- **Supports UXGA Resolution (Output Pixel Rates Up to 165 MHz)**
- **Digital Visual Interface (DVI) Specification Compliant[1]**
- **True-Color, 24 Bit/Pixel, 16.7M Colors at 1 or 2-Pixels Per Clock**
- **Laser Trimmed Internal Termination Resistors for Optimum Fixed Impedance Matching**
- **Skew Tolerant Up to One Pixel Clock Cycle**
- **4x Over-Sampling**
- **Reduced Power Consumption – 1.8 V Core Operation With 3.3 V I/Os and Supplies[2]**
- **Reduced Ground Bounce Using Time Staggered Pixel Outputs**
- **Lowest Noise and Best Power Dissipation Using TI PowerPAD™ Packaging**
- **Advanced Technology Using TI 0.18-μm EPIC-5™ CMOS Process**
- **TFP401A Incorporates HSYNC Jitter Immunity[3]**

description

The Texas Instruments TFP401 and TFP401A are TI *PanelBus*™ flat panel display products, part of a comprehensive family of end-to-end DVI 1.0 compliant solutions. Targeted primarily at desktop LCD monitors and digital projectors, the TFP401/401A finds applications in any design requiring high-speed digital interface.

The TFP401/401A supports display resolutions up to UXGA in 24-bit true color pixel format. The TFP401/401A offers design flexibility to drive one or two pixels per clock, supports TFT or DSTN panels, and provides an option for time staggered pixel outputs for reduced ground bounce.

PowerPAD™ advanced packaging technology results in best of class power dissipation, footprint, and ultra-low ground inductance.

The TFP401/401A combines *PanelBus*™ circuit innovation with TI's advanced 0.18-μm EPIC-5™ CMOS process technology, along with TI PowerPAD™ package technology to achieve a reliable, low-powered, low noise, high-speed digital interface solution.

AVAILABLE OPTIONS

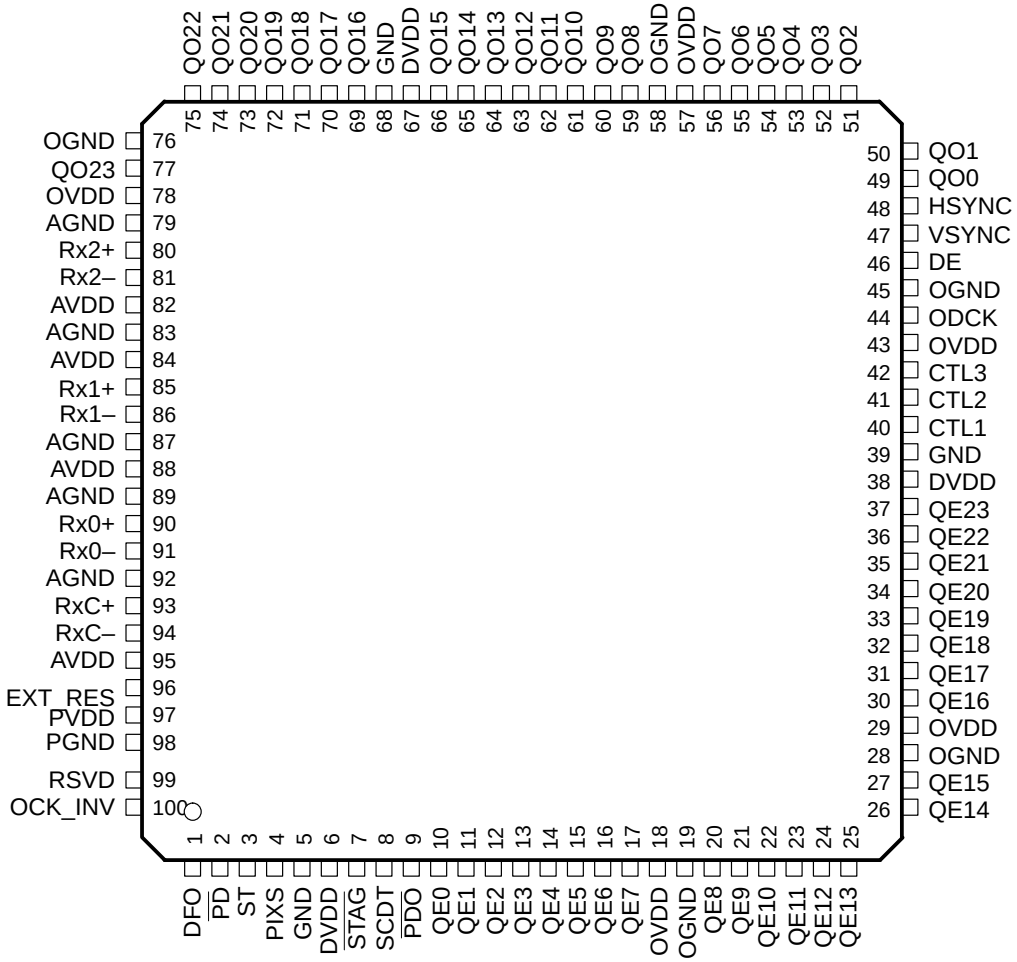
T_A	PACKAGED DEVICE
	100-TQFP (PZP)
0°C to 70°C	TFP401PZP
	TFP401APZP

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

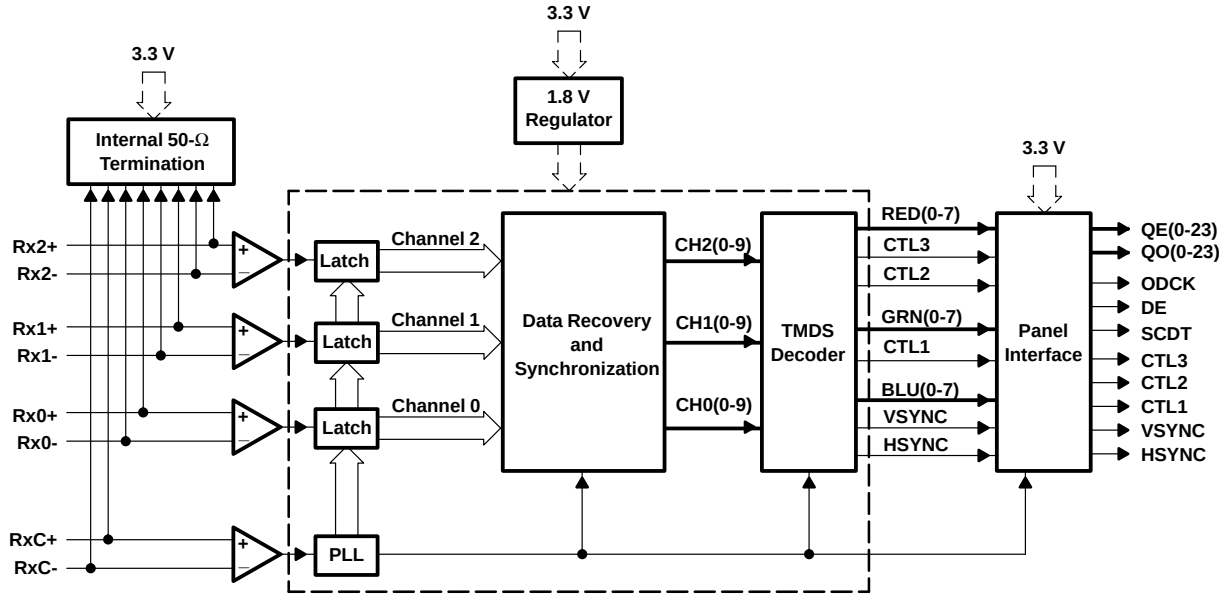
1. The Digital Visual Interface Specification, DVI, is an industry standard developed by the Digital Display Working Group (DDWG) for high-speed digital connection to digital displays The TFP401 and TFP401A are compliant to the DVI Specification Rev. 1.0.
2. The TFP401/401A has an internal voltage regulator that provides the 1.8-V core power supply from the externally supplied 3.3-V supplies.
3. The TFP401A incorporates additional circuitry to create a stable HSYNC from DVI transmitters that introduce undesirable jitter on the transmitted HSYNC signal.

