURSE_B | R/W | 0b | Enable the Blue brightness compensation level caurse tange 0b: disabled 1b: enabled |
| 38-35 | FIRST_LINE_DIM | R/W | 0000ь | Adjust the first line dim level 0000b: level 1 0111b: level 8 1111b: level 16 |
| 39 | DE_COUPLE2 | R/W | 0b | Decoupling between ON and OFF channels 0b: disabled 1b: enabled |
| 43-40 | DE_COUPLE3 | R/W | 1000Ь | Set decoupling enhancement level 0000b: level 1 0111b: level 8 1111b: level 16 |
| 44 | DE_COUPLE3_EN | R/W | 0b | Enable decoupling enhancement 0b: disabled 1b: enabled |
| 47-45 | RESERVED | R/W | 000b | |

8.7.6 FC14

FC14 is shown in FC14 Register and described in FC14 Register Field Descriptions.

Figure 8-34. FC14 Register

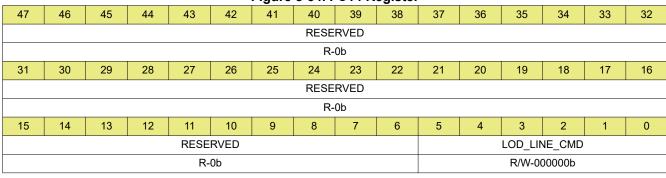


Table 8-12. FC14 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|--------------|------|-------|--|
| 5-0 | LOD_LINE_CMD | R/W | | Locate the line with LED open load warnings: 000000b: Line 0 011111b: Line 31 111111b: Line 63 |
| 47-6 | RESERVED | R | 0b | Reserved bits |



8.7.7 FC15

FC15 is shown in FC15 Register and described in FC15 Register Field Descriptions.

Figure 8-35. FC15 Register

| | | | | | | <u> </u> | | | 3 | | | | | | |
|----|----------|----|----|----|----|----------|------|------|----|----|----|---------|--------|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| | RESERVED | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | | | • | | • | | RESE | RVED | | | • | | | | |
| | | | | | | | R- | 0b | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | RESERVED | | | | | | | | | | | LSD_LIN | NE_CMD | | |
| | R-0b | | | | | | | | | | | R/W-00 | 00000b | | |

Table 8-13. FC15 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|--------------|------|-------|--|
| 5-0 | LSD_LINE_CMD | R/W | | Locate the line with LED short circuitry warnings: 000000b: Line 0 011111b: Line 31 111111b: Line 63 |
| 47-6 | RESERVED | R | 0b | Reserved bits |

8.7.8 FC16

FC16 is shown in FC16 Register and described in FC16 Register Field Descriptions.

Figure 8-36. FC16 Register

| | | | | | | . igaic | 0 00 | 0.0.0 | cgiotoi | | | | | | |
|----|----------------------|----|----|----|----|---------|------|-------|---------|----|----|----|----|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| | | | | | | | RESE | RVED | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | | | | • | • | | RESE | RVED | | • | | | | | |
| | | | | | | | R- | 0b | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | LOD_LINE_WARN[63:48] | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |

Table 8-14. FC16 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|-------|----------------------|------|-------|--|
| 15-0 | LOD_LINE_WARN[63:48] | R | 0b | Read the line with LED open load warnings: Bit 0 = 0, Line 48 has no warning; Bit 0 = 1, Line 48 has warning Bit 15 = 0, Line 63 has no warning; Bit 15 = 1, Line 63 has warning |
| 47-16 | RESERVED | R | 0b | Reserved bits |

8.7.9 FC17

FC17 is shown in FC17 Register and described in FC17 Register Field Descriptions.

Figure 8-37. FC17 Register

| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
|----|----|----|----|----|----|-----|---------|--------|------|----|----|----|----|----|----|
| | | | | | | LOI | D_LINE_ | WARN[4 | 7:0] | | | | | | |

Figure 8-37. FC17 Register (continued)

| | | | | | iguie | 0-31. | | egiste | ı (COIII | mueuj | | | | | |
|----|---------------------|----|----|----|-------|-------|---------|--------|----------|-------|----|----|----|----|----|
| | R-0b | | | | | | | | | | | | | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | • | | | | | LOI | D_LINE_ | WARN[4 | 7:0] | | | | | • | |
| | R-0b | | | | | | | | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | LOD_LINE_WARN[47:0] | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |

Table 8-15. FC17 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|---------------------|------|-------|--|
| 47-0 | LOD_LINE_WARN[47:0] | R | | Read the line with LED open load warnings: Bit 0 = 0, Line 0 has no warning; Bit 0 = 1, Line 0 has warning Bit 47 = 0, Line 47 has no warning; Bit 47 = 1, Line 47 has warning |

8.7.10 FC18

FC18 is shown in FC18 Register and described in FC18 Register Field Descriptions.

