



HDMI HIDER

FEATURES

- Supports 2.25 Gbps Signaling Rate for 480i/p, 720i/p, and 1080i/p Resolution to 12-Bit Color Depth
- Compatible with HDMI 1.3a
- Integrated Receiver Termination
- 8-dB Equalizer Compensates Losses from 5-m or Longer HDMI Cables
- Selectable Output De-Emphasis Supports 1-m HDMI Transmission
- I²C Repeater Isolates Bus Capacitance at Both Ends

- High Impedance Outputs When Disabled
- TMDS Inputs HBM ESD Protection Exceeds 6 kV
- 3.3-V Supply Operation
- 40-Pin QFN Package (RHA)
- ROHS Compatible and 260°C Reflow Rated

APPLICATIONS

- Digital TV
- DVD Player
- Set-Top-Box
- Audio Video Receiver
- Digital Projector
- DVI or HDMI cable

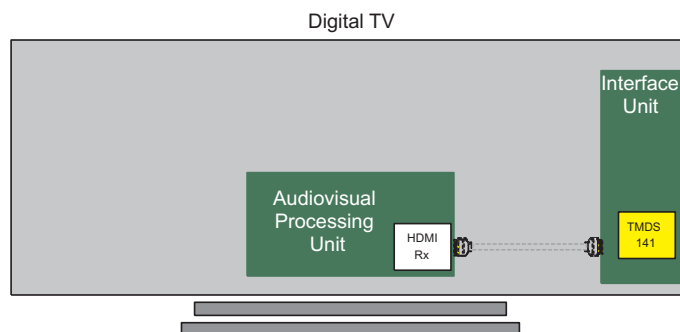
DESCRIPTION

The TMDS141 HDMI hider is designed to accommodate a 1-m HDMI cable between a HDMI connector and a receiver. The internal cable causes signal distortion to high-speed TMDS signals, as well as increasing capacitance to the DDC channel. Each TMDS141 contains four TMDS repeaters to transmit digital content with signaling rates of up to 2.25-Gbps, and an I²C repeater to link extended display identification data (EDID) reading and high-bandwidth digital content protection (HDCP) key exchange under I²C standard mode operations.

The device includes four TMDS compliant differential receivers with 50-Ω termination resistors and 3.3-V termination voltage integrated at each receiver input pin. External terminations are not required. A built-in frequency response equalization circuit, 8 dB at 825 MHz, compensates inter-symbol interference (ISI) losses from a 5-m or longer input cable link.

The device also includes four TMDS compliant differential drivers. A precision resistor is connected externally from the VSADJ pin to ground for setting the differential output voltage to be compliant with the TMDS standard. A selectable de-emphasis circuit is available via the PRE input to drive long PCB traces or cables. When PRE is high, the 3.5-dB high frequency gain offsets the losses due to the FR4 trace. PRE can be left open or kept low when the de-emphasis function is not desired.

TYPICAL APPLICATION



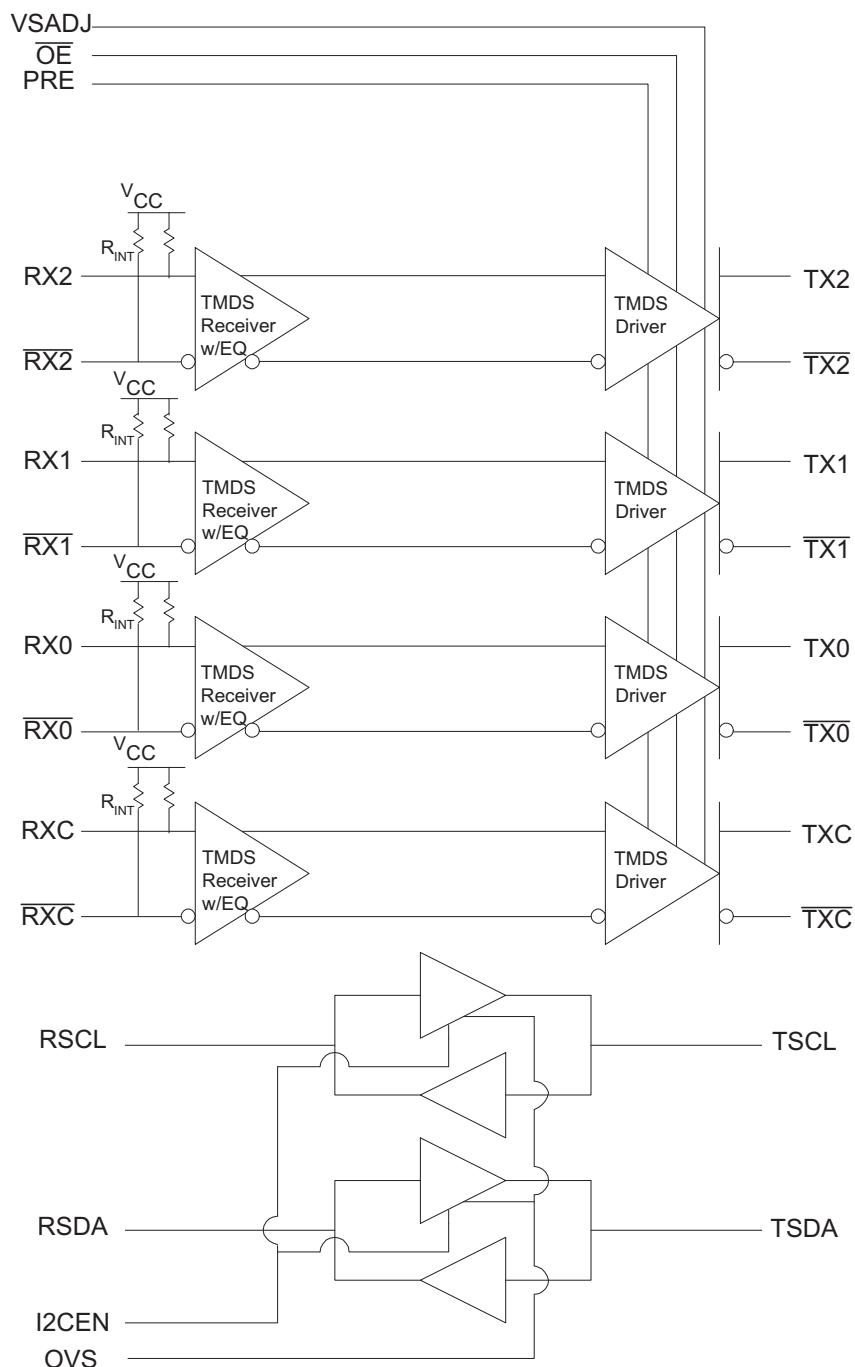
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

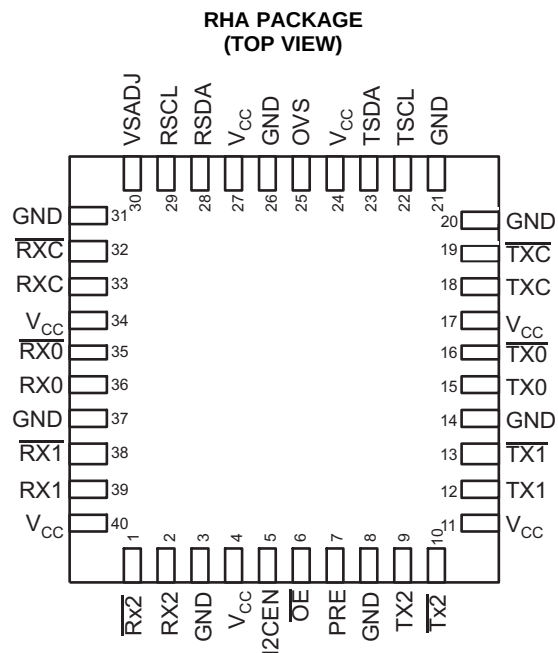
With standard TMDS terminations at the outputs, all TMDS outputs are forced high-impedance when $\overline{OE}$ is set high. The I²C repeater isolates the buses without accumulating the capacitance of both sides. It allows DDC capacitance to be controlled under the desired load. The I²C outputs are high-impedance when device supply voltage is less than 1.5 V or I2CEN is low. The OVS pin, output voltage select, provides the flexibility of adjusting the output voltage level of the TSCL and TSDA side to optimize noise margins while interfacing to different HDMI receivers. The device is characterized for operation from 0°C to 70°C.