PanelBus, PowerPAD and EPIC-5 are trademarks of Texas Instruments.
I²C is a licensed bus protocol from Phillips Semiconductor, Inc.

100-PIN PACKAGE
(TOP VIEW)



functional block diagram



Terminal Functions

TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
AGND	79,83,87, 89,92	GND	Analog Ground – Ground reference and current return for analog circuitry.
AV_{DD}	82,84,88, 95	V_{DD}	Analog V_{DD} – Power supply for analog circuitry. Nominally 3.3 V
CTL[3:1]	42,41,40	DO	General-purpose control signals – Used for user defined control. CTL1 is not powered-down via $\overline{PDO}$.
DE	46	DO	Output data enable – Used to indicate time of active video display versus non-active display or blank time. During blank, only HSYNC, VSYNC, and CTL1-3 are transmitted. During times of active display, or non-blank, only pixel data, QE[23:0] and QO[23:0], is transmitted. High : Active display time Low: Blank time
DFO	1	DI	Output clock data format – Controls the output clock (ODCK) format for either TFT or DSTN panel support. For TFT support ODCK clock runs continuously. For DSTN support ODCK only clocks when DE is high, otherwise ODCK is held low when DE is low. High : DSTN support/ODCK held low when DE = low Low: TFT support/ODCK runs continuously.
DGND	5,39,68	GND	Digital ground – Ground reference and current return for digital core
DV_{DD}	6,38,67	V_{DD}	Digital V_{DD} – Power supply for digital core. Nominally 3.3 V
EXT_RES	96	AI	Internal impedance matching – The TFP401/40A is internally optimized for impedance matching at 50 Ω. An external resistor tied to this pin will have no effect on device performance.
HSYNC	48	DO	Horizontal sync output
RSVD	99	DI	Reserved. Must be tied high for normal operation.
OV_{DD}	18,29,43, 57,78	V_{DD}	Output driver V_{DD} – Power supply for output drivers. Nominally 3.3 V
ODCK	44	DO	Output data clock - Pixel clock. All pixel outputs QE[23:0] and QO[23:0] (if in 2-pixel/clock mode) along with DE, HSYNC, VSYNC and CTL[3:1] are synchronized to this clock.

Terminal Functions (continued)

TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
OGND	19,28,45, 58,76	GND	Output driver ground – Ground reference and current return for digital output drivers
OCK_INV	100	DI	ODCK Polarity – Selects ODCK edge on which pixel data (QE[23:0] and QO[23:0]) and control signals (HSYNC, VSYNC, DE, CTL1-3) are latched Normal Mode: High : Latches output data on rising ODCK edge Low : Latches output data on falling ODCK edge
$\overline{PD}$	2	DI	Power down – An active low signal that controls the TFP401/401A power-down state. During power down all output buffers are switched to a high impedance state. All analog circuits are powered down and all inputs are disabled, except for $\overline{PD}$. If $\overline{PD}$ is left unconnected an internal pullup will default the TFP401/401A to normal operation. High : Normal operation Low: Power down
$\overline{PDO}$	9	DI	Output drive power down – An active low signal that controls the power-down state of the output drivers. During output drive power down, the output drivers (except SCDT and CTL1) are driven to a high impedance state. When $\overline{PDO}$ is left unconnected, an internal pullup defaults the TFP401/401A to normal operation. High : Normal operation/output drivers on Low: Output drive power down.
PGND	98	GND	PLL GND – Ground reference and current return for internal PLL
PIXS	4	DI	Pixel select – Selects between one or two pixels per clock output modes. During the 2-pixel/clock mode, both even pixels, QE[23:0], and odd pixels, QO[23:0], are output in tandem on a given clock cycle. During 1-pixel/clock, even and odd pixels are output sequentially, one at a time, with the even pixel first, on the even pixel bus, QE[23:0]. (The first pixel per line is pixel-0, the even pixel. The second pixel per line is pixel-1, the odd pixel.) High : 2-pixel/clock Low: 1-pixel/clock
PV_{DD}	97	V_{DD}	PLL V_{DD} – Power supply for internal PLL
QE[8:15]	20-27	DO	Even green pixel output – Output for even and odd green pixels when in 1-pixel/clock mode. Output for even only green pixel when in 2-pixel/clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QE8/pin 20 MSB: QE15/pin 27
QE[16:23]	30-37	DO	Even red pixel output – Output for even and odd red pixels when in 1-pixel/clock mode. Output for even only red pixel when in 2-pixel/clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QE16/pin 30 MSB: QE23/pin 37
QO[0:7]	49-56	DO	Odd blue pixel output – Output for odd only blue pixel when in 2-pixel/clock mode. Not used, and held low, when in 1-pixel/clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QO0/pin 49 MSB: QO7/pin 56
QO[8:15]	59-66	DO	Odd green pixel output – Output for odd only green pixel when in 2-pixel/clock mode. Not used, and held low, when in 1-pixel/clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QO8/pin 59 MSB: QO15/pin 66
QO[16:23]	69-75,77	DO	Odd red pixel output – Output for odd only red pixel when in 2-pixel/clock mode. Not used, and held low, when in 1-pixel/clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QO16/pin 69 MSB: QO23/pin 77
QE[0:7]	10-17	DO	Even blue pixel output – Output for even and odd blue pixels when in 1-pixel/clock mode. Output for even only blue pixel when in 2-pixel per clock mode. Output data is synchronized to the output data clock, ODCK. LSB: QE0/pin 10 MSB: QE7/pin 17

Terminal Functions (continued)

TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
RxC+	93	AI	Clock positive receiver input – Positive side of reference clock. TMDS low voltage signal differential input pair
RxC–	94	AI	Clock negative receiver input – Negative side of reference clock. TMDS low voltage signal differential input pair.
Rx0+	90	AI	Channel-0 positive receiver input – Positive side of channel-0. TMDS low voltage signal differential input pair. Channel-0 receives blue pixel data in active display and HSYNC, VSYNC control signals in blank.
Rx0–	91	AI	Channel-0 negative receiver input – Negative side of channel-0. TMDS low voltage signal differential input pair.
Rx1+	85	AI	Channel-1 positive receiver input – Positive side of channel-1 TMDS low voltage signal differential input pair. Channel-1 receives green pixel data in active display and CTL1 control signals in blank.
Rx1–	86	AI	Channel-1 negative receiver input – Negative side of channel-1 TMDS low voltage signal differential input pair
Rx2+	80	AI	Channel-2 positive receiver input – Positive side of channel-2 TMDS low voltage signal differential input pair. Channel-2 receives red pixel data in active display and CTL2, CTL3 control signals in blank.
Rx2–	81	AI	Channel-2 negative receiver input – Negative side of channel-2 TMDS low voltage signal differential input pair.
SCDT	8	DO	Sync detect – Output to signal when the link is active or inactive. The link is considered to be active when DE is actively switching. The TFP401/401A monitors the state DE to determine link activity. SCDT can be tied externally to $\overline{\text{PDO}}$ to power down the output drivers when the link is inactive. High: Active link Low: Inactive link
ST	3	DI	Output drive strength select – Selects output drive strength for high or low current drive. (See dc specifications for I_{OH} and I_{OL} vs ST state.) High : High drive strength Low : Low drive strength
$\overline{\text{STAG}}$	7	DI	Staggered pixel select – An active low signal used in the 2-pixel/clock pixel mode (PIXS = high). Time staggers the even and odd pixel outputs to reduce ground bounce. Normal operation outputs the odd and even pixels simultaneously. High : Normal simultaneous even/odd pixel output Low: Time staggered even/odd pixel output
VSYNC	47	DO	Vertical sync output

absolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Supply voltage range, DV_{DD}, AV_{DD}, OV_{DD}, PV_{DD} . . . . . -0.3 V to 4 V
Input voltage range, logic/analog signals . . . . . -0.3 V to 4 V
Operating ambient temperature range . . . . . 0°C to 70°C
Storage temperature range . . . . . -65°C to 150°C
Case temperature for 10 seconds . . . . . 260°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . . 260°C
Package power dissipation/PowerPAD™: Soldered (see Note 1) . . . . . 4.3 W
Not soldered (see Note 2) . . . . . 2.7 W
ESD Protection, all pins . . . . . 2.5 KV Human Body Model
JEDEC latchup (EIA/JESD78) . . . . . 100 mA

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. Specified with PowerPAD™ bond pad on the backside of the package soldered to a 2 oz. Cu plate PCB thermal plane. Specified at maximum allowed operating temperature, 70°C.
2. PowerPAD™ bond pad on the backside of the package is not soldered to a thermal plane. Specified at maximum allowed operating temperature, 70°C.

recommended operating conditions

	MIN	TYP	MAX	UNIT
Supply voltage, V_{DD} (DV_{DD}, AV_{DD}, PV_{DD}, OV_{DD})	3	3.3	3.6	V
Pixel time, t_{pix}†	6.06		40	ns
Single ended analog input termination resistance, R_t	45	50	55	Ω
Operating free-air temperature, T_A	0	25	70	°C

† t_{pix} is the pixel time defined as the period of the RxC clock input. The period of the output clock, ODCK is equal to t_{pix} when in 1-pixel/clock mode and $2t_{pix}$ when in 2-pixel/clock mode.

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

dc digital I/O specifications

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IH}	High level digital input voltage‡			2		DV_{DD}	V
V_{IL}	Low level digital input voltage‡			0		0.8	V
I_{OH}	High level output drive current§	ST = High,	V_{OH} = 2.4 V	5	10	14	mA
		ST = Low,	V_{OH} = 2.4 V	3	6	9	
I_{OL}	Low level output drive current§	ST = High,	V_{OL} = 0.8 V	10	13	19	mA
		ST = Low,	V_{OL} = 0.8 V	5	7	11	
I_{OZ}	Hi-Z output leakage current	$\overline{PD}$ = Low or $\overline{PDO}$ = Low		–1		1	μA

‡ Digital inputs are labeled DI in I/O column of Terminal Functions Table.
§ Digital outputs are labeled DO in I/O column of Terminal Functions Table.

dc specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{ID}	Analog input differential voltage (see Note 3)		75		1200	mv
V_{IC}	Analog input common mode voltage (see Note 3)		AV_{DD}-300		AV_{DD}-37	mv
$V_{I(OC)}$	Open circuit analog input voltage		AV_{DD}-10		AV_{DD}+10	mv
$I_{DD(2PIX)}$	Normal 2-pix/clock power supply current (see Note 4)	ODCK = 82.5 MHz 2-pix/clock			370	mA
I_{PD}	Power down current (see Note 5)	$\overline{PD}$ = Low			10	mA
I_{PDO}	Output drive power down current (see Note 5)	$\overline{PDO}$ = Low		35		mA

NOTES: 3. Specified as dc characteristic with no overshoot or undershoot.
4. Alternating 2-pixel black/2-pixel white pattern. ST = high, $\overline{STAG}$ = high, QE[23:0] and QO[23:0] C_L = 10 pF.
5. Analog inputs are open circuit (transmitter is disconnected from TFP401/401A).

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted) (continued)

ac specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{ID(2)}$	Differential input sensitivity†		150		1560	mV_{p-p}
t_{ps}	Analog input intra-pair (+ to -) differential skew (see Note 6)				0.4	t_{bit}‡
t_{ccs}	Analog Input inter-pair or channel-to-channel skew (see Note 6)				1	t_{pix}§
t_{ijit}	Worse case differential input clock jitter tolerance¶ (see Note 6)		50			ps
t_{f1}	Fall time of data and control signals#, ‖	ST = Low, C_L=5 pF ST = High, C_L=10 pF			2.4 1.9	ns
t_{r1}	Rise time of data and control signals#, ‖	ST = Low, C_L=5 pF ST = High, C_L=10 pF			2.4 1.9	ns
t_{r2}	Rise time of ODCK clock#	ST = Low, C_L=5 pF ST = High, C_L=10 pF			2.4 1.9	ns
t_{f2}	Fall time of ODCK clock#	ST = Low, C_L=5 pF ST = High, C_L=10 pF			2.4 1.9	ns
t_{su1}	Setup time, data and control signal to falling edge of ODCK	1 pixel/clock, PIXS = low, OCK_INV = low	1.8			ns
		2 pixel/clock, PIXS = high, STAG/ = high, OCK_INV = low	3.8			
		2 pixel and STAG, PIXS = high, STAG/ = low, OCK_INV = low	0.7			
t_{h1}	Hold time, data and control signal to falling edge of ODCK	1 pixel/clock, PIXS = low, OCK_INV = low	0.6			ns
		2 pixel and STAG, PIXS = high, STAG/ = low, OCK_INV = low	2.5			
		2 pixel/clock, PIXS = high, STAG/ = high, OCK_INV = low	2.9			
t_{su2}	Setup time, data and control signal to rising edge of ODCK	1 pixel/clock, PIXS = low, OCK_INV = high	2.1			ns
		2 pixel/clock, PIXS = high, STAG/ = high, OCK_INV = high	4			
		2 pixel and STAG, PIXS = high, STAG/ = low, OCK_INV = high	1.5			
t_{h2}	Hold time, data and control signal to rising edge of ODCK	1 pixel/clock, PIXS = low, OCK_INV = high	0.5			ns
		2 pixel and STAG, PIXS = high, STAG/ = low, OCK_INV = high	2.4			
		2 pixel/clock, PIXS = high, STAG/ = high, OCK_INV = high	2.1			
f_{ODCK}	ODCK frequency	PIX = Low (1-PIX/CLK)	25		165	MHz
		PIX = High (2-PIX/CLK)	12.5		82.5	
	ODCK duty-cycle		45%	60%	75%	