Figure 8-38. FC18 Register

| | | | | | | ı iyule | 0-30. i | CIUIN | egistei | | | | | | |
|----|----------------------|----|----|----|----|---------|---------|-------|---------|----|----|----|----|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| | | | | | | | RESE | RVED | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | RESERVED | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | LSD_LINE_WARN[63:48] | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

Table 8-16. FC18 Register Field Descriptions

| | 10.010 | | | |
|-------|----------------------|------|-------|--|
| Bit | Field | Туре | Reset | Description |
| 16-0 | LSD_LINE_WARN[63:48] | R | ОЬ | Read the line with LED short circuitry warnings: Bit 0 = 0, Line 48 has no warning; Bit 0 = 1, Line 48 has warning Bit 15 = 0, Line 63 has no warning; Bit 15 = 1, Line 63 has warning |
| 47-16 | RESERVED | R | 0b | Reserved bits |

8.7.11 FC19

FC19 is shown in FC19 Register and described in FC19 Register Field Descriptions.

| Figure 8-39. FC19 Registe | Figure | 8-39. | FC19 | Register |
|---------------------------|--------|-------|------|----------|
|---------------------------|--------|-------|------|----------|

| | | | | | | | | | • | | | | | | |
|----|---------------------|----|----|----|----|-----|---------|--------|------|----|----|----|----|----|----|
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| | | | | | | LSE | D_LINE_ | WARN[4 | 7:0] | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| | LSD_LINE_WARN[47:0] | | | | | | | | | | | | | | |
| | R-0b | | | | | | | | | | | | | | |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | LSD_LINE_WARN[47:0] | | | | | | | | | | | | | | |

Figure 8-39. FC19 Register (continued)

R-0b

Table 8-17. FC19 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|---------------------|------|-------|--|
| 47-0 | LSD_LINE_WARN[47:0] | R | | Read the line with LED short circuitry warnings: Bit 0 = 0, Line 0 has no warning; Bit 0 = 1, Line 0 has warning Bit 47 = 0, Line 47 has no warning; Bit 47 = 1, Line 47 has warning |

8.7.12 FC20

FC20 is shown in FC20 Register and described in FC20 Register Field Descriptions.

Figure 8-40. FC20 Register

| 47 | | | | | | | 94.0 | 0 70. 1 | 0_0.0 | og.o.o. | | | | | | |
|--|----|--------|----|----|----|----|------|---------|-------|---------|----|----|----|----|----|----|
| R-0b 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 LOD_CH R-0b 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 LOD_CH | | LOD_CH | | | | | | | | | | | | | | |
| LOD_CH R-0b 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 LOD_CH | | R-0b | | | | | | | | | | | | | | |
| R-0b 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 LOD_CH | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 LOD_CH | | LOD_CH | | | | | | | | | | | | | | |
| LOD_CH | | R-0b | | | | | | | | | | | | | | |
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R-0b | | LOD_CH | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

Table 8-18. FC20 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|--------|------|-------|---|
| 47-0 | LOD_CH | R | | Locate the LED opem load channel: Bit 0 = 0, CH 0 is normal; Bit 0 = 1, CH 0 is short circuitry Bit 47 = 0, CH 47 is normal; Bit 47 = 1, CH 47 is short circuitry |

8.7.13 FC21

FC21 is shown in FC21 Register and described in FC21 Register Field Descriptions.

Figure 8-41. FC21 Register

| 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 | | | | | | | | | | | |
|---|--|--|--|--|--|--|--|--|--|--|--|
| R-0b | | | | | | | | | | | |
| | | | | | | | | | | | |
| 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 | | | | | | | | | | | |
| | | | | | | | | | | | |
| LSD_CH | | | | | | | | | | | |
| R-0b | | | | | | | | | | | |
| 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 | | | | | | | | | | | |
| LSD_CH | | | | | | | | | | | |
| R-0b | | | | | | | | | | | |

Table 8-19. FC21 Register Field Descriptions

| Bit | Field | Туре | Reset | Description |
|------|--------|------|-------|---|
| 47-0 | LSD_CH | R | | Locate the LED short circuitry channel: Bit 0 = 0, CH 0 is normal; Bit 0 = 1, CH 0 is short circuitry Bit 47 = 0, CH 47 is normal; Bit 47 = 1, CH 47 is short circuitry |

9 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.

9.1 Application Information

The TLC6984 integrates 48 constant current sources and 16 scanning FETs. A single TLC6984 is capable of driving 16 × 16 RGB LED pixels while stacking two TLC6984s can drive 32 × 32 RGB LED pixels. To achieve low power consumption, the TLC6984 supports separated power supplies for the red, green, and blue LEDs by its common cathode structure.

The TLC6984 implements a high speed dual-edge transmission interface (up to 25 MHz) to support high device count daisy-chained and high refresh rate while minimizing electrical-magnetic interference (EMI). SCLK must be continuous, no matter there are data on SIN or not, because SCLK is not only used to sample the data on SIN, but also used as a clock source to generate GCLK by internal frequency multiplier. Based on dual-edge CCSI protocol, all the commands/FC registers/SRAM data are written from the SIN input terminal, and all the FC registers/ LED open and short flag can be read out from the SOUT output terminal. Moreover, the device supports up to 160-MHz GCLK frequency and can achieve 16-bit PWM resolution, with 3840 Hz or even higher refresh rate.

Meanwhile, the TLC6984 integrates enhanced circuits and intelligent algorithms to solve the various display challenges in Narrow Pixel Pitch (NPP) LED display applications and mini and micro-LED products: dim at the first scan line, upper and downside ghosting, non-uniformity in low grayscale, coupling, caterpillar caused by open or short LEDs, which make the TLC6984 a perfect choice in such applications.

The TLC6984 also implements LED open and weak, short and short detections and removals during operations and can also report this information out to the accompanying digital processor.

9.2 Typical Application

The TLC6984 is typically connected in series in a daisy-chain to drive the LED matrix with only a few controller ports. Figure 9-1 shows a typical application diagram with two TLC6984 devices stackable connection to drive 32 × 32 RGB LED pixels.