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

FUNCTIONAL BLOCK DIAGRAM

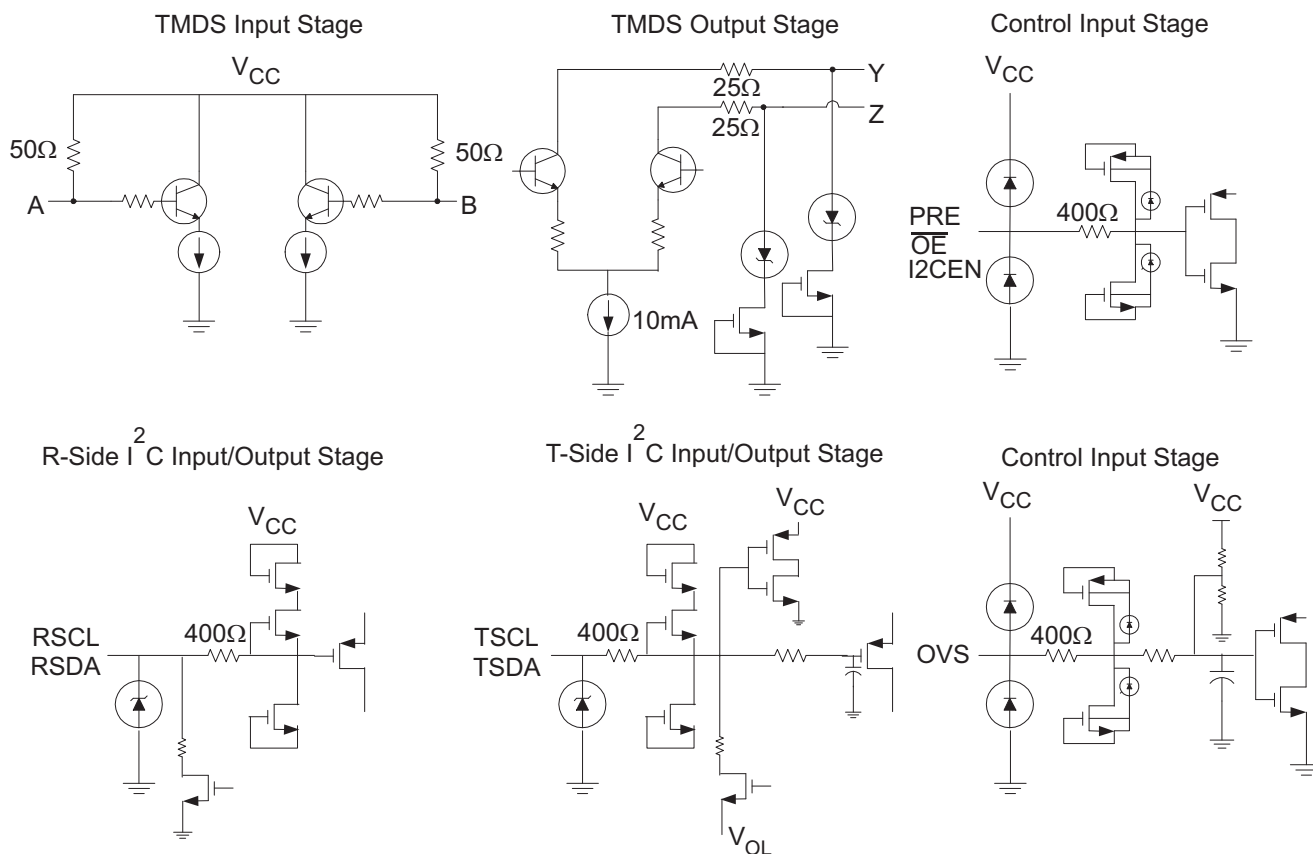




TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
$\overline{RX2}$, $\overline{RX1}$, $\overline{RX0}$, $\overline{RXC}$	1, 38, 35, 32	I	TMDS Negative inputs
RX2, RX1, RX0, RXC	2, 39, 36, 33	I	TMDS Positive inputs
$\overline{TX2}$, $\overline{TX1}$, $\overline{TX0}$, $\overline{TXC}$	10, 13, 16, 19	O	TMDS Negative outputs
TX2, TX1, TX0, TXC	9, 12, 15, 18	O	TMDS Positive outputs
RSCL	29	I/O	DDC Bus clock line to source
RSDA	28	I/O	DDC Bus data line to source
TSCL	22	I/O	DDC Bus clock line to sink
TSDA	23	I/O	DDC Bus data line to sink
VSADJ	30	I	TMDS Compliant voltage swing control
I2CEN	5	I	I ² C Repeater enable Low: High-Z High: Active
OVS	25	I	TSCL/TSDA Output voltage select
$\overline{OE}$	6	I	TMDS Output enable Low: Active High: High-Z
PRE	7	I	TMDS Output de-emphasis adjustment Low: 0 dB High: 3.5 dB
V _{CC}	4, 11, 17, 24, 27, 34, 40		Power supply
GND	3, 8, 14, 20, 21, 26, 31, 37		Ground

EQUIVALENT INPUT AND OUTPUT SCHEMATIC DIAGRAMS



ORDERING INFORMATION⁽¹⁾

PART NUMBER	PART MARKING	PACKAGE
TMDS141RHAR	TMDS141	40-PIN QFN Tape/Reel

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS

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

			UNIT
V _{CC}	Supply voltage range ⁽²⁾		−0.5 V to 4 V
Voltage range	RX, $\overline{\text{RX}}$		2.0 V to 4 V
	TX, $\overline{\text{TX}}$, PRE, VSADJ, $\overline{\text{OE}}$, I2CEN, OVS, HPDn		−0.5V to 4 V
	RSCL, RSDA, TSCL, TSDA		−0.5 V to 6 V
Electrostatic discharge	Human body model ⁽³⁾	RX, $\overline{\text{RX}}$	±6 kV
		All pins	±4 kV
	Charged-device model ⁽⁴⁾ (all pins)		±1500 V
	Machine model ⁽⁵⁾ (all pins)		± 200 V
Continuous power dissipation			See Dissipation Rating Table

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only and functional operation of the device 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.

(2) All voltage values, except differential I/O bus voltages, are with respect to network ground terminal.

(3) Tested in accordance with JEDEC Standard 22, Test Method A114-B

(4) Tested in accordance with JEDEC Standard 22, Test Method C101-A

(5) Tested in accordance with JEDEC Standard 22, Test Method A115-A

DISSIPATION RATINGS

PACKAGE	PCB JEDEC STANDARD	T _A ≤ 25°C	DERATING FACTOR ⁽¹⁾ ABOVE T _A = 25°C	T _A = 70°C POWER RATING
40-QFN RHA	Low-K ⁽²⁾	839.7 mW	8.39 mW/°C	461.8 mW
40-QFN RHA	High-K ⁽³⁾	3030.3 mW	30.3 mW/°C	1666.6mW

(1) This is the inverse of the junction-to-ambient thermal resistance when board-mounted and with no air flow.

(2) In accordance with the Low-K thermal metric definitions of EIA/JESD51-3

(3) In accordance with the High-K thermal metric definitions of EIA/JESD51-7

THERMAL CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
R _{θJB} Junction-to-board thermal resistance			30.9 6		°C/W
R _{θJC} Junction- to-case thermal resistance			32.4 2		°C/W
P _D Device power dissipation	V _{IH} = V _{CC} , V _{IL} = V _{CC} - 0.5 V, R _T = 50 Ω, V _{CC} = AV _{CC} = 3.3V, R _{vsadj} = 4.64 kΩ	PRE = Low	344	370	mW
		PRE = High	381	407	
	V _{IH} = V _{CC} , V _{IL} = V _{CC} - 0.6 V, R _T = 50 Ω, V _{CC} = 3.6 V, AV _{CC} = 3.3V, R _{vsadj} = 4.6 kΩ	PRE = Low		484	mW
		PRE = High		526	

RECOMMENDED OPERATING CONDITIONS

	MIN	NOM	MAX	UNIT
V _{CC} Supply voltage	3	3.3	3.6	V
T _A Operating free-air temperature	0		70	°C
TMDS DIFFERENTIAL PINS (RX/ RXC)				
V _{IC} Input common mode voltage	V _{CC} –400		V _{CC} +10	mV
V _{ID} Receiver peak-to-peak differential input voltage	150		1560	mVp-p
R _{VSADJ} Resistor for TMDS compliant voltage swing range	4.6	4.64	4.68	kΩ
AV _{CC} TMDS Output termination voltage, see Figure 1	3	3.3	3.6	V
R _T Termination resistance, see Figure 1	45	50	55	Ω
Signaling rate	0		2.25	Gbps

RECOMMENDED OPERATING CONDITIONS (continued)

		MIN	NOM	MAX	UNIT
CONTROL PINS (PRE, $\overline{OE}$, I2CEN)					
V _{IH}	LVTTL High-level input voltage	2		V _{CC}	V
V _{IL}	LVTTL Low-level input voltage	GND		0.8	V
CONTROL PINS (OVS)					
V _{IH}	LVTTL High-level input voltage	3		3.6	V
V _{IL}	LVTTL Low-level input voltage	-0.5		0.5	V
I²C PINS (TSCL, TSDA)					
V _{IH}	High-level input voltage	0.7V _{CC}		5.5	V
V _{IL}	Low-level input voltage	-0.5		0.3V _{CC}	V
V _{ICL}	Low-level input voltage contention ⁽¹⁾	-0.5		0.4	V
I²C PINS (RSCL, RSDA)					
V _{IH}	High-level input voltage	2.1		5.5	V
V _{IL}	Low-level input voltage	-0.5		1.5	V

(1) V_{IL} specification is for the first low level seen by the SCL/SDA lines. V_{ICL} is for the second and subsequent low levels seen by the TSCL/TSDA lines.

ELECTRICAL CHARACTERISTICS

over recommended operating conditions (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP ⁽¹⁾	MAX	UNIT
I _{CC}	Supply current V _{IH} = V _{CC} , V _{IL} = V _{CC} - 0.4 V, R _T = 50 Ω, AV _{CC} = 3.3 V, R _{VSADJ} = 4.64 kΩ, 1.65-Gbps HDMI data pattern, 165-MHz Pixel clock, PRE = Low		108	130 ⁽²⁾	mA
P _D	Power dissipation V _{IH} = V _{CC} , V _{IL} = V _{CC} - 0.4 V, R _T = 50 Ω, AV _{CC} = 3.3 V, R _{VSADJ} = 4.64 kΩ, 1.65-Gbps HDMI data pattern, 165-MHz Pixel clock, PRE = Low			497 ⁽²⁾	mW
TMDS DIFFERENTIAL PINS (TX, TXC)					
V _{OH}	Single-ended high-level output voltage	AV _{CC} -10		AV _{CC} +10	mV
V _{OL}	Single-ended low-level output voltage	AV _{CC} -600		AV _{CC} -400	mV
V _{swing}	Single-ended output swing voltage	400		600	mV
V _{OD(O)}	Overshoot of output differential voltage			15%	2× V _{swing}
V _{OD(U)}	Undershoot of output differential voltage			25%	2× V _{swing}
ΔV _{OC(SS)}	Change in steady-state common-mode output voltage between logic states			5	mV
I _{(O)OFF}	Single-ended standby output current 0 V ≤ V _{CC} ≤ 1.5 V, AV _{CC} = 3.3 V, R _T = 50 Ω	-10		10	μA
V _{OD(pp)}	Peak-to-peak output differential voltage	800		1200	mVp-p
V _{ODE(SS)}	Steady state output differential voltage with de-emphasis	600		820	
I _(OS)	Short circuit output current See Figure 4	-12		12	mA
V _{I(open)}	Single-ended input voltage under high impedance input or open input I _I = 10 μA	V _{CC} -10		V _{CC} +10	mV
R _{INT}	Input termination resistance V _{IN} = 2.9 V	45	50	55	Ω
CONTROL PINS (PRE, $\overline{OE}$, I2CEN, OVS)					
I _{IH}	High-level digital input current V _{IH} = 2 V or V _{CC}	-10		10	μA
I _{IL}	Low-level digital input current V _{IL} = GND or 0.8 V	-10		10	μA
I²C PINS (TSCL, TSDA)					
I _{Ikg}	Input leakage current V _I = 5.5 V	-50		50	μA
	V _I = V _{CC}	-10		10	
I _{OH}	High-level output current V _O = 3.6 V	-10		10	μA

(1) All typical values are at 25°C and with a 3.3-V supply.

(2) The maximum rating is characterized under 3.6 V V_{CC} and 600 mV V_{ID}.

ELECTRICAL CHARACTERISTICS (continued)

over recommended operating conditions (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP ⁽¹⁾	MAX	UNIT
I _{IL}	Low-level input current	V _{IL} = GND		-40		40	μA
V _{OL}	Low-level output voltage	I _{OL} = 400 μA or 4 mA	OVS = NC ⁽³⁾	0.47		0.6	V
			OVS = GND ⁽³⁾	0.6		0.75	
			OVS = V _{CC} ⁽³⁾	0.75		0.95	
V _{OL} -V _{ILC}	Low-level input voltage below output low-level voltage level	Ensured by design	OVS = NC ⁽³⁾	70		mV	
			OVS = GND ⁽³⁾	220			
			OVS = V _{CC} ⁽³⁾	370			
C _{IO}	Input/output capacitance	V _I = 5.0 V or 0 V, Freq = 100 kHz				25	pF
		V _I = 3.0 V or 0 V, Freq = 100 kHz				10	
I ² C PINS (RSCL, RSDA)							
I _{IKG}	Input leakage current	V _I = 5.5 V		-50		50	μA
		V _I = V _{CC}		-10		10	
I _{OH}	High-level output current	V _O = 3.6 V		-10		10	μA
I _{IL}	Low-level input current	V _{IL} = GND		-10		10	μA
V _{OL}	Low-level output voltage	I _{OL} = 4 mA				0.2	V
C _I	Input capacitance	V _I = 5.0 V or 0 V, Freq = 100 kHz				25	pF
		V _I = 3.0 V or 0 V, Freq = 100 kHz				10	

(3) The patent of the OVS pin is filed.