† Specified as ac parameter to include sensitivity to overshoot, undershoot and reflection.
‡ t_{bit} is 1/10 the pixel time, tpix
§ t_{pix} is the pixel time defined as the period of the RxC input clock. The period of ODCK is equal to t_{pix} in 1-pixel/clock mode or $2t_{pix}$ when in 2-pixel/clock mode.
¶ Measured differentially at 50% crossing using ODCK output clock as trigger.
# Rise and fall times measured as time between 20% and 80% of signal amplitude.
‖ Data and control signals are : QE[23:0], QO[23:0], DE, HSYNC, VSYNC and CTL[3:1]
☆Link active or inactive is determined by amount of time detected between DE transitions. SCDT indicates link activity.
NOTE 6: By characterization

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted) (continued)

ac specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{pd(PDL)}$	Propagation delay time from $\overline{PD}$ low to Hi-Z outputs				9	ns
$t_{pd(PDOL)}$	Propagation delay time from $\overline{PDO}$ low to Hi-Z outputs				9	ns
$t_{t(HSC)}$	Transition time between DE transition to SCDT low☆			1e6		t_{pix}
$t_{t(FSC)}$	Transition time between DE transition to SCDT high☆			1600		t_{pix}
$t_{d(st)}$	Delay time, ODCK latching edge to QE[23:0] data output	$\overline{STAG}$ = Low Pixs = High		0.25		t_{pix}