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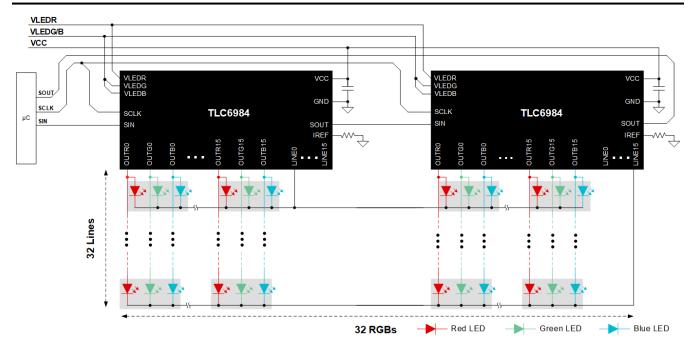


Figure 9-1. TLC6984 With Dual Devices Stackable Connection

9.2.1 Design Requirements

Taking 4K micro-LED televation for example, the resolution of the screen is 3840×2160 , and the screen consists of many modules. The following sections show an example to build a LED display module with 240×180 pixels.

The example uses the following values as the system design parameters.

DESIGN PARAMETER EXAMPLE VALUE 2.8 V V_{CC} and V_R V_G and V_B 3.8 V Maximum current per LED I_{RED} = 3 mA, I_{GREEN} = 2 mA, I_{BLUE} = 1 mA PWM resolution 14 bits 120 Hz Frame rate 3840 Hz Refresh rate Display module size 240 × 180 pixels cascaded devices number 8 devices number per LED display module 96

Table 9-1. TLC6984 Design Parameters

9.2.1.1 System Structure

To build an LED display module with 240 × 180 pixels, 96 TLC6984s are required.

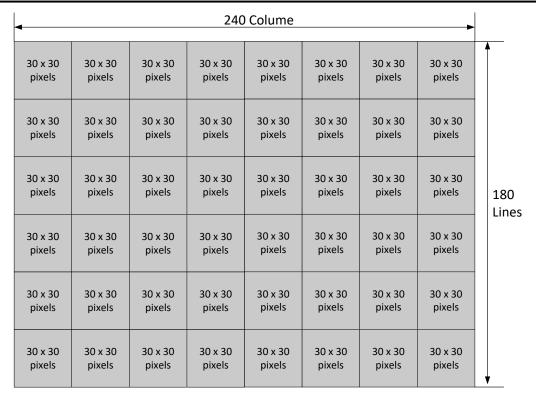


Figure 9-2. LED Display Module

As shown in Figure 9-2, the total module can be divided into 48 32 × 32 matrix. Each matrix includes two devices with stackable connection.

Note

To achieve the best performance, TI suggests to distribute the redundant channels and lines to each 32 × 32 matrix. For this case, two Red/Green/Blue channels and two lines are not used in each matrix. And these unused pins can be floated. For the software, TI suggests zero data is to send to the unused channels. There is no must send the zero data to unused lines.

9.2.1.2 SCLK Frequency

The SCLK frequency is determined by the data volume of one frame and frame rate. In this application, the data volume V_Data is $30 \times 32 \times 48$ bits $\times 4 = 184.32$ Kb, the frame rate is 120 Hz. Suppose the data transmission efficiency is 0.8, the minimum frequency of SCLK must be: $f_{SCLK} = V_{Data} \times f_{frame} / 0.8$. So the minimum SCLK frequency is 13.83 MHz with dual-edge transmission.

9.2.1.3 Internal GCLK Frequency

The internal GCLK frequency is configured by the Frequency Multiplier (FREQ_MUL), and is determined by the PWM resolution. The GCLK frequency can be calculated by the below equations:

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$$N_{sub_period} = \frac{f_{refresh_rate}}{f_{frame_rate}}$$

$$GS_{max} = 2^K$$

$$GS_{max} = N_{GCLK_Seg} \times N_{sub_period}$$

$$\frac{1}{f_{frame_rate}} = \left(\frac{N_{GCLK_Seg}}{f_{GCLK}} + T_{SW}\right) \times N_{Scan_line} \times N_{sub_period} + T_{Blank}$$
(3)

where

- f_{refresh rate} means the refresh rate
- f_{frame rate} means the frame rate
- K means the PWM resolution
- N_{sub_period} means the sub-period numbers within one frame
- N_{GCLK} seg means the GCLK number per segment (Line switch time excluded)
- f_{GCLK} means GCLK frequency
- T_{SW} means line switching time
- N_{scan line} means the scan line number
- T_{blank} means the blank time in one frame, equals to 0 in ideal configuration
- GS_{max} means the maximum grayscale that the device can output in one frame

Table 9-2 gives the values based on the system configuration and equation.

Table 9-2. TLC6984 Design Parameters for GCLK Frequency Calculation

| DESIGN PARAMETER | EXAMPLE VALUE |
|-------------------------|---------------|
| N _{sub_period} | 32 |
| N _{scan_line} | 30 |
| T _{SW} | 1.5 µs |
| T _{blank} | 0 |
| N _{GCLK_seg} | 512 |
| GS _{max} | 16383 |
| f _{GCLK} | 71.3 MHz |

Considering SCLK frequency and FREQ_MUL, the SCLK can be 13.9 MHz, and FREQ_MUL can be 6. So the GCLK is 83.4 MHz.

9.2.1.4 Line Switch Time

The line switch time is digitalized with the GCLK number and can be set by the LINE_SWT (Bit 40-37 in FC1 register). In this application, it is 1.5 us \times 83.4 MHz = 125 GCLKs, so the LINE_SWT equals to 0011b (120 GCLKs), the actual line switch time is 1.44 us.