SWITCHING CHARACTERISTICS

over recommended operating conditions (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP ⁽¹⁾	MAX	UNIT
TMD5 DIFFERENTIAL PINS (TX/TXC)					
t_{PLH} Propagation delay time, low-to-high-level output	See Figure 2, $AV_{CC} = 3.3 V$, $R_T = 50 \Omega$	100		500	ps
t_{PHL} Propagation delay time, high-to-low-level output		100		500	ps
t_r Differential output signal rise time (20% - 80%)		75		240	ps
t_f Differential output signal fall time (20% - 80%)		75		240	ps
$t_{sk(p)}$ Pulse skew ($ t_{PHL} - t_{PLH} $) ⁽²⁾				50	ps
$t_{sk(D)}$ Intra-pair differential skew, see Figure 5				60	ps
$t_{sk(o)}$ Inter-pair channel-to-channel output skew ⁽³⁾				80	ps
$t_{sk(pp)}$ Part-to-part skew ⁽⁴⁾				200	ps
t_{en} Enable time	See Figure 6			10	ns
t_{dis} Disable time				10	ns
$t_{jit(pp)}$ Peak-to-peak output jitter from TXC, residual jitter ⁽⁵⁾	See Figure 7, RXC = 165-MHz clock, RX = 1.65-Gbps HDMI pattern, Input: 5m 28AWG HDMI cable, Output: 1m 28AWG HDMI cable, PRE = high		14	30	ps
$t_{jit(pp)}$ Peak-to-peak output jitter from TX0 - TX2, residual jitter ⁽⁵⁾			30	88	ps
$t_{jit(pp)}$ Peak-to-peak output jitter from TXC, residual jitter ⁽⁵⁾	See Figure 7, RXC = 225-MHz clock, RX = 2.25-Gbps HDMI pattern, Input: 5m 28AWG HDMI cable, Output: 1m 28AWG HDMI cable, PRE = high		25		ps
$t_{jit(pp)}$ Peak-to-peak output jitter from TX0 - TX2, residual jitter ⁽⁵⁾			42	88	

(1) All typical values are at 25°C and with a 3.3-V supply.

(2) $t_{sk(p)}$ is the magnitude of the time difference between t_{PLH} and t_{PHL} of a specified terminal.

(3) $t_{sk(o)}$ is the magnitude of the difference in propagation delay times between any specified terminals of channel 2 to 4 of a device when inputs are tied together.

(4) $t_{sk(pp)}$ is the magnitude of the difference in propagation delay times between any specified terminals of channel 2 to 4 of two devices, or between channel 1 of two devices, when both devices operate with the same source, the same supply voltages, at the same temperature, and have identical packages and test circuits.

(5) Jitter specifications are ensured by design and characterization and measured in BER⁻¹²

SWITCHING CHARACTERISTICS (continued)

over recommended operating conditions (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP ⁽¹⁾	MAX	UNIT
I2C PINS (RSCL, RSDA, TSCL, TSDA)						
t_{PLH}	Propagation delay time, low-to-high-level output TSCL/TSDA to RSCL/RSDA	See Figure 8 , OVS = NC	204		459	ns
t_{PHL}	Propagation delay time, high-to-low-level output TSCL/TSDA to RSCL/RSDA		35		120	ns
t_{PLH}	Propagation delay time, low-to-high-level output RSCL/RSDA to TSCL/TSDA		194		351	ns
t_{PHL}	Propagation delay time, high-to-low-level output RSCL/RSDA to TSCL/TSDA		35		120	ns
t_r	TSCL/TSDA Output signal rise time		500		800	ns
t_f	TSCL/TSDA Output signal fall time		30		72	ns
t_r	RSCL/RSDA Output signal rise time		796		999	ns
t_f	RSCL/RSDA Output signal fall time		20		72	ns
t_{set}	Enable to start condition	See Figure 9	100			ns
t_{hold}	Enable after stop condition		100			ns

PARAMETER MEASUREMENT INFORMATION

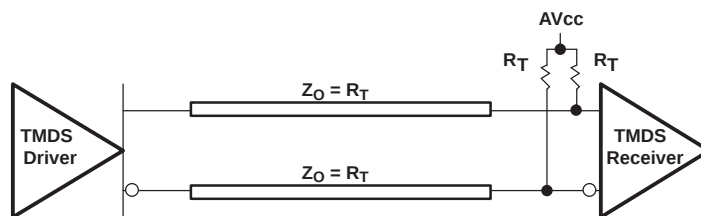
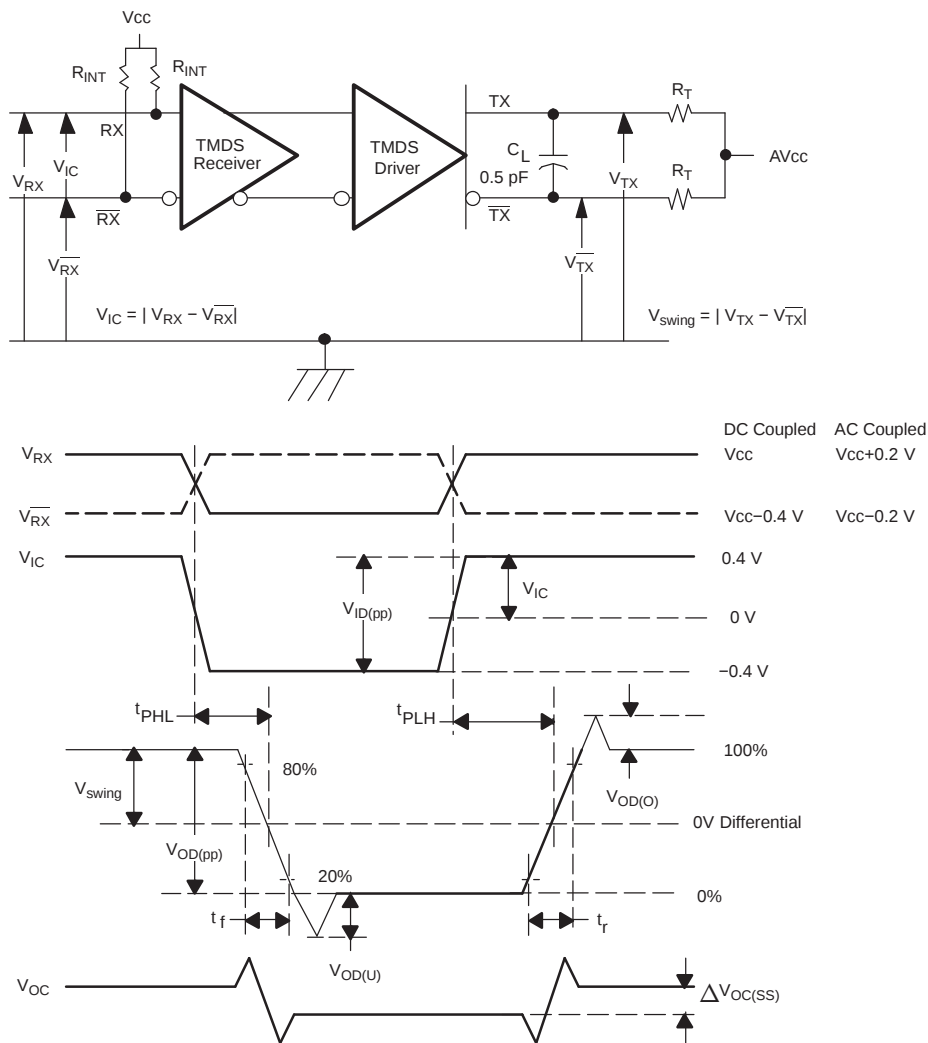


Figure 1. Typical Termination for TMDS Output Driver



NOTE: PRE = low. All input pulses are supplied by a generator having the following characteristics: t_r or $t_f < 100$ ps, 100 MHz from Agilent 81250. C_L includes instrumentation and fixture capacitance within 0.06 m of the D.U.T. Measurement equipment provides a bandwidth of 20 GHz minimum.

Figure 2. TMDS Timing Test Circuit and Definitions

PARAMETER MEASUREMENT INFORMATION (continued)

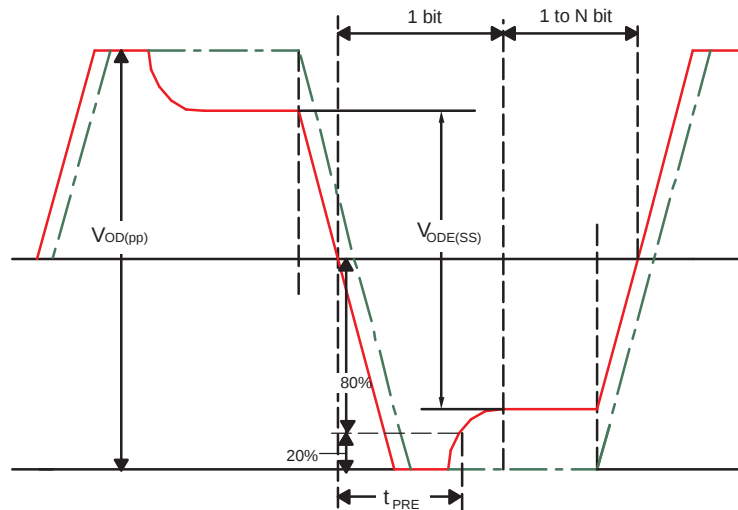


Figure 3. De-Emphasis Output Voltage Waveforms and Duration Measurement Definitions