PARAMETER MEASUREMENT INFORMATION

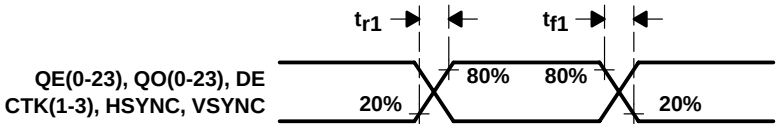


Figure 1. Rise and Fall TIme of Data and Control Signals

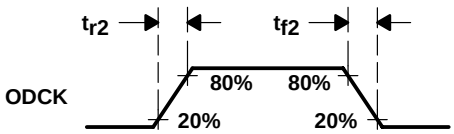


Figure 2. Rise and Fall Time of ODCK

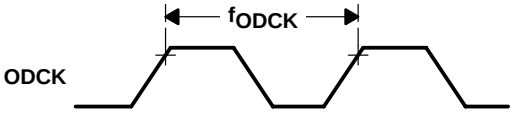


Figure 3. ODCK Frequency

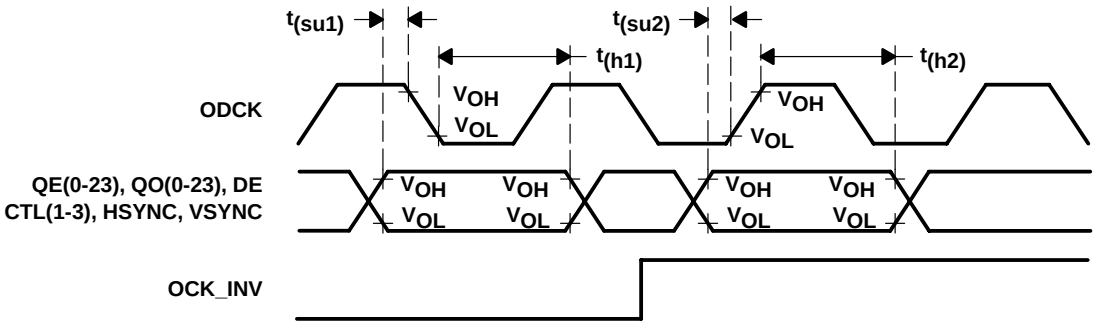


Figure 4. Data Setup and Hold Time to Rising and Falling Edge of ODCK

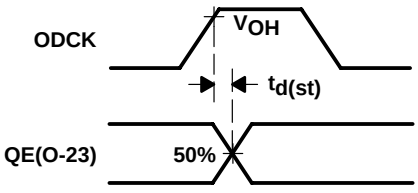


Figure 5. ODCK High to QE[23:0] Staggered Data Output

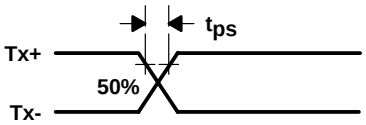


Figure 6. Analog Input Intra-Pair Differential Skew

PARAMETER MEASUREMENT INFORMATION

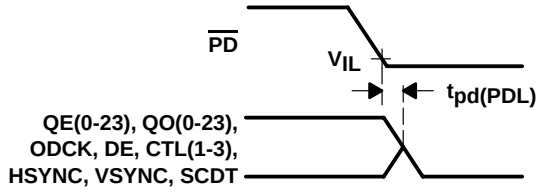


Figure 7. Delay From $\overline{PD}$ Low to Hi-Z Outputs

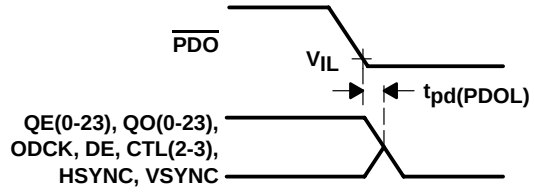


Figure 8. Delay From $\overline{PDO}$ Low to Hi-Z Outputs

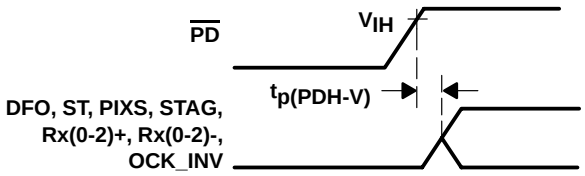


Figure 9. Delay From $\overline{PD}$ Low to High Before Inputs are Active

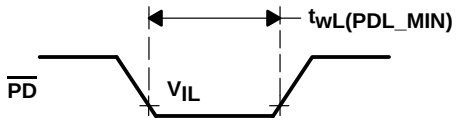


Figure 10. Minimum Time $\overline{PD}$ Low

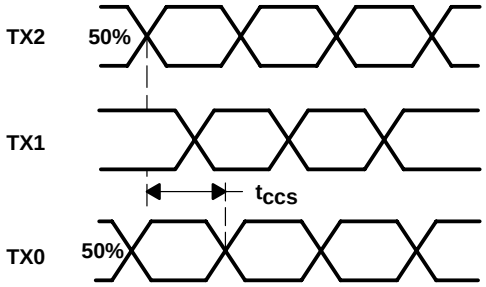


Figure 11. Analog Input Channel-to-Channel Skew

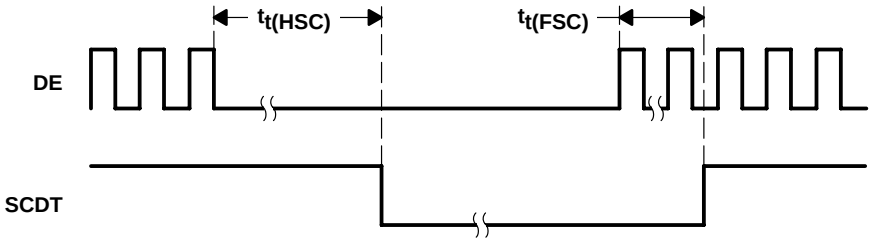


Figure 12. Time Between DE Transitions to SCDT Low and SCDT High

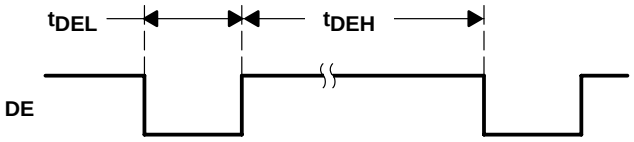


Figure 13. Minimum DE Low and Maximum DE High

detailed description

fundamental operation

The TFP401/401A is a digital visual interface (DVI) compliant TMDS digital receiver that is used in digital flat panel display systems to receive and decode TMDS encoded RGB pixel data streams. In a digital display system a host, usually a PC or workstation, contains a TMDS compatible transmitter that receives 24 bit pixel data along with appropriate control signals and encodes them into a high-speed low-voltage differential serial bit stream fit for transmission over a twisted-pair cable to a display device. The display device, usually a flat-panel monitor, will require a TMDS compatible receiver like the TI TFP401/401A to decode the serial bit stream back to the same 24 bit pixel data and control signals that originated at the host. This decoded data can then be applied directly to the flat panel drive circuitry to produce an image on the display. Since the host and display can be separated by distances up to 5 meters or more, serial transmission of the pixel data is preferred. To support modern display resolutions up to SXGA a high bandwidth receiver with good jitter and skew tolerance is required.

TMDS pixel data and control signal encoding

TMDS stands for transition minimized differential signaling. Only one of two possible TMDS characters for a given pixel will be transmitted at a given time. The transmitter keeps a running count of the number of ones and zeros previously sent and transmits the character that will minimize the number of transitions and approximate a dc balance of the transmission line.

Three TMDS channels are used to receive RGB pixel data during active display time, DE = high. The same three channels also receive control signals, HSYNC, VSYNC, and user defined control signals CTL[3:1]. These control signals are received during inactive display or blanking-time. Blanking-time is when DE = low. The following table maps the received input data to appropriate TMDS input channel in a DVI compliant system.

RECEIVED PIXEL DATA ACTIVE DISPLAY DE = HIGH	INPUT CHANNEL	OUTPUT PINS (VALID FOR DE = HIGH)
Red[7:0]	Channel – 2 (Rx2 ±)	QE[23:16] QO[23:16]
Green[7:0]	Channel – 1 (Rx1 ±)	QE[15:8] QO[15:8]
Blue[7:0]	Channel – 0 (Rx0 ±)	QE[7:0] QO[7:0]
RECEIVED CONTROL DATA BLANKING DE = LOW	**INPUT CHANNEL**	**OUTPUT PINS (VALID FOR DE = LOW)**
CTL[3:2]	Channel – 2 (Rx2 ±)	CTL[3:2]
CTL[1: 0] (see Note 6)	Channel – 1 (Rx1 ±)	CTL1
HSYNC, VSYNC	Channel – 0 (Rx0 ±)	HSYNC, VSYNC

NOTE 7: Some TMDS transmitters transmit a CTL0 signal. The TFP401/401A decodes and transfers CTL[3:1] and ignores CTL0 characters. CTL0 is not available as a TFP401/401A output.

The TFP401/401A discriminates between valid pixel TMDS characters and control TMDS characters to determine the state of active display versus blanking, i.e., state of DE.

detailed description (continued)

TFP401/401A clocking and data synchronization

The TFP401/401A receives a clock reference from the DVI transmitter that has a period equal to the pixel time, Tpix. The frequency of this clock is also referred to as the pixel rate. Since the TMDS encoded data on Rx[2:0] contains 10 bits per 8 bit pixel it follows that the Rx[2:0] serial bit rate is 10 times the pixel rate. For example, the required pixel rate to support an UXGA resolution with 60 Hz refresh rate is 165 MHz. The TMDS serial bit rate is 10x the pixel rate or 1.65 Gb/s. Due to the transmission of this high-speed digital bit stream, on three separate channels (or twisted-pair wires) of long distances (3-5 meters), phase synchronization between the data steams and the input reference clock is not guaranteed. In addition, skew between the three data channels is common. The TFP401/401A uses a 4x oversampling scheme of the input data streams to achieve reliable synchronization with up to 1-Tpix channel-to-channel skew tolerance. Accumulated jitter on the clock and data lines due to reflections and external noise sources is also typical of high speed serial data transmission, hence the TFP401/401A's design for high jitter tolerance.

The input clock to the TFP401/401A is conditioned by a phase-locked-loop (PLL) to remove high frequency jitter from the clock. The PLL provides four 10x clock outputs of different phase to locate and sync the TMDS data streams (4x oversampling). During active display the pixel data is encoded to be transition minimized, whereas in blank, the control data is encoded to be transition maximized. A DVI compliant transmitter is required to transmit in blank for a minimum period of time, 128-Tpix, to ensure sufficient time for data synchronization when the receiver sees a transition maximized code. Synchronization during blank, when the data is transition maximized, ensures reliable data bit boundary detection. Phase synchronization to the data streams is unique for each of the three input channels and is maintained as long as the link remains active.

TFP401/401A TMDS input levels and input impedance matching

The TMDS inputs to the TFP401/401A receiver have a fixed single-ended termination to AV_{DD} The TFP401/401A is internally optimized using a laser trim process to precisely fix the impedance at 50 Ω. The device will function normally with or without a resistor on the EXT_RES pin, so it remains drop-in compatible with current sockets. The fixed impedance eliminates the need for an external resistor while providing optimum impedance matching to standard 50-Ω DVI cables.