9.2.1.5 Blank Time Removal

The TLC6984 has an algorithm to distribute the blank time into each subperiod to prevent the black field when taking photos or video.

From Equation 3, 83.4-MHz GCLK frequency and 1.44-us line switch time, the calculated blank time is 1.059 ms (88280 GCLK), which is too long and brings black field.

Here are detailed steps of the algorithm.

Step 1: Distribute blank time into each segment

When the blank GCLK number is larger than $N_{sub\ period} \times N_{scan\ line}$, it can be distributed into each segment.

In this application, the blank GCLK number is 88280, and $N_{sub_period} \times N_{scan_line}$ is 960, so the distributed GCLK number in each segment is 88280/960 = 91...920. These 91GCLKs can be used to increase PWM length or extend line switch time. If used to increase PWM length, the GCLK number in each segment is 512 + 91= 603, so the SEG_LENGTH (Bit9-0 in FC1 register) is 1001011010b.

Step 2: Distribute blank time into each sub-period

If the left GCLK number is larger than N_{sub} period, it can be distributed into each sub-period.

In this application, the left GCLK is 697, the distributed GCLK number in each sub-period is 920/32=28...24. The BLK_ADJ (Bit46-41 in FC1 register) is 011100b.

After distributing into each sub-period, the left GCLK number is 24, which is about 300 ns, this time is too short to bring black field.

9.2.1.6 BC and CC

Select the reference current-setting resistor R_{IREF} and configure a proper BC value to set the maximum current of the RGB LEDs (see *Brightness Control (BC) Function* for more details). Here the maximum current is 3 mA, BC value is 03h, according to equation Equation 1, the reference resistor value is 0.8 V/3 mA × 85.33 = 22.75 k Ω .

Configure the CC_R/CC_B registers to set the current of Red/ Green/Blue LED current to 3 mA/2 mA/1 mA (see *Color Brightness Control (CC) Function* for more details).

Table 9-3 shows the reference current setting resistor R_{IRFF}, BC and CC R/CC G/CC B register value.

Table 9-3. Current Setting Value

| DESIGN PARAMETER | EXAMPLE VALUE | | | |
|-------------------|---------------|--|--|--|
| R _{IREF} | 22.75 kΩ | | | |
| BC | 011 b | | | |
| CC_R | 11111111 b | | | |
| CC_G | 10101001 b | | | |
| CC_B | 01010100 b | | | |

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9.2.2 Detailed Design Procedure

Figure 9-3 gives a detail design procedure for LED display. After power on and digital signals are ready, the first step for the controller is to send the chip index command to let the devices know their identifications. Then, the controller sends the configuration data to the FC registers. After this, it sends the VSYNC at the beginning of each frame and also sends the data to each device. The devices display the data of last frame when the VSYNC comes and meanwhile receive the data of current frame transmitted from controller. The registers can be read at anytime of the frame.

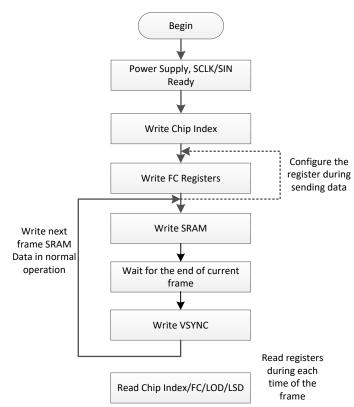


Figure 9-3. Design Procedure for LED Display

9.2.2.1 Chip Index Command

The chip index is used to distribute the address of the devices in a data chain. Each device gets its unique address by this command. Details can be found in *Chip Index Write Command*.

9.2.2.2 FC Registers Settings

Some bits of FC0, FC1, FC2, FC3 registers must be configured properly before the devices work normally. In this application, the registers value can be:

| Table | 9- | 4. | F | С | R | leg | isters | Value |
|-------|----|----|---|---|---|-----|--------|-------|
| | | | | | | | | |

| FC Registers | Register Value (BIN) | Register Value (HEX) |
|--------------|---|----------------------|
| FC0 | 0010 0000 0000 0000 1011 1000 0101 1101 1000 0001 0000 0111 b | 2000 B85D 8107h |
| FC1 | 0010 1010 1110 0000 0000 0000 1001 0100 1010 0110 0011 0001 b | 2AE0 0094 A631 h |
| FC2 | 0000 1011 1000 0000 0000 0000 0000 000 | 0B80 0000 0AA0 h |
| FC3 | 0000 0000 0011 1011 0101 0100 1010 1001 1111 1111 0000 0000 b | 003B 54A9 FF00 h |

FC6, FC7, FC8, FC9, FC10, FC11, FC12, FC13 registers are used for programmable scanning sequence function.

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The controller can configure the FC by the data write command with broadcast mode (see *Data Write Command* for more detail). The FC0, FC1 registers are updated after the VSYNC command comes, and the other FC registers are updated right away regardless the VSYNC command.

9.2.2.3 Grayscale Data Write

The channel grayscale data is written to SRAM of the device by the data write command with non-broadcast way. Details can be found in *Data Write Command* and *Write a Frame Data into Memory Book*.