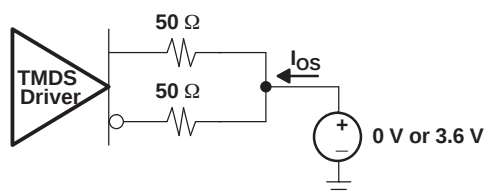


Figure 4. Short Circuit Output Current Test Circuit

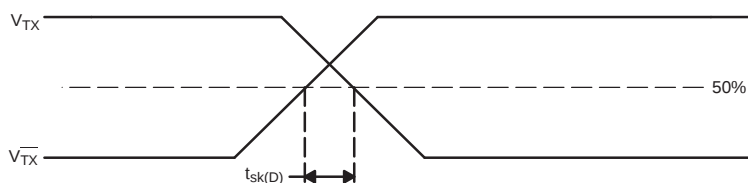


Figure 5. Definition of Intra-Pair Differential Skew

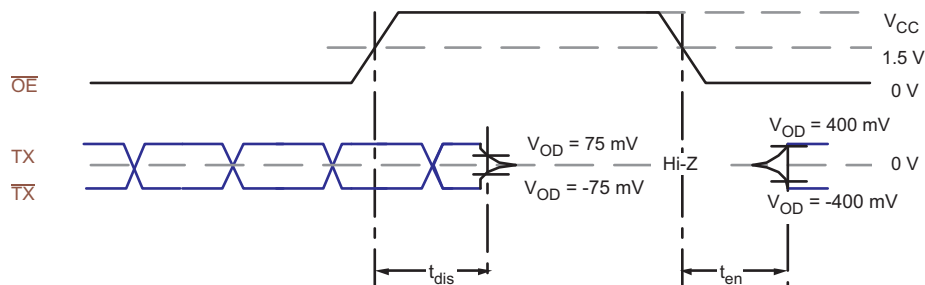
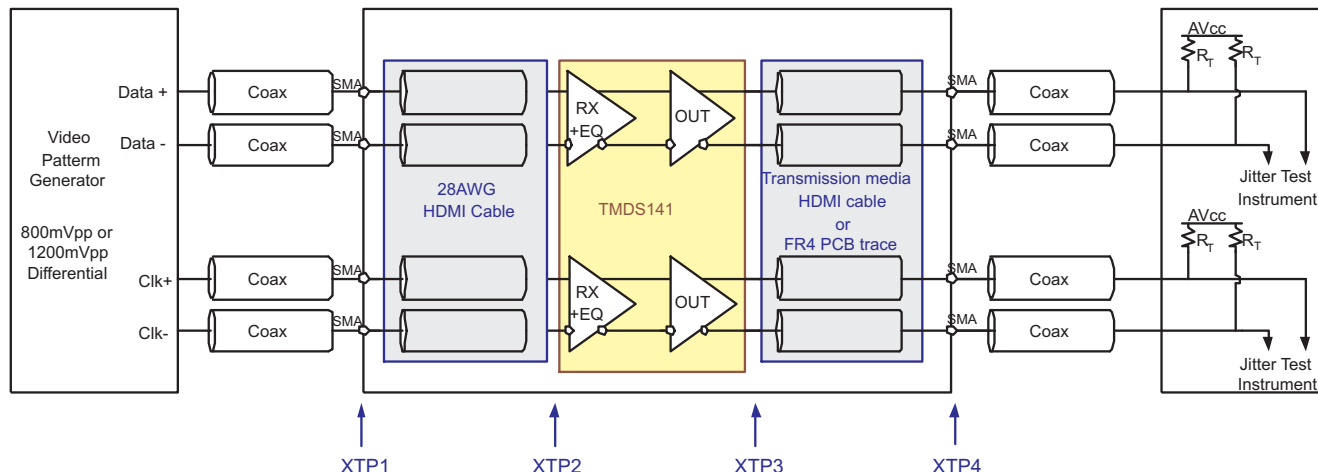


Figure 6. TMDS Enable and Disable Timing Definitions

PARAMETER MEASUREMENT INFORMATION (continued)



- All jitters are measured in BER of 10^{-12}
- The residual jitter reflects the total jitter measured at XTP4, subtract the total jitter at XTP1

Figure 7. Jitter Test Circuit

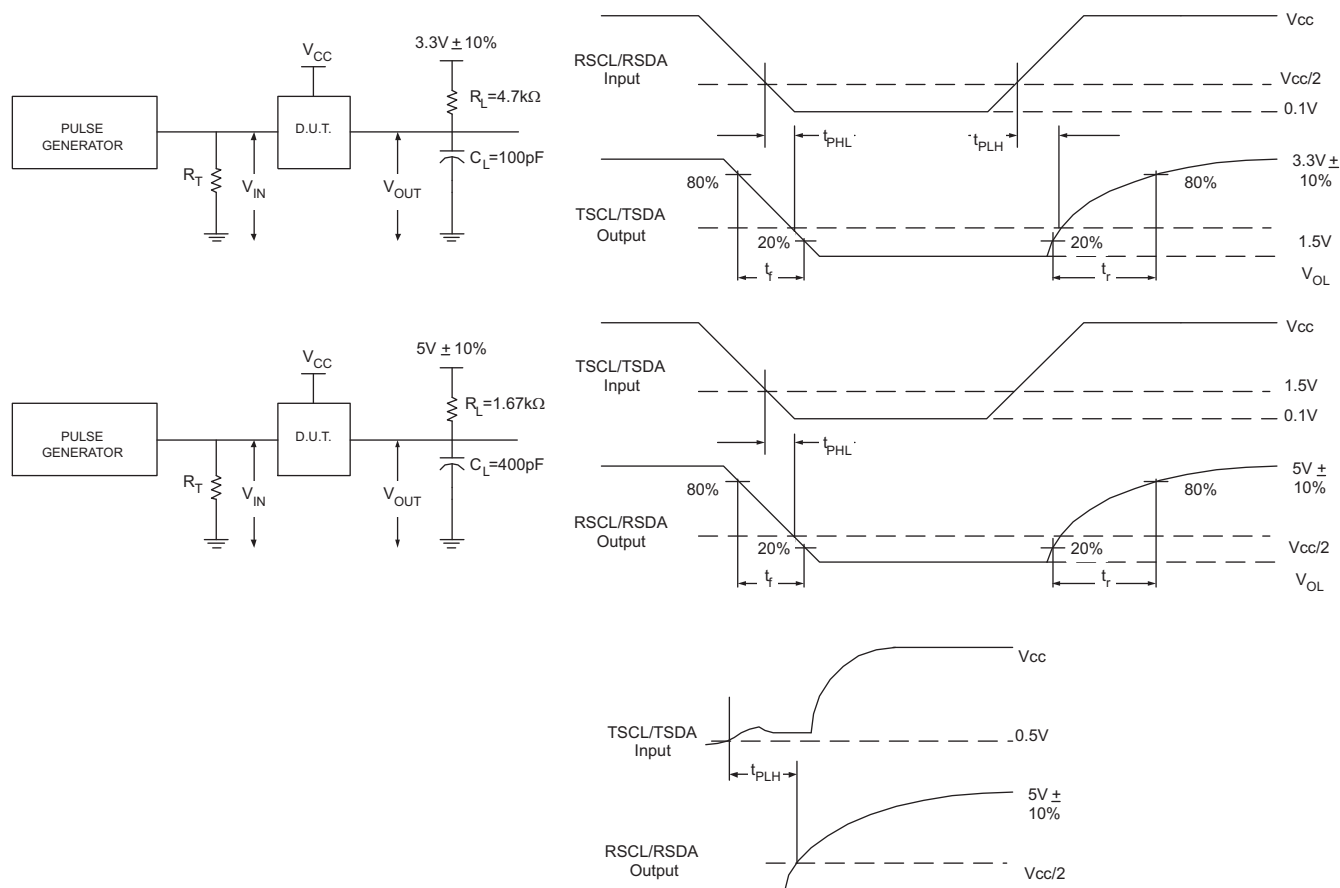
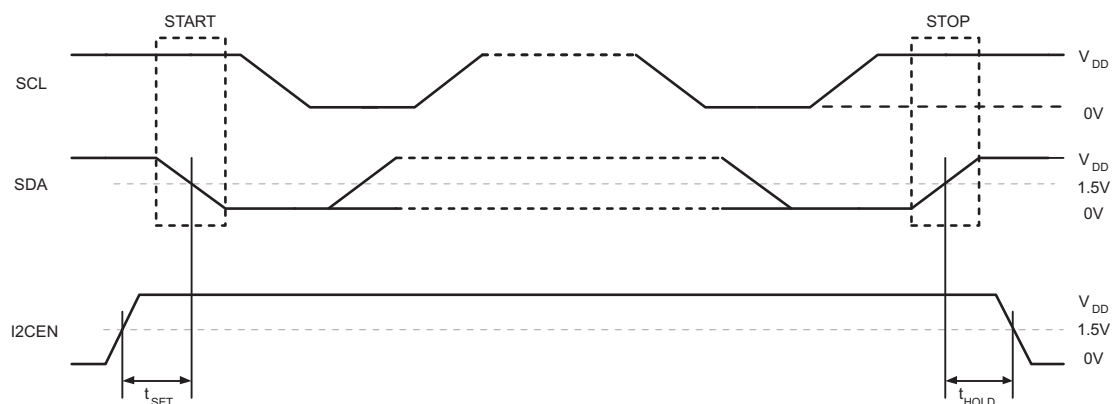


Figure 8. I²C Timing Test Circuit and Definition

PARAMETER MEASUREMENT INFORMATION (continued)**Figure 9. I²C Setup and Hold Definition**

TYPICAL CHARACTERISTICS

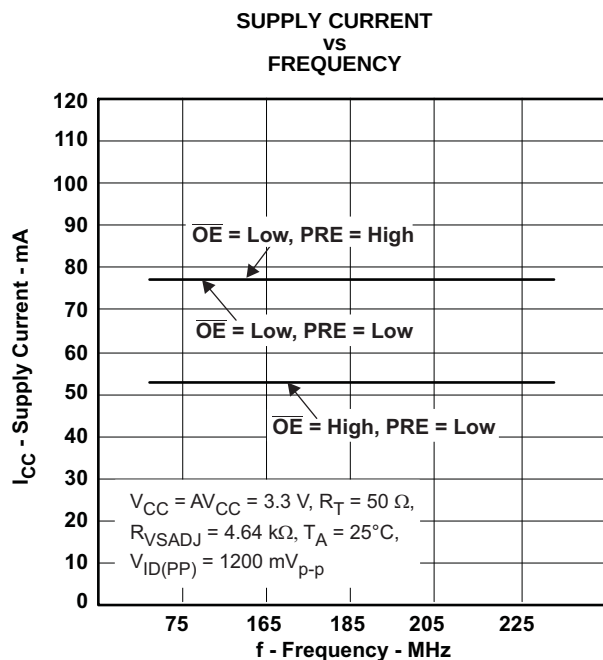


Figure 10.

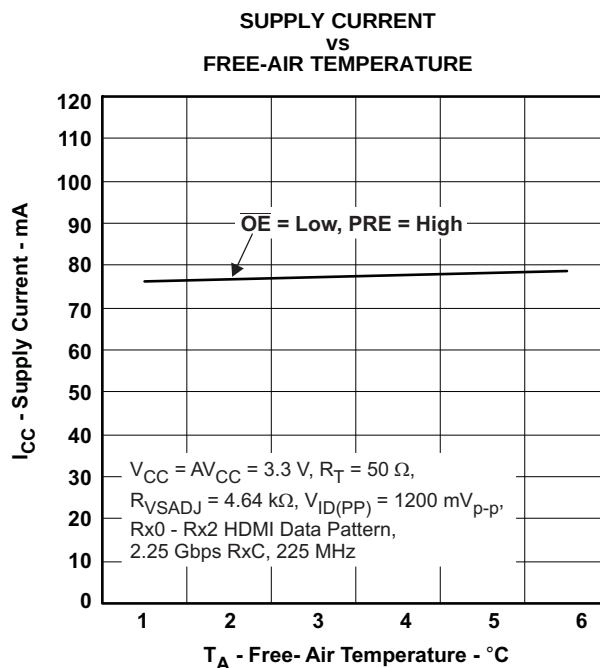


Figure 11.