Figure 14 shows a conceptual schematic of a DVI transmitter and TFP401/401A receiver connection. A transmitter drives the twisted pair cable via a current source, usually achieved with an open drain type output driver. The internal resistor, which is matched to the cable impedance, at the TFP401/401A input provides a pullup to AV_{DD} . Naturally, when the transmitter is disconnected and the TFP401/401A DVI inputs are left unconnected, the TFP401/401A receiver inputs pullup to AV_{DD}. The single ended differential signal and full differential signal is shown in Figure 15. The TFP401/401A is designed to respond to differential signal swings ranging from 150 mV to 1.56 V with common mode voltages ranging from (AV_{DD}-300 mV) to (AV_{DD}-37 mV).

TFP401/401A TMDS input levels and input impedance matching (continued)

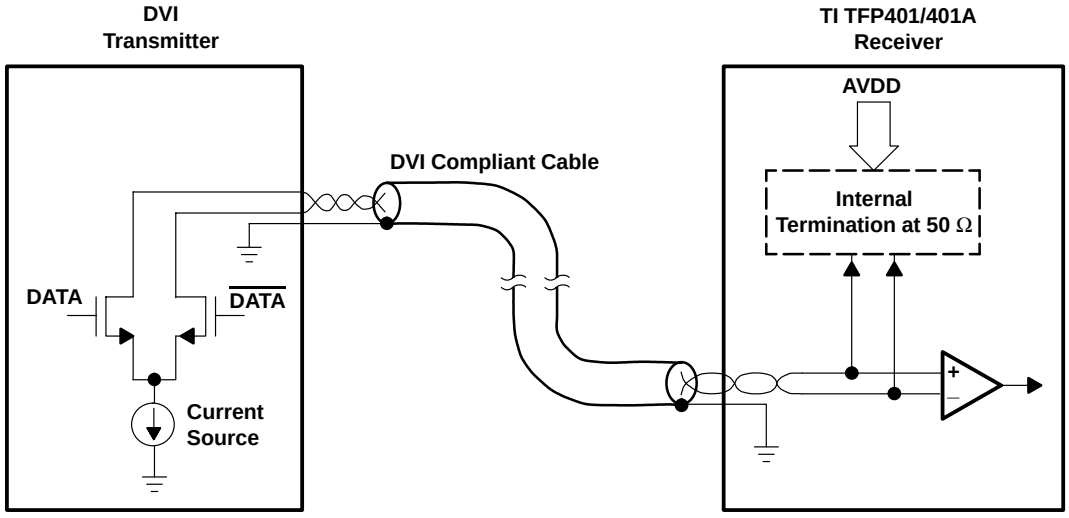


Figure 14. TMDS Differential Input and Transmitter Connection

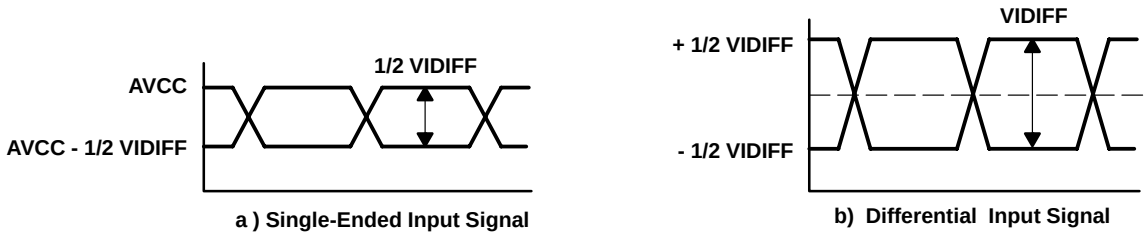


Figure 15. TMDS Inputs

TFP401A incorporates HSYNC jitter immunity

Several DVI transmitters available in the market introduce jitter on the transmitted HSYNC and VSYNC signals during the TMDS encryption process. The HSYNC signal can shift by one pixel position (one clock) from nominal in either direction, resulting in up to two cycles of HSYNC shift. This jitter carries through to the DVI receiver, and if the position of HSYNC shifts continuously, the receiver can lose track of the input timing and pixel noise will occur on the display. For this reason, a DVI compliant receiver with HSYNC jitter immunity should be used in all displays that could be connected to host PCs with transmitters that have this HSYNC jitter problem.

The TFP401A integrates HSYNC regeneration circuitry that provides a seamless interface to these noncompliant transmitters. The position of the data enable (DE) signal is always fixed in relation to data, irrespective of the location of HSYNC. The TFP401A receiver uses the DE and clock signals recreate stable vertical and horizontal sync signals. The circuit filters the HSYNC output of the receiver, and HSYNC is shifted to the nearest eighth bit boundary, producing a stable output with respect to data, as shown in Figure 16. This will ensure accurate data synchronization at the input of the display timing controller.

TFP401A incorporates HSYNC jitter immunity (continued)

This HSYNC regeneration circuit is transparent to the monitor and need not be removed even if the transmitted HSYNC is stable. For example, the PanelBus line of DVI 1.0 compliant transmitters, such as the TFP6422 and TFP420, do not have the HSYNC jitter problem. The TFP401A will operate correctly with either compliant or noncompliant transmitters. In contrast, the TFP401 is ideal for customers who have control over the transmit portion of the design such as bundled system manufacturers and for internal monitor use (the DVI connection between monitor and panel modules).

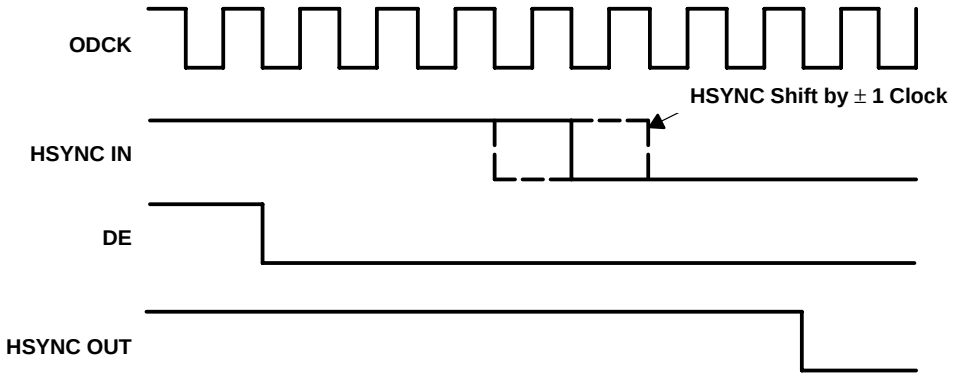


Figure 16. HSYNC Regeneration Timing Diagram

TFP401/401A modes of operation

The TFP401/401A provides systems design flexibility and value by providing the system designer with configurable options or modes of operation to support varying system architectures. The following table outlines the various panel modes that can be supported along with appropriate external control pin settings.