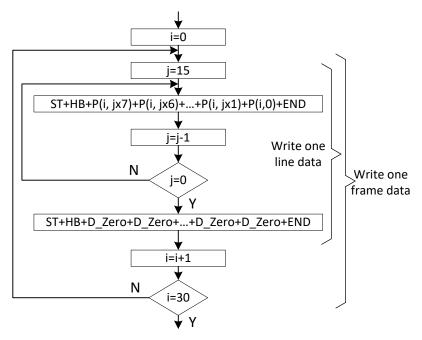


Figure 9-4. Data Write Flow

9.2.2.4 VSYNC Command

The VSYNC is used to sync the display of each frame for the devices in a cascaded chain. Details can be found in VSYNC Write Command.

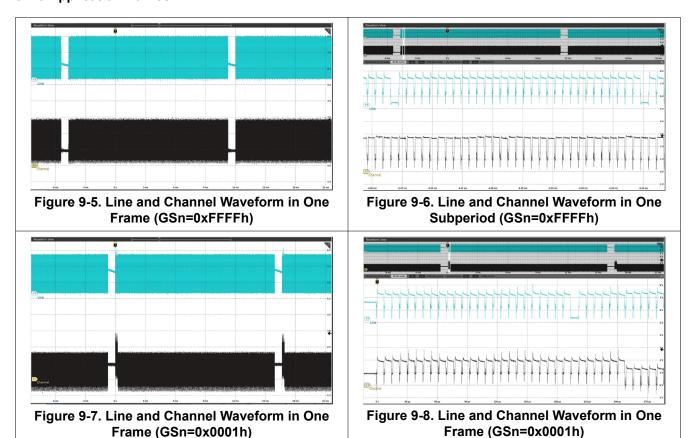
9.2.2.5 LED Open and Short Read

FC14, FC15, FC16, FC17, FC18, FC19, FC20, FC21 are the read command for LOD/LSD information. Details can be found in *Read LED-open Information* and *Read LED-short Information*.

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9.2.3 Application Curves



10 Power Supply Recommendations

Decouple the VCC power supply voltage by placing a $0.1-\mu F$ ceramic capacitor close to VCC pin and GND plane. Depending on panel size, several electrolytic capacitors must be placed on the board equally distributed to get well regulated LED supply voltage VR/VG/VB. The ripple of the LED supply voltage must be less than 5% of their nominal value. Generally, the green and blue LEDs have the similar forward voltage and they can be supplied by the same power rail.

Furthermore, the VR > Vf(R) + 0.35 V (10-mA constant current example), the VG = VB > Vf(G/B) + 0.35 V (10-mA constant current example), here Vf(R), Vf(G/B) are representative for the maximum forward voltage of red, green/blue LEDs.

To simplify the power design, VCC can be connected to VR power rail.



11 Layout

11.1 Layout Guidelines

- Place the decoupling capacitor near the VCC/VR, VG/VB pins and GND plane.
- Place the current programming resistor RIREF close to IREF pin and GND plane.
- Route the GND thermal pad as widely as possible for large GND currents. Maximum GND current is approximately 2 A for two devices (96-CH × 20 mA = 1.92 A).
- The Thermal pad must be connected to GND plane because the pad is used as power ground pin internally. There is a large current flow through this pad when all channels turn on. Furthermore, this pad must be connected to a heat sink layer by thermal via to reduce device temperature. For more information about suggested thermal via pattern and via size, see PowerPAD™ Thermally Enhanced Package application note.
- Routing between the LED Anode side and the device OUTXn pin must be as short and straight as possible to reduce wire inductance.
- The line switch pins must be located in the middle of the matrix, which must be laid out as symmetrically as possible.

11.2 Layout Example

To simplify the system power rails design, we suggest that VR, VCC use one power rail, and VG, VB use another power rail. Figure 11-1 gives an example for power rails routing.

Connect the GND pin to thermal pad on board with the shortest wire and the thermal pad is connected to GND plane with the vias, as many as possible to help the power dissipation.

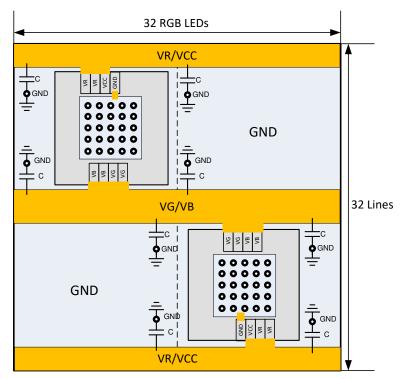


Figure 11-1. Power Rails Routing Suggestion

Figure 11-2 gives an example for line routing. Connect the line switch to the center of the line bus, so as to uniform the current flowing from the line switch to the left side and right side LEDs in white grayscale. With this connection, the unbalance of the parasitic inductor from the routing is the smallest and the display performance is better, especially in low grayscale condition.

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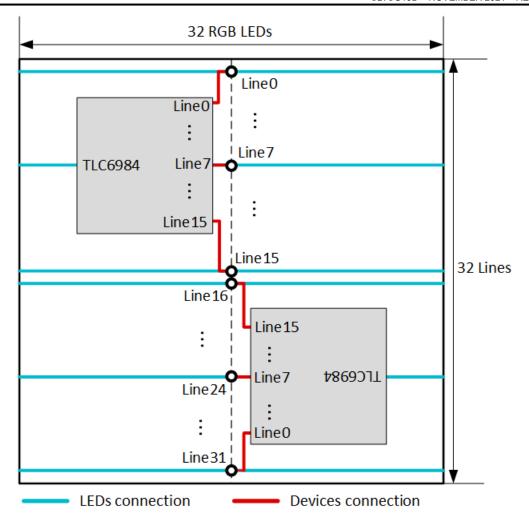


Figure 11-2. Line Routing Suggestion

Figure 11-3 gives an example for channel routing with the shortest wire. With this connection, the channel to the LED path is the shortest, which can reduce the wire inductance, and be a benefit to the performance. However, the data transmission sequence must be adjusted to follow the pins routing map. For example, R0 connects to column 15 (LED15). The first data must be column 15 (LED15) rather than column 0 (LED0).