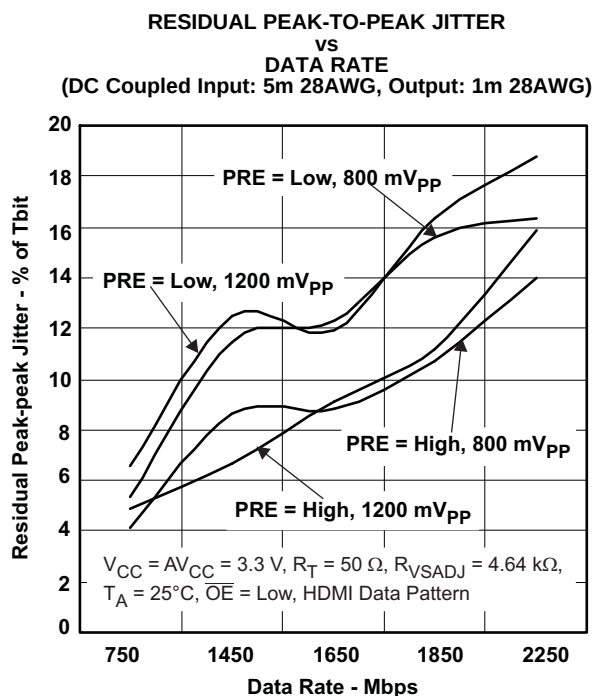


Figure 12.

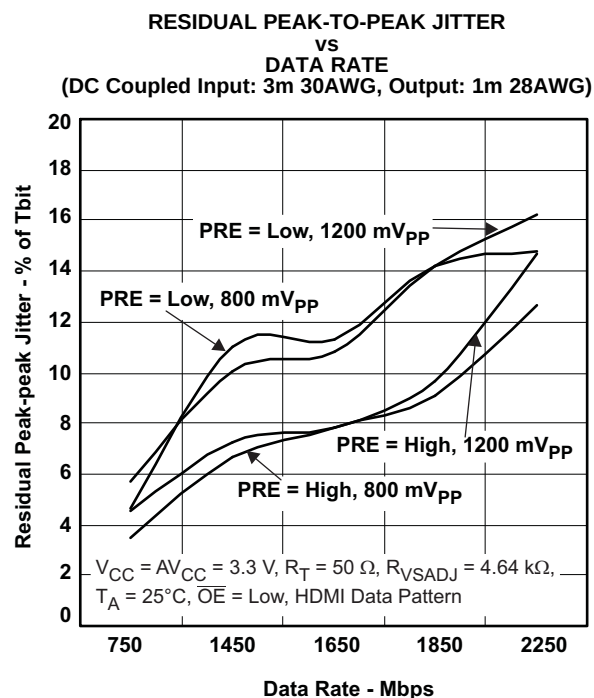


Figure 13.

TYPICAL CHARACTERISTICS (continued)

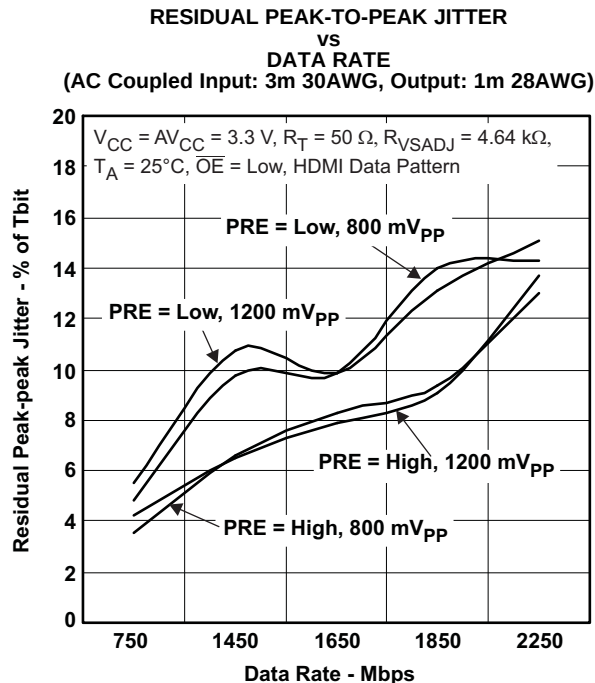


Figure 14.

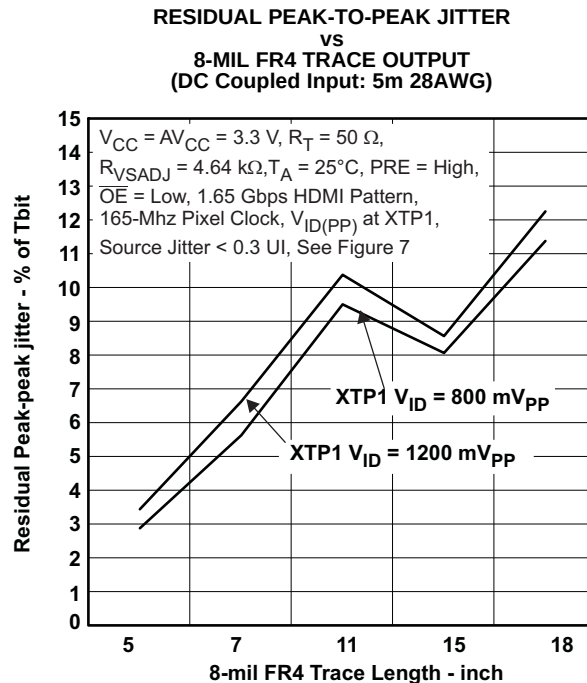


Figure 15.

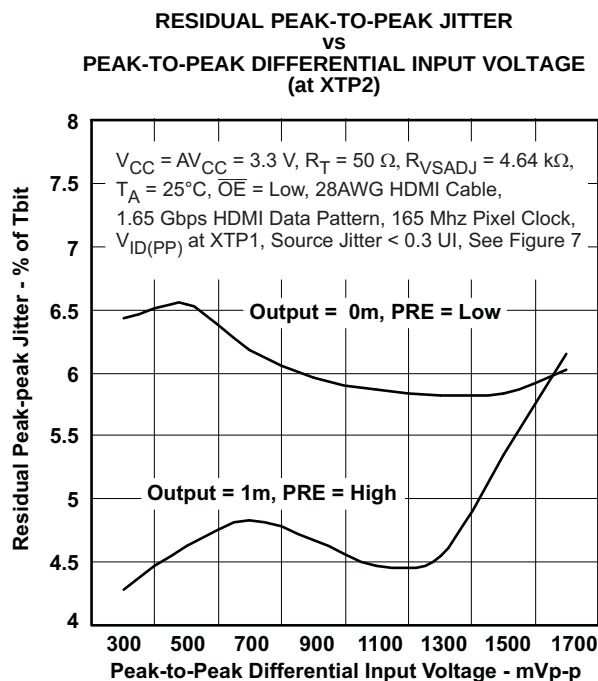


Figure 16.

APPLICATION INFORMATION

Supply Voltage

All V_{CC} pins can be tied to a single 3.3-V power source. A 0.01- μ F capacitor is connected from each V_{CC} pin directly to ground to filter supply noise.

TMDS Inputs

Standard TMDS terminations are integrated on all TMDS inputs. External terminations are not required. Each input channel contains an 8-dB equalization circuit to compensate for cable losses. The voltage at the TMDS input pins must be limited per the absolute maximum ratings. An unused input should not be connected to ground as this would result in excessive current flow damaging the device. TMDS input pins do not incorporate failsafe circuits. An unused input channel can be externally biased to prevent output oscillation. The complementary input pin is recommended to be grounded through a 1-k Ω resistor and the other pin left open.

TMDS Outputs

A 1% precision resistor, 4.64-k Ω , connected from VSADJ to ground is recommended to allow the differential output swing to comply with TMDS signal levels. The differential output driver provides a typical 10-mA current sink capability, which provides a typical 500-mV voltage drop across a 50- Ω termination resistor.

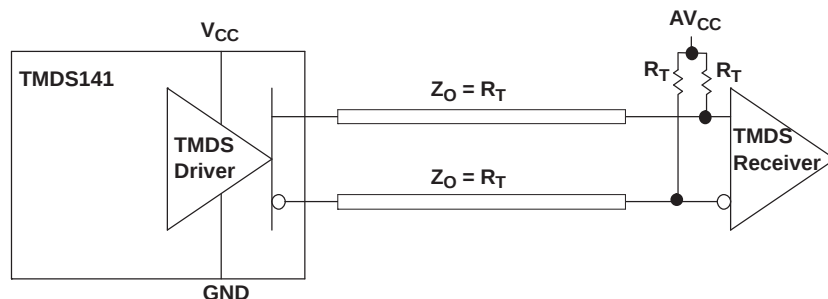


Figure 17. TMDS Driver and Termination Circuit

Referring to [Figure 17](#), if both V_{CC} (TMDS141 supply) and AV_{CC} (sink termination supply) are both powered, the TMDS output signals is high impedance when OEB = high. Both supplies being active is the normal operating condition.

Again refer to [Figure 17](#), if V_{CC} is on and AV_{CC} is off, the TMDS outputs source a typical 5-mA current through each termination resistor to ground. A total of 10-mW of power is consumed by the terminations independent of the OEB logical selection. When AV_{CC} is powered on, normal operation (OEB controls output impedance) is resumed.

When the power source of the device is off and the power source to termination is on, the $I_{O(off)}$, output leakage current, specification ensures the leakage current is limited 10- μ A or less.

The PRE pin provides 3dB de-emphasis, allowing output signal pre-conditioning to offset interconnect losses from the TMDS141 outputs to a TMDS receiver. PRE is recommended to be set low while connecting to a receiver throw short PCB route.

I²C Function Description

The RSCL/RSDA and TSCL/TSDA pins are 5-V tolerant when the device is powered off and high impedance under low supply voltage, 1.5 V or below. If the device is powered up and the I²C circuits are enabled, and I2CEN = high, the driver T (see [Figure 18](#)) is turned on or off depending up on the corresponding R side voltage level.

When the R side is pulled low below 1.5 V, the corresponding T side driver turns on and pulls the T side down to a low level output voltage, V_{OL} . The value of V_{OL} depends on the input to the OVS pin. When OVS is left floating

APPLICATION INFORMATION (continued)

or not connected, V_{OL} is typically 0.5 V. When OVS is connected to GND, V_{OL} is typically 0.65 V. When OVS is connected to V_{CC} , V_{OL} is typically 0.8 V. V_{OL} is always higher than the driver R input threshold, V_{IL} , which is typically 0.4 V, preventing lockup of the repeater loop. The V_{OL} value can be selected to improve or optimize noise margins between V_{OL} and the V_{IL} of the repeater itself or the V_{IL} of some external device connected on the T side.