PANEL	PIXEL RATE	ODCK LATCH EDGE	ODCK	DFO	PIXS	OCK_INV
TFT or 16-bit DSTN	1 pix/clock	Falling	Free run	0	0	0
TFT or 16-bit DSTN	1 pix/clock	Rising	Free run	0	0	1
TFT	2 pix/clock	Falling	Free run	0	1	0
TFT	2 pix/clock	Rising	Free run	0	1	1
24-bit DSTN	1 pix/clock	Falling	Gated low	1	0	0
NONE	1 pix/clock	Rising	Gated low	1	0	1
24-bit DSTN	2 pix/clock	Falling	Gated low	1	1	0
24-bit DSTN	2 pix/clock	Rising	Gated low	1	1	1

TFP401/401A output driver configurations

The TFP401/401A provides flexibility by offering various output driver features that can be used to optimize power consumption, ground-bounce and power-supply noise. The following sections outline the output driver features and their effects.

Output driver power down ($\overline{PDO}$ = low), Pulling $\overline{PDO}$ low will place all the output drivers, except CTL1 and SCDT, into a high-impedance state. The SCDT output which indicates link-disabled or link-inactive can be tied directly to the $\overline{PDO}$ input to disable the output drivers when the link is inactive or when the cable is disconnected. An internal pullup on the $\overline{PDO}$ pin will default the TFP401/401A to the normal nonpower down output drive mode if left unconnected.

TFP401/401A output driver configurations (continued)

Drive Strength (ST = high for high drive strength, ST=low for low drive strength.) The TFP401/401A allows for selectable output drive strength on the data, control and ODCK outputs. See the dc specifications table for the values of I_{OH} and I_{OL} current drives for a given ST state. The high output strength offers approximately two times the drive as the low output drive strength.

Time Staggered Pixel Output. This option works only in conjunction with the 2-pixel/clock mode (PIXS = high). Setting $\overline{\text{STAG}}$ = low will time stagger the even and odd pixel output so as to reduce the amount of instantaneous current surge from the power supply. Depending on the PCB layout and design this can help reduce the amount of system ground bounce and power supply noise. The time stagger is such that in 2-pixel/clock mode the even pixel is delayed from the latching edge of ODCK by 0.25 Tcip. (Tcip is the period of ODCK. The ODCK period is 2Tpix when in 2-pixel/clock mode.)

Depending on system constraints of output load, pixel rate, panel input architecture and board cost the TFP401/401A drive strength and staggered pixel options allow flexibility to reduce system power-supply noise, ground bounce and EMI.

Power Management. The TFP401/401A offers several system power management features.

The output driver power down ($\overline{\text{PDO}}$ = low) is an intermediate mode which offers several uses. During this mode, all output drivers except SCDT and CTL1 are driven to a high impedance state while the rest of the device circuitry remains active

The TFP401/401A power down ($\overline{\text{PD}}$ = low) is a complete power down in that it powers down the digital core, the analog circuitry, and output drivers. All output drivers are placed into a Hi-Z state. All inputs are disabled except for the $\overline{\text{PD}}$ input. The TFP401/401A will not respond to any digital or analog inputs until $\overline{\text{PD}}$ is pulled high.

Both $\overline{\text{PDO}}$ and $\overline{\text{PD}}$ have internal pullups so if left unconnected they will default the TFP401/401A to normal operating modes.

Sync Detect. The TFP401/401A offers an output, SCDT to indicate link activity. The TFP401/401A monitors activity on DE to determine if the link is active. When 1 million (1e6) pixel clock periods pass without a transition on DE, the TFP401/401A considers the link inactive and SCDT is driven low. While SCDT is low, if two DE transitions are detected within 1600 pixel clock periods, the link will be considered active and SCDT is pulled high.

SCDT can be used to signal a system power management circuit to initiate a system power down when the link is considered inactive. The SCDT can also be tied directly to the TFP401/401A $\overline{\text{PDO}}$ input to power down the output drivers when the link is inactive. It is not recommended to use the SCDT to drive the $\overline{\text{PD}}$ input since, once in complete power-down, the analog inputs are ignored and the SCDT state will not change. An external system power management circuit to drive $\overline{\text{PD}}$ is preferred.

TI PowerPAD™ 100-TQFP package

The TFP401/401A is packaged in TI's thermally enhanced PowerPAD™ 100TQFP packaging. The PowerPAD™ package is a 14 mm × 14 mm × 1 mm TQFP outline with 0.5 mm lead-pitch. The PowerPAD™ package has a specially designed die mount pad that offers improved thermal capability over typical TQFP packages of the same outline. The TI 100-TQFP PowerPAD™ package offers a back-side solder plane that connects directly to the die mount pad for enhanced thermal conduction. Soldering the back side of the TFP401/401A to the application board is not required thermally as the device power dissipation is well within the package capability when not soldered.

Soldering the back side of the device to the PCB ground plane is recommended for electrical considerations. Since the die pad is electrically connected to the chip substrate and hence chip ground, connection of the PowerPAD back side to a PCB ground plane will help to improve EMI, ground bounce, and power supply noise performance.

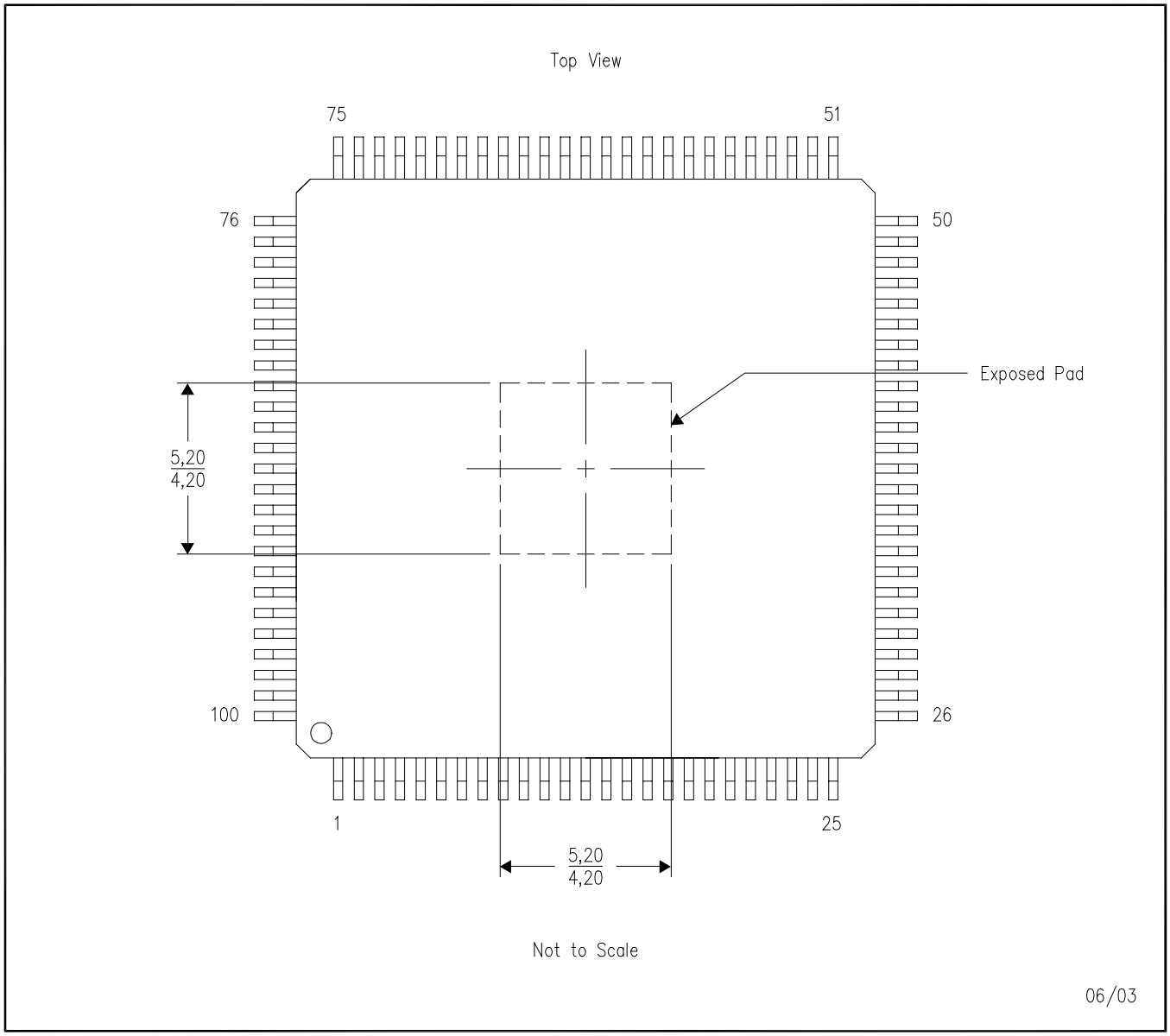
Table 1 outlines the thermal properties of the TI 100-TQFP PowerPAD™ package. The 100-TQFP non-PowerPAD™ package is included only for reference.