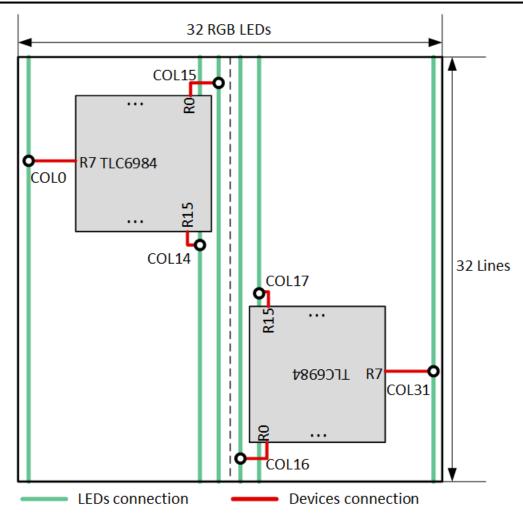


Figure 11-3. Channel Routing Suggestion With Shortest Wire

Figure 11-4 gives an example for channel routing with pin number sequence. With this connection, the data transmission sequence are the same with pin number sequence. For example, R0 connects to column 0 (LED0). The first data is column 0 (LED0). However, with this connection, the inductance for each channel can be different, which can bring a slight difference for the worst case.

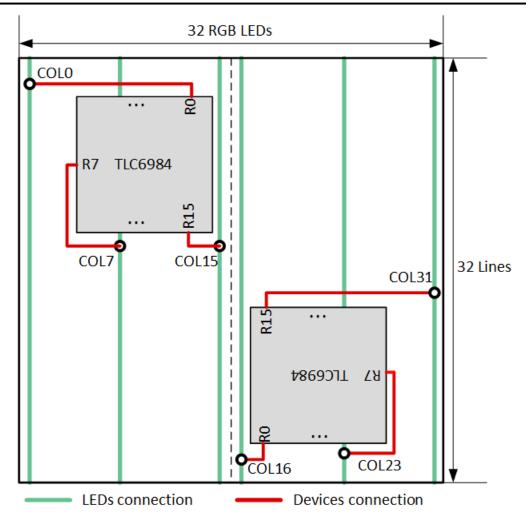


Figure 11-4. Channel Routing Suggestion With Channel Order Sequence



12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

• Texas Instruments, PowerPAD™ Thermally Enhanced Package application note

12.2 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.

12.3 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.

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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.

12.6 Glossary

TI Glossary

This glossary lists and explains terms, acronyms, and definitions.

13 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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PACKAGING INFORMATION

| Orderable part number | Status | Material type | Package Pins | Package qty Carrier | RoHS | Lead finish/ Ball material | MSL rating/ Peak reflow | Op temp (°C) | Part marking (6) |
|-----------------------|--------|---------------|------------------|-----------------------|------|-------------------------------|----------------------------|--------------|------------------|
| | | | | | | (4) | (5) | | |
| TLC6984RRFR | Active | Production | VQFN (RRF) 76 | 2000 LARGE T&R | Yes | NIPDAU | Level-3-260C-168 HR | -40 to 85 | TLC6984 |
| TLC6984RRFR.A | Active | Production | VQFN (RRF) 76 | 2000 LARGE T&R | Yes | NIPDAU | Level-3-260C-168 HR | -40 to 85 | TLC6984 |
| TLC6984ZXLR | Active | Production | NFBGA (ZXL) 96 | 2500 LARGE T&R | Yes | SNAGCU | Level-3-260C-168 HR | -40 to 85 | TLC6984 |
| TLC6984ZXLR.A | Active | Production | NFBGA (ZXL) 96 | 2500 LARGE T&R | Yes | SNAGCU | Level-3-260C-168 HR | -40 to 85 | TLC6984 |

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

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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⁽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.

PACKAGE MATERIALS INFORMATION

www.ti.com 17-Mar-2023

TAPE AND REEL INFORMATION





| A0 | Dimension designed to accommodate the component width |
|----|---|
| В0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

| Device | | Package Drawing | | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-------------|-------|--------------------|----|------|--------------------------|--------------------------|------------|------------|------------|------------|-----------|------------------|
| TLC6984ZXLR | NFBGA | ZXL | 96 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 2.1 | 8.0 | 16.0 | Q1 |

PACKAGE MATERIALS INFORMATION

www.ti.com 17-Mar-2023



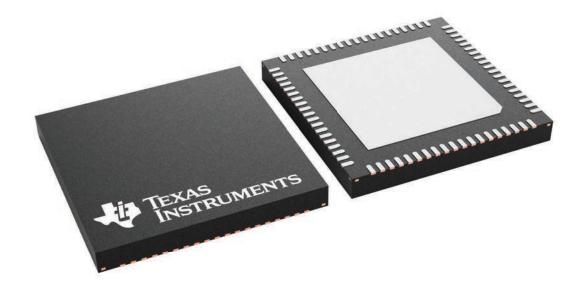
*All dimensions are nominal

| Ì | Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) | |
|---|-------------|--------------|-----------------|------|------|-------------|------------|-------------|--|
| ı | TLC6984ZXLR | NFBGA | ZXL | 96 | 2500 | 336.6 | 336.6 | 31.8 | |