When the R side is pulled up, above 1.5 V, the T side driver turns off and the T side pin is high impedance.

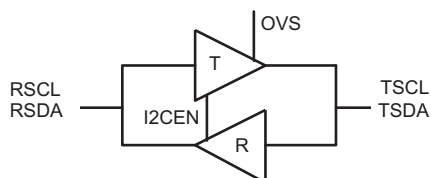


Figure 18. I²C Drivers in TMDS141

When the T side is pulled below 0.4 V by an external I²C driver, both drivers R and T are turned on. Driver R pulls the R side to near 0 V, and driver T is on, but is overridden by the external I²C driver. If driver T is already on, due to a low on the R side, driver R just turns on.

When the T side is released by the external I²C driver, driver T is still on, so the T side is only able to rise to the V_{OL} of driver T. Driver R turns off, since V_{OL} is above its 0.4-V V_{IL} threshold, releasing the R side. If no external I²C driver is keeping the R side low, the R side rises, and driver T turns off once the R side rises above 1.5 V, see Figure 19.

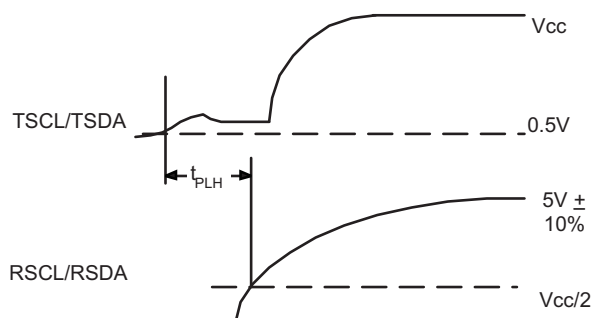


Figure 19. Waveform of Turning Driver T Off

It is important that any external I²C driver on the T side is able to pull the bus below 0.4 V to ensure full operation. If the T side cannot be pulled below 0.4 V, driver R may not recognize and transmit the low value to the R side.

I²C Enable

The I2CEN pin is active high with an internal pull-up to V_{CC} . It can be used to isolate a badly behaved slave during power up. It should never change state during an I²C operation because disabling during a bus operation may hang the bus and enabling part way through a bus cycle could confuse the I²C parts being enabled.

I²C Behavior

The typical application of the TMDS141 is as a repeater in a TV connecting the HDMI input connector and an internal HDMI Rx through flat cables. The I²C repeater is 5-V tolerant, and no additional circuitry is required to translate between 3.3-V to 5-V bus voltages. In the following example, the system master is running on an R-side I²C-bus while the slave is connected to a T-side bus. Both buses run at 100 kHz supporting standard-mode I²C operation. Master devices can be placed on either bus.

APPLICATION INFORMATION (continued)

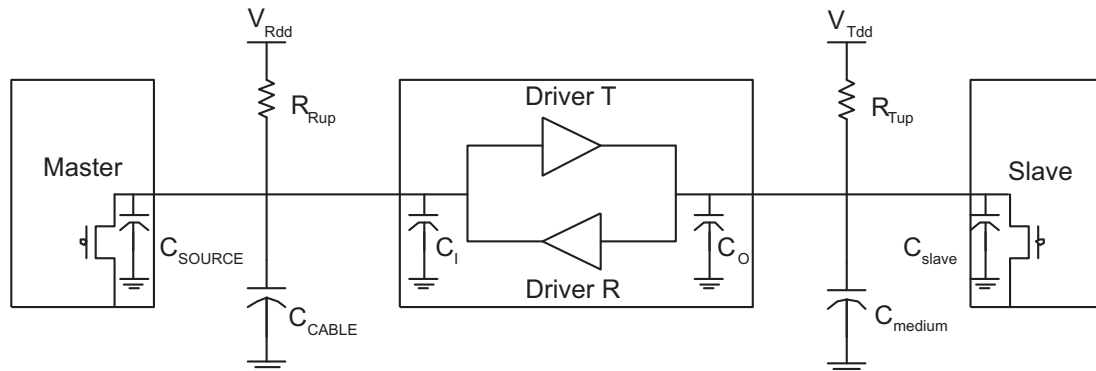


Figure 20. Typical Application

Figure 21 illustrates the waveforms seen on the R-side I²C-bus when the master writes to the slave through the I²C repeater circuit of the TMDS141. This looks like a normal I²C transmission, and the turn on and turn off of the acknowledge signals are slightly delayed.

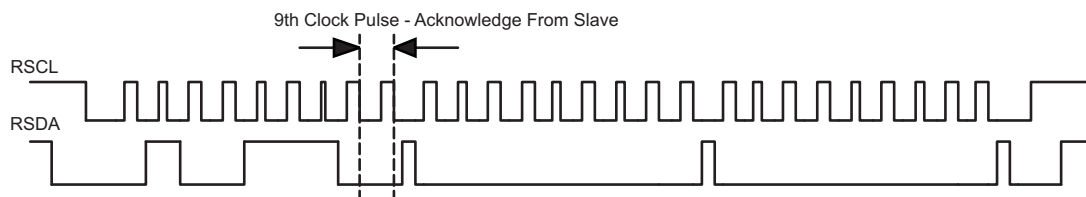


Figure 21. Bus R Waveform

Figure 22 illustrates the waveforms seen on the T-side I²C-bus under the same operation in Figure 21. On the T-side of the I²C repeater, the clock and data lines would have a positive offset from ground equal to the V_{OL} of the driver T. After the 8th clock pulse, the data line is pulled to the V_{OL} of the slave device which is very close to ground in this example. At the end of the acknowledge, the slave device releases and the bus level rises back to the V_{OL} set by the driver until the R-side rises above $V_{CC}/2$, after which it continues to high. It is important to note that any arbitration or clock stretching events require that the low level on the T-side bus at the input of the TMDS141 I²C repeater is below 0.4 V to be recognized by the device and then transmitted to the R-side I²C bus.

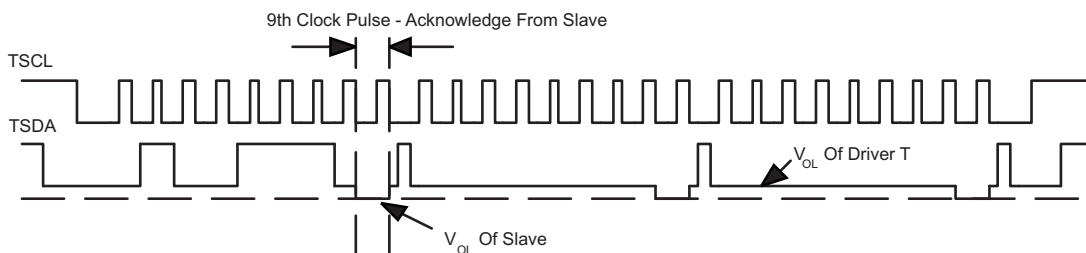
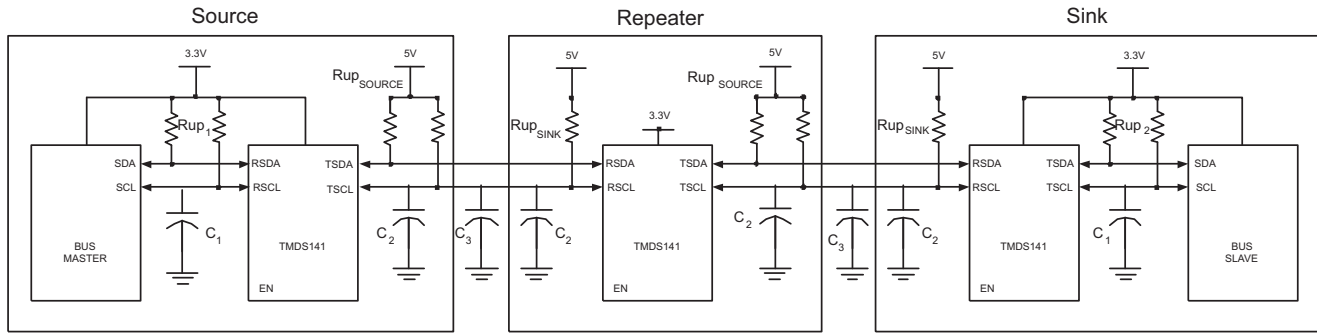


Figure 22. Bus T Waveform

The I²C circuitry inside the TMDS141 allows multiple stage operation as shown in Figure 23. I²C-Bus slave devices can be connected to any of the bus segments. The number of devices that can be connected in series is limited by repeater delay/time of flight considerations for the maximum bus speed requirements.

APPLICATION INFORMATION (continued)**Figure 23. Typical Series Application****I²C Pull-up Resistors**

The pull-up resistor value is determined by two requirements:

1. The maximum sink current of the I²C buffer:

The maximum sink current is 3 mA or slightly higher for an I²C driver supporting standard-mode I²C operation.

$$R_{up(min)} = V_{DD}/I_{sink} \quad (1)$$

2. The maximum transition time on the bus:

The maximum transition time, T, of an I²C bus is set by an RC time constant, where R is the pull-up resistor value, and C is the total load capacitance. The parameter, k, can be calculated from equation 3 by solving for t, the times at which certain voltage thresholds are reached. Different input threshold combinations introduce different values of t. [Table 1](#) summarizes the possible values of k under different threshold combinations.

$$T = k \times RC \quad (2)$$

$$V(t) = V_{DD}(1 - e^{-t/RC}) \quad (3)$$

Table 1. Value k Upon Different Input Threshold Voltages

$V_{th}-V_{th+}$	$0.7V_{DD}$	$0.65V_{DD}$	$0.6V_{DD}$	$0.55V_{DD}$	$0.5V_{DD}$	$0.45V_{DD}$	$0.4V_{DD}$	$0.35V_{DD}$	$0.3V_{DD}$
$0.1V_{DD}$	1.0986	0.9445	0.8109	0.6931	0.5878	0.4925	0.4055	0.3254	0.2513
$0.15V_{DD}$	1.0415	0.8873	0.7538	0.6360	0.5306	0.4353	0.3483	0.2683	0.1942
$0.2V_{DD}$	0.9808	0.8267	0.6931	0.5754	0.4700	0.3747	0.2877	0.2076	0.1335
$0.25V_{DD}$	0.9163	0.7621	0.6286	0.5108	0.4055	0.3102	0.2231	0.1431	0.0690
$0.3V_{DD}$	0.8473	0.6931	0.5596	0.4418	0.3365	0.2412	0.1542	0.0741	-

From equation 1, $R_{up(min)} = 5.5V/3mA = 1.83 \text{ k}\Omega$ to operate the bus under a 5-V pull-up voltage and provide less than 3 mA when the I²C device is driving the bus to a low state. If a higher sink current, for example 4 mA, is allowed, $R_{up(min)}$ can be as low as 1.375 k Ω .