Table 1. TI 100-TQFP (14 × 14 × 1 mm)/0.5 mm Lead Pitch

PARAMETER	WITHOUT PowerPAD™	PowerPAD™ NOT CONNECTED TO PCB THERMAL PLANE	PowerPAD™ CONNECTED TO PCB THERMAL PLANE†
Theta-JA†,‡	45°C/W	27.3°C/W	17.3°C/W
Theta-JC†,‡	3.11°C/W	0.12°C/W	0.12°C/W
Maximum power dissipation†,‡,§	1.6 W	2.7 W	4.3 W

† Specified with 2 oz. Cu PCB plating.
‡ Airflow is at 0 LFM (no airflow)
§ Measured at ambient temperature, T_A = 70°C.

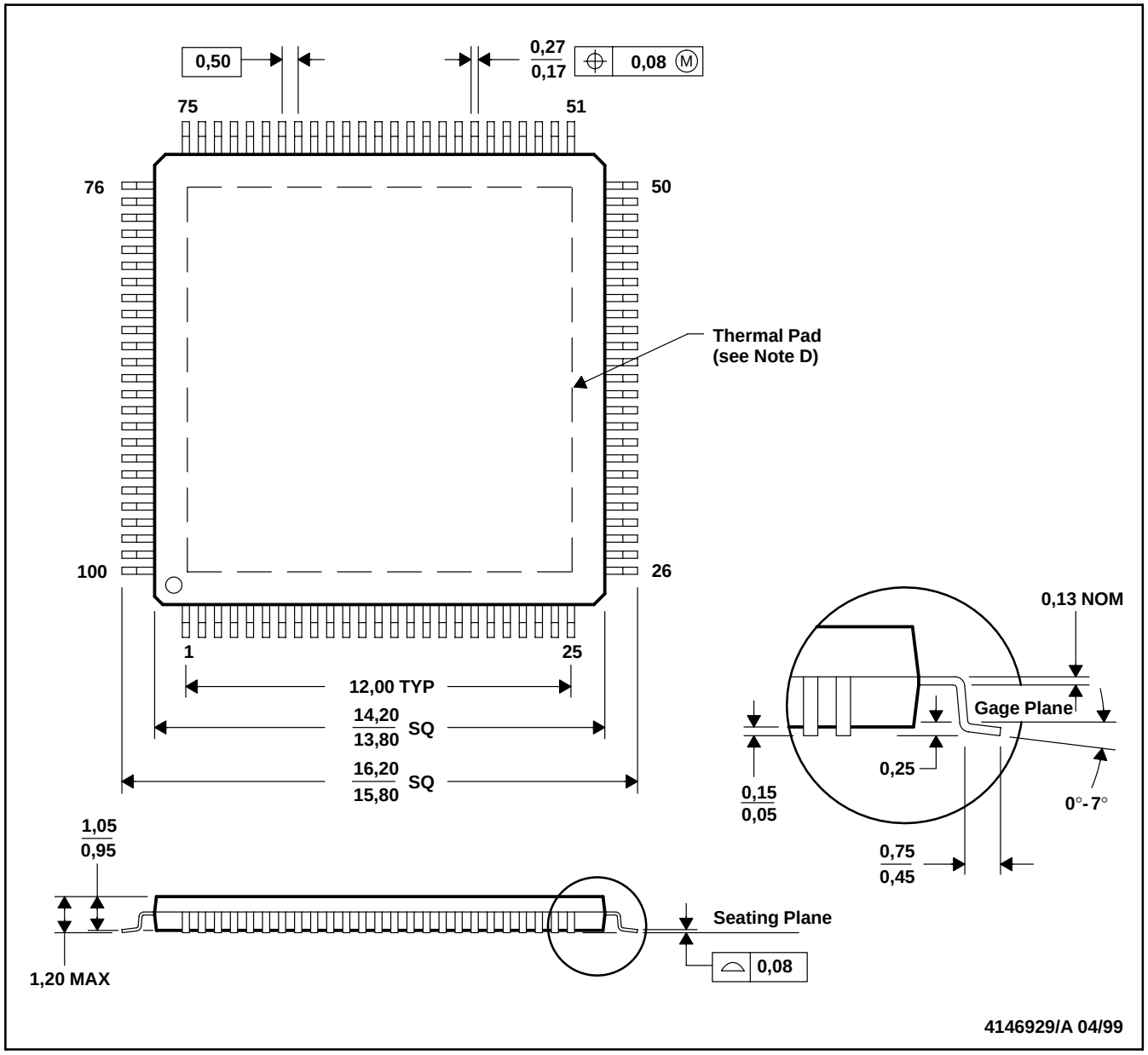
PZP (S-PQFP-G100) **PowerPAD™ PLASTIC QUAD FLATPACK**



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. For additional information on the PowerPAD™ package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, ***PowerPAD Thermally Enhanced Package***, Texas Instruments Literature No. SLMA002 and Application Brief, ***PowerPAD Made Easy***, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

MECHANICAL DATA

PZP (S-PQFP-G100) **PowerPAD™ PLASTIC QUAD FLATPACK**



NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. The package thermal performance may be enhanced by bonding the thermal pad to an external thermal plane. This pad is electrically and thermally connected to the backside of the die and possibly selected leads.
E. Falls within JEDEC MS-026

PowerPAD is a trademark of Texas Instruments.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third–party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products & application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265