9 x 9, 0.4 mm pitch

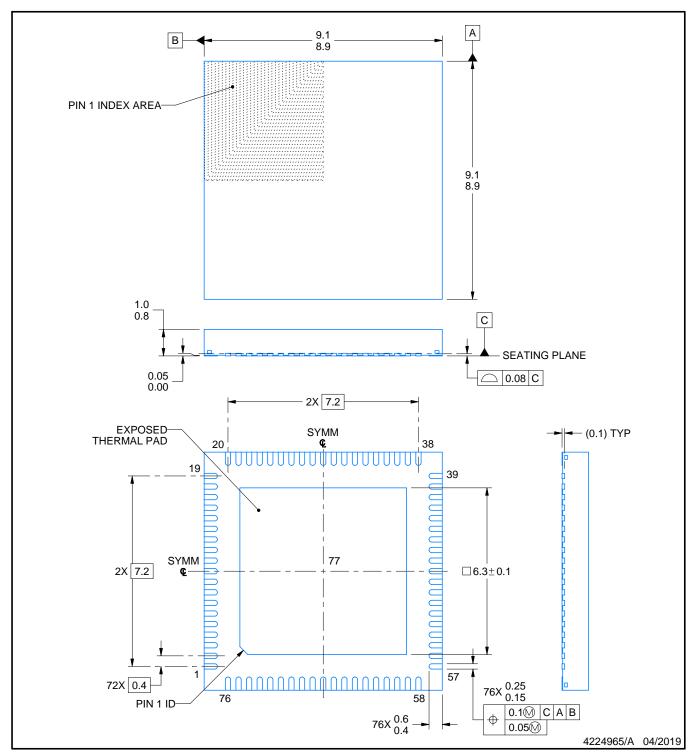
PLASTIC QUAD FLATPACK - NO LEAD

This image is a representation of the package family, actual package may vary. Refer to the product data sheet for package details.





PLASTIC QUAD FLATPACK - NO LEAD

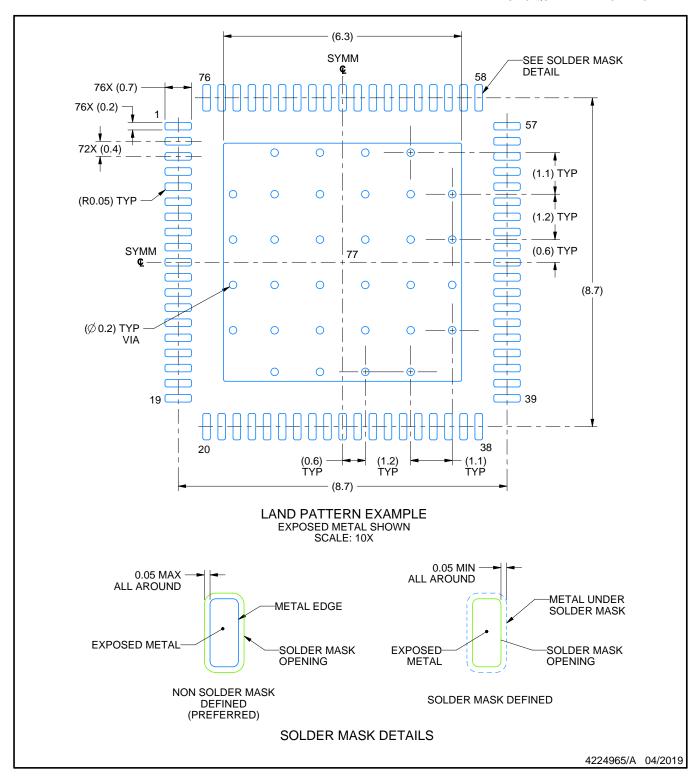


NOTES:

- 1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
 2. This drawing is subject to change without notice.
- 3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



PLASTIC QUAD FLATPACK - NO LEAD

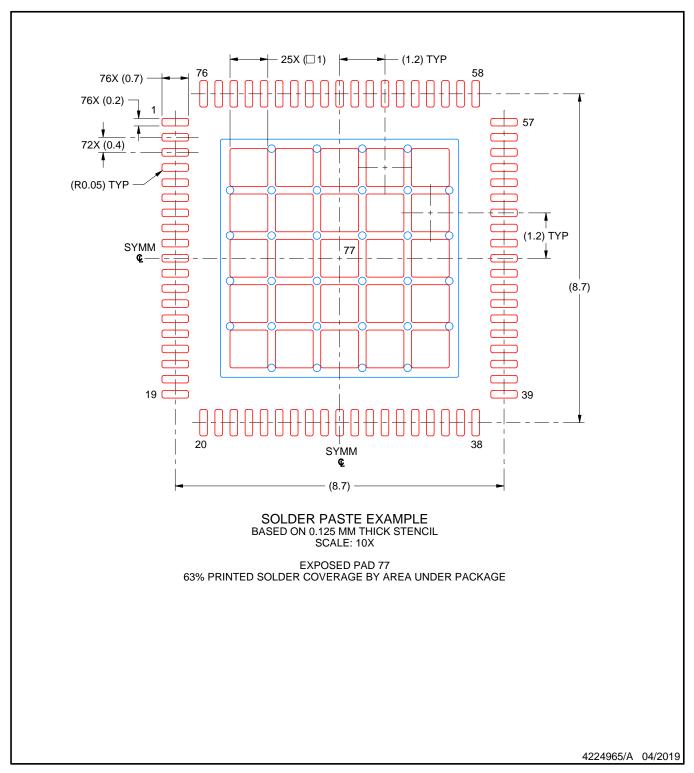


NOTES: (continued)