Given a 5-V I²C device with input low and high threshold voltages at $0.3 V_{dd}$ and $0.7 V_{dd}$, the value of k is 0.8473 from [Table 1](#). Taking into account the 1.83-k Ω pull-up resistor, the maximum total load capacitance is $C_{(total-5V)} = 645 \text{ pF}$. $C_{cable(max)}$ should be restricted to be less than 545 pF if C_{source} and C_i can be as heavy as 50 pF. Here the C_i is treated as C_{sink} , the load capacitance of a sink device.

Fixing the maximum transition time from [Table 1](#), $T = 1 \text{ }\mu\text{s}$, and using the k values from [Table 1](#), the recommended maximum total resistance of the pull-up resistors on an I²C bus can be calculated for different system setups.

To support the maximum load capacitance specified in the HDMI spec, $C_{cable(max)} = 700\text{pF}/C_{source} = 50\text{pF}/C_i = 50\text{pF}$, $R_{(max)}$ can be calculated as shown in [Table 2](#).

Table 2. Pull-Up Resistor Upon Different Threshold Voltages and 800-pF Loads

$V_{th-} \setminus V_{th+}$	$0.7V_{DD}$	$0.65V_{DD}$	$0.6V_{DD}$	$0.55V_{DD}$	$0.5V_{DD}$	$0.45V_{DD}$	$0.4V_{DD}$	$0.35V_{DD}$	$0.3V_{DD}$	UNIT
$0.1V_{DD}$	1.14	1.32	1.54	1.80	2.13	2.54	3.08	3.84	4.97	k Ω
$0.15V_{DD}$	1.20	1.41	1.66	1.97	2.36	2.87	3.59	4.66	6.44	k Ω
$0.2V_{DD}$	1.27	1.51	1.80	2.17	2.66	3.34	4.35	6.02	9.36	k Ω
$0.25V_{DD}$	1.36	1.64	1.99	2.45	3.08	4.03	5.60	8.74	18.12	k Ω
$0.3V_{DD}$	1.48	1.80	2.23	2.83	3.72	5.18	8.11	16.87	-	k Ω

Or, limiting the maximum load capacitance of each cable to be 400 pF to accommodate with I²C spec version 2.1. $C_{cable(max)} = 400pF/C_{source} = 50pF/C_i = 50pF$, the maximum values of $R_{(max)}$ are calculated as shown in [Table 3](#).

Table 3. Pull-Up Resistor Upon Different Threshold Voltages and 500-pF Loads

$V_{th-} \setminus V_{th+}$	$0.7V_{DD}$	$0.65V_{DD}$	$0.6V_{DD}$	$0.55V_{DD}$	$0.5V_{DD}$	$0.45V_{DD}$	$0.4V_{DD}$	$0.35V_{DD}$	$0.3V_{DD}$	UNIT
$0.1V_{DD}$	1.82	2.12	2.47	2.89	3.40	4.06	4.93	6.15	7.96	k Ω
$0.15V_{DD}$	1.92	2.25	2.65	3.14	3.77	4.59	5.74	7.46	10.30	k Ω
$0.2V_{DD}$	2.04	2.42	2.89	3.48	4.26	5.34	6.95	9.63	14.98	k Ω
$0.25V_{DD}$	2.18	2.62	3.18	3.92	4.93	6.45	8.96	13.98	28.99	k Ω
$0.3V_{DD}$	2.36	2.89	3.57	4.53	5.94	8.29	12.97	26.99	-	k Ω

Obviously, to accommodate the 3-mA drive current specification, a narrower threshold voltage range is required to support a maximum 800-pF load capacitance for a standard-mode I²C bus.

When the input low and high level threshold voltages, V_{th-} and V_{th+} , are 0.7 V and 1.9 V, which is $0.15 V_{DD}$ and $0.4 V_{DD}$ approximately with $V_{DD} = 5 V$, from [Table 2](#), the maximum pull-up resistor is 3.59 k Ω . The allowable pull-up resistor is in the range of 1.83 k Ω and 3.59 k Ω .

Thermal Dissipation

On a high-K board – It is always recommended to solder the PowerPAD onto the thermal land. A thermal land is the area of solder-tinned-copper underneath the PowerPAD package. On a high-K board the TMDS141 can operate over the full temperature range by soldering the PowerPAD onto the thermal land without vias.

On a low-K board – In order for the device to operate across the temperature range on a low-K board, a 1-oz Cu trace connecting the GND pins to the thermal land must be used. A simulation shows $R_{\theta JA} = 100.84^{\circ}C/W$ allowing 545 mW power dissipation at 70°C ambient temperature.

A general PCB design guide for PowerPAD packages is provided in the document SLMA002 - PowerPAD Thermally Enhanced Package.

PACKAGE OPTION ADDENDUM

PACKAGING INFORMATION 11-August-2006

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/Ball Finish	MSL Peak Temp ⁽³⁾
TMDS141RHAR	ACTIVE	QFN	RHA	40	2500	Green (RoHS & no Sb/ Br)	CU NIPDAU	Level-3-260C-168 HR
TMDS141RHARG4	ACTIVE	QFN	RHA	40	2500	Green (RoHS & no Sb/ Br)	CU NIPDAU	Level-3-260C-168 HR

1. The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

2. Eco Plan -The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) -please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

3. MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

Revision History

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

Changes from A Revision (August 2006) to B Revision	Page
• Changed Features	1
• Changed Signaling rate from 1.65 Gbps to 2.25 Gbps	5
• Added PRE = Low to supply current test conditions	6
• Added PRE = Low to power dissipation test conditions	6
• Deleted TTL high- and low-level output voltages	7
• Changed Peak-to-peak output jitter from TX0 - TX2, residual jitter from 90 to 88 ps	7
• Added Peak-to-peak output jitter from TXC, residual jitter	7
• Added Peak-to-peak output jitter from TX0 - TX2, residual jitter	7
• Changed Figure 10	13
• Changed Figure 11	13
• Changed Figure 12	13
• Changed Figure 13	13
• Changed Figure 14	14

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/Ball Finish	MSL Peak Temp ⁽³⁾
TMDS141RHAR	ACTIVE	QFN	RHA	40	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
TMDS141RHARG4	ACTIVE	QFN	RHA	40	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR

⁽¹⁾ The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

⁽²⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

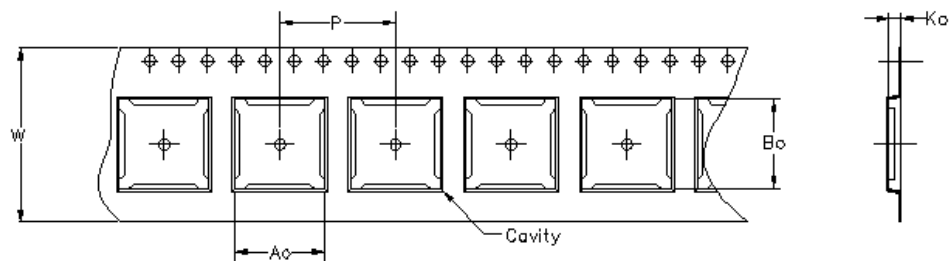
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

⁽³⁾ MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

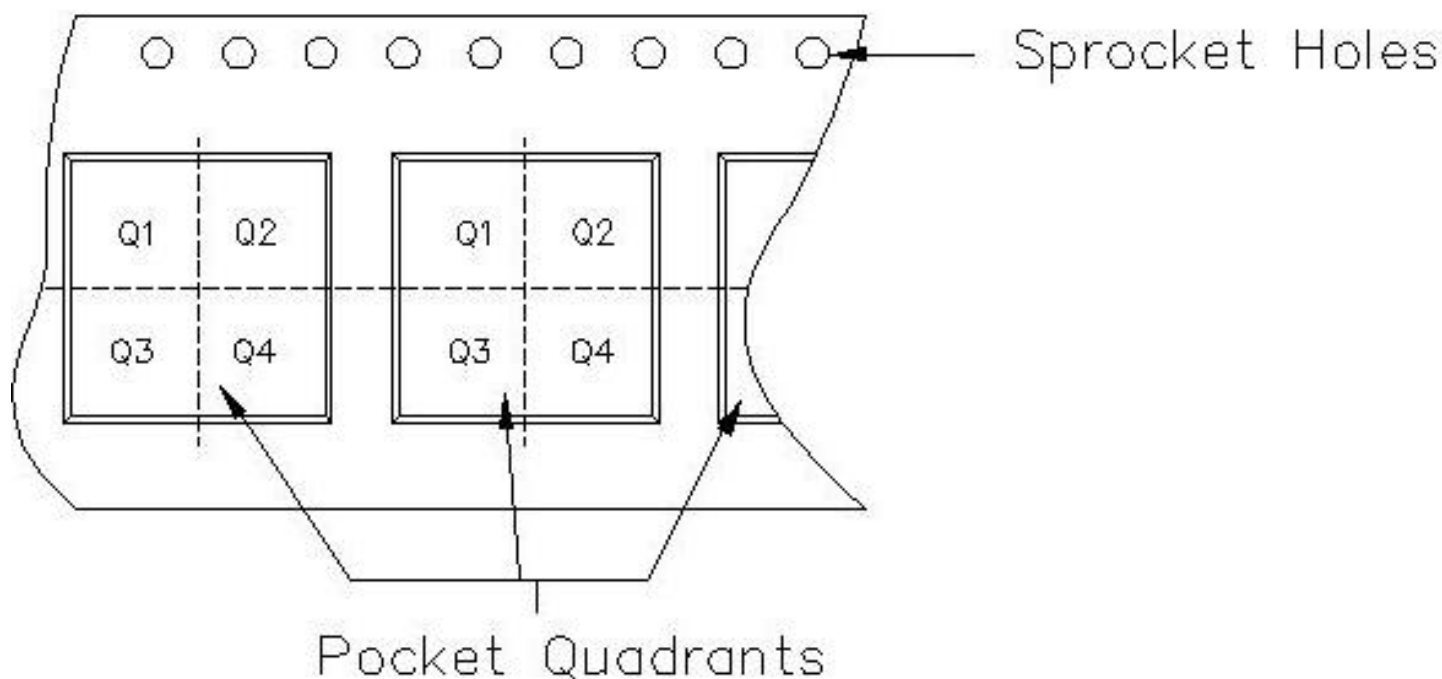
Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.



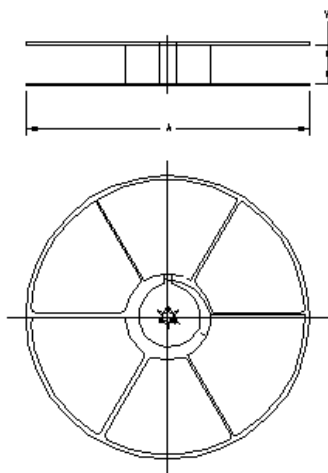
Carrier tape design is defined largely by the component length, width, and thickness.

A_0 = Dimension designed to accommodate the component width.
B_0 = Dimension designed to accommodate the component length.
K_0 = Dimension designed to accommodate the component thickness.
W = Overall width of the carrier tape.
P = Pitch between successive cavity centers.



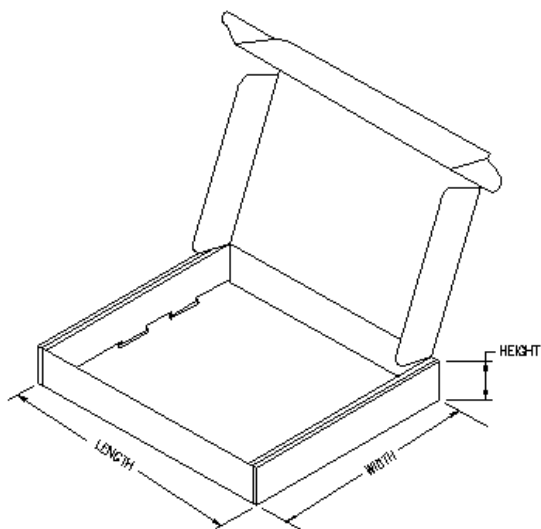
TAPE AND REEL INFORMATION

Device	Package	Pins	Site	Reel Diameter (mm)	Reel Width (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TMDS141RHAR	RHA	40	MLA	330	16	6.3	6.3	1.5	12	16	PKGORN T2TR-MS P



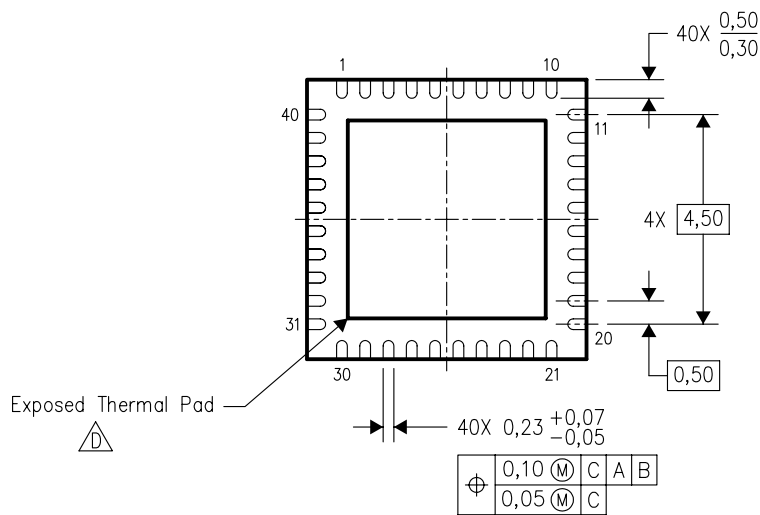
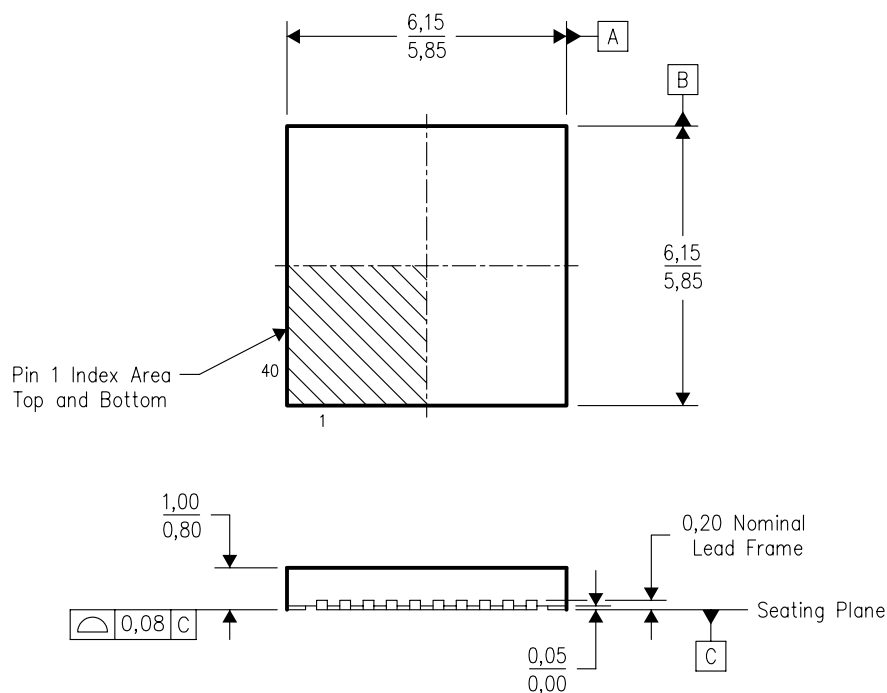
TAPE AND REEL BOX INFORMATION

Device	Package	Pins	Site	Length (mm)	Width (mm)	Height (mm)
TMDS141RHAR	RHA	40	MLA	346.0	346.0	33.0



RHA (S-PQFP-N40)

PLASTIC QUAD FLATPACK



Bottom View

4204276/C 12/2004

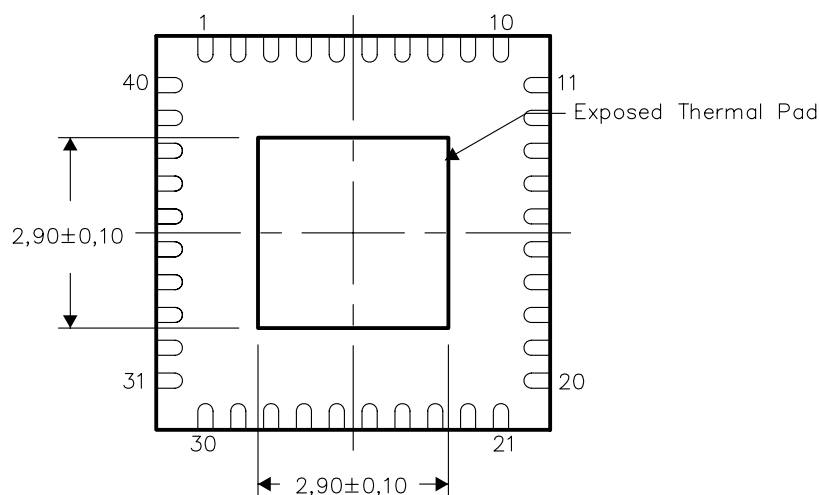
- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. QFN (Quad Flatpack No-Lead) Package configuration.
 - The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
 - E. Package complies to JEDEC MO-220 variation VJJD-2.

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to a ground or power plane (whichever is applicable), or alternatively, a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No-Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

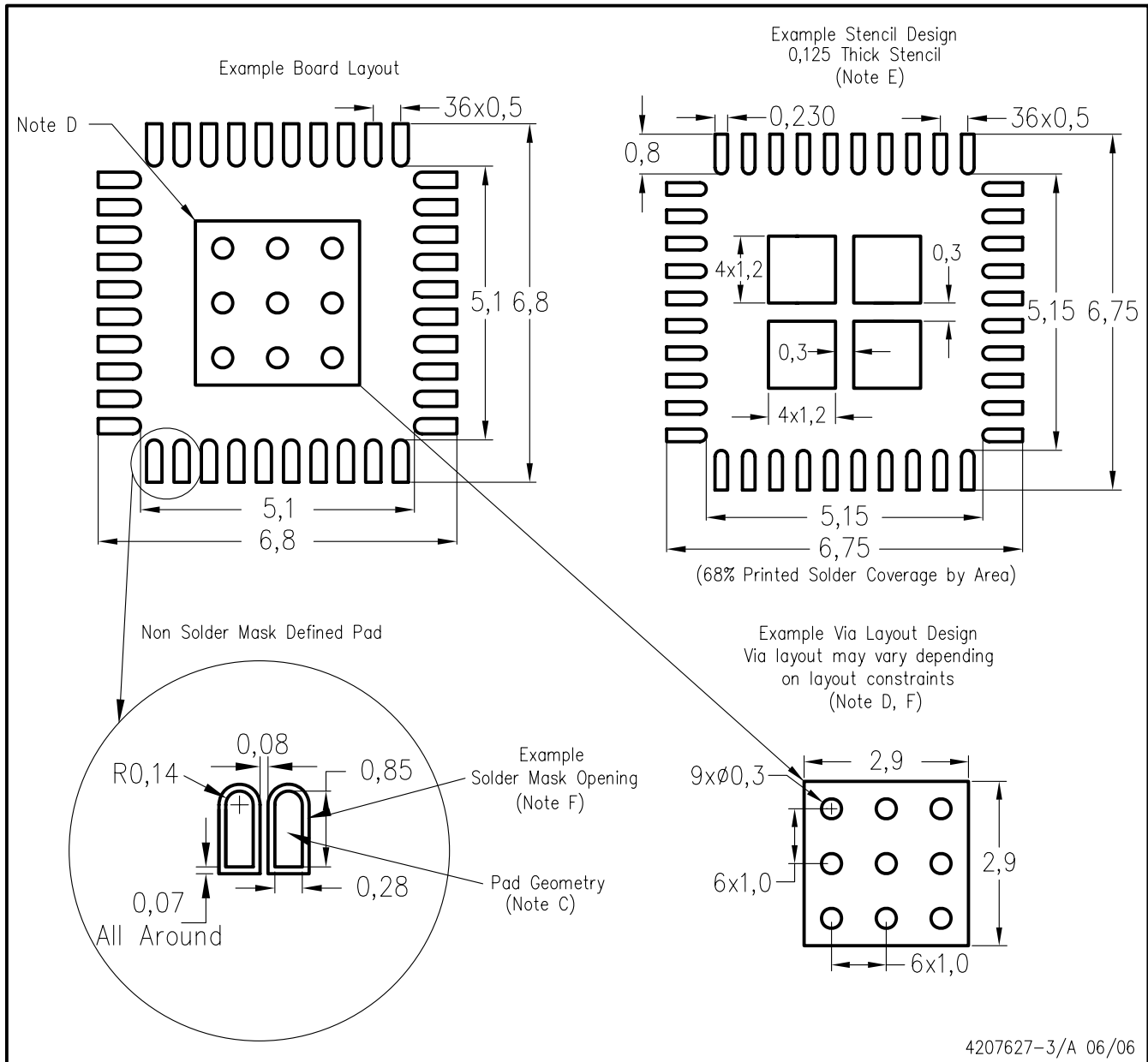


Bottom View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

RHA (S-PQFP-N40)



4207627-3/A 06/06

- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Publication IPC-7351 is recommended for alternate designs.
 - This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SCBA017, SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <<http://www.ti.com>>.
 - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
 - Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad.

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.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

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

Products

Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DSP	dsp.ti.com
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
Low Power Wireless	www.ti.com/lpw

Applications

Audio	www.ti.com/audio
Automotive	www.ti.com/automotive
Broadband	www.ti.com/broadband
Digital Control	www.ti.com/digitalcontrol
Military	www.ti.com/military
Optical Networking	www.ti.com/opticalnetwork
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
Copyright © 2007, Texas Instruments Incorporated