- 4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
- 5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



PLASTIC QUAD FLATPACK - NO LEAD

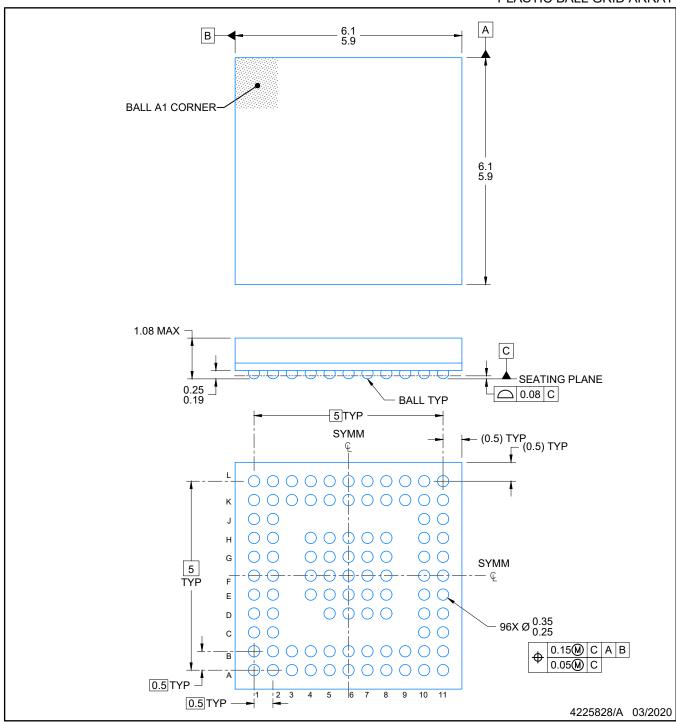


NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.



PLASTIC BALL GRID ARRAY



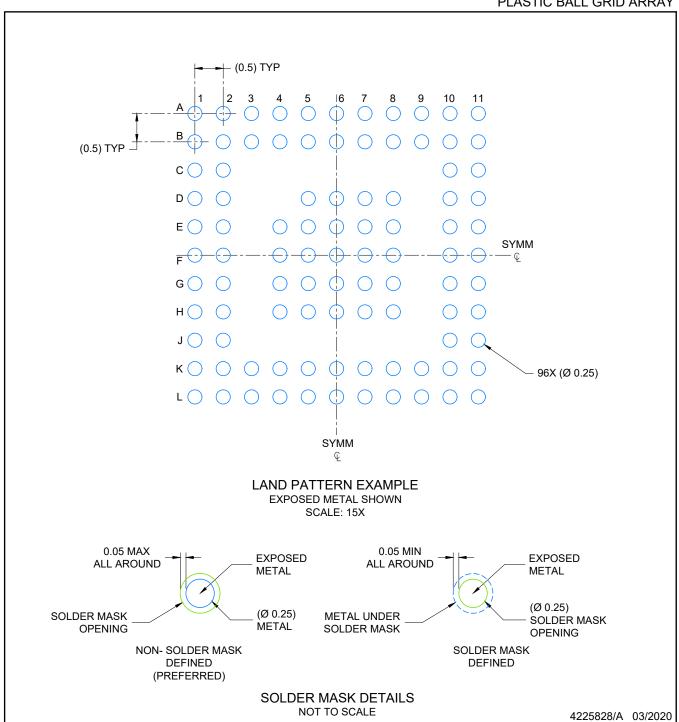
NOTES:

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- All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
- 2. This drawing is subject to change without notice.



PLASTIC BALL GRID ARRAY

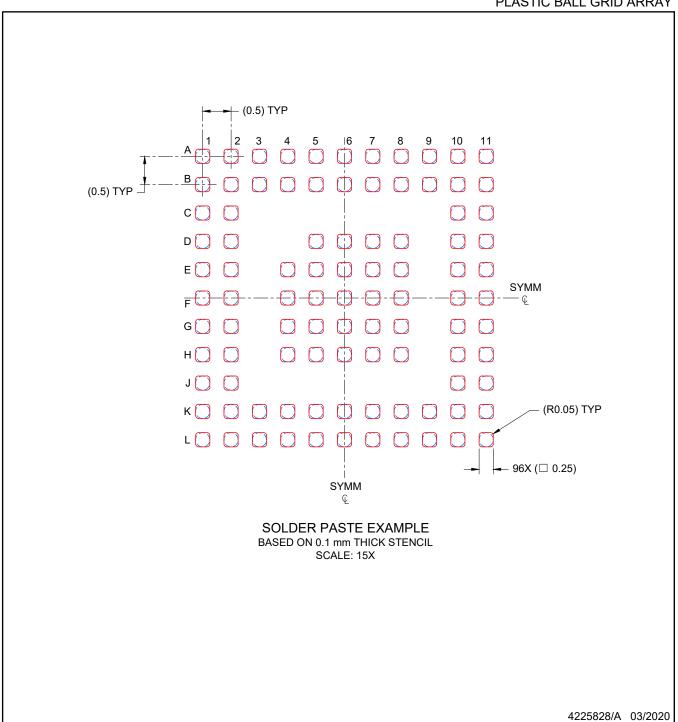


NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. Refer to Texas Instruments Literature number SNVA009 (www.ti.com/lit/snva009).



PLASTIC BALL GRID ARRAY



NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.



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