THS6301 G.Fast DSL Line Driver Amplifier With Bandwidth and Power-Scaling Features

1 Features

- Enables G.Fast 106-MHz, 212-MHz DSL Applications
- Supports Legacy VDSL and ADSL2+ Applications
- High MTPR for G.Fast and Legacy Applications (Line Power = 8 dBm):
  - ADSL2+ = 69 dB
  - VDSL-17a = 73 dB
  - VDSL-30a = 69 dB
  - G.Fast 106 MHz = 62 dB
  - G.Fast 212 MHz = 55 dB
- Multiple Power Modes for Different Profiles
- Adjustable Bias Current With External Resistor
- Low-Power Line Termination Mode: 10.2 mA
- Power-Down Mode
- 12-V Technology to Support High-Power Output

2 Applications

- G.Fast and Legacy DSL Line Drivers
- Generic Wideband Line Drivers
- PLC Drivers
- DAC Output Amplifier

3 Description

The THS6301 is a single-channel, current-feedback architecture, differential line driver that enables G.Fast and different digital subscriber line (DSL) home gateway systems. The device enables 106-MHz and 212-MHz G.Fast digital subscriber line profiles that use native discrete multitone modulation (DMT) signals. The THS6301 functions with high linearity at an 8-dBm line power through 212 MHz.

The unique architecture of this device minimizes quiescent current while providing very high linearity. Internally-fixed bias settings of the amplifier provide power savings for line-driving modes where the full performance of the amplifier is not needed. For further flexibility and power savings, the overall quiescent current is adjustable by a single external bias resistor connected to one of the device pins. The device also features two line-termination modes to maintain impedance matching at very low power consumption.

The device can also be used as a fixed-gain differential amplifier with bandwidth and power-scaling to suit the needs of differential applications.

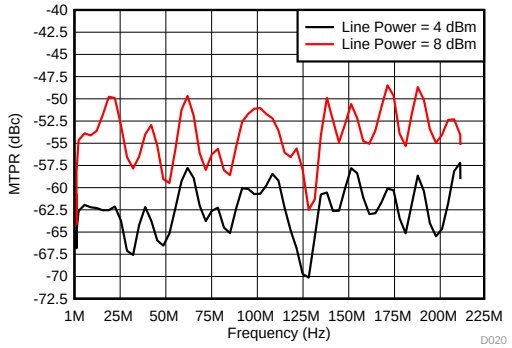
The device is available in a 4-mm × 4-mm, 16-pin, VQFN package.

Device Information(1)

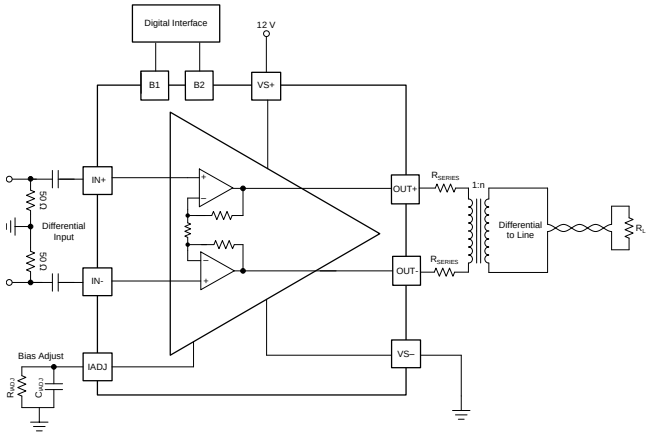
PART NUMBER	PACKAGE	BODY SIZE (NOM)
THS6301	VQFN (16)	4.00 mm × 4.00 mm

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

MTPR G.Fast 212 MHz (Bias 10, PAR = 15 dB, 1-in-64 Missing Tones)



Multitone Power Ratio (MTPR) Profile (G.Fast, 212 MHz, 8 dBm)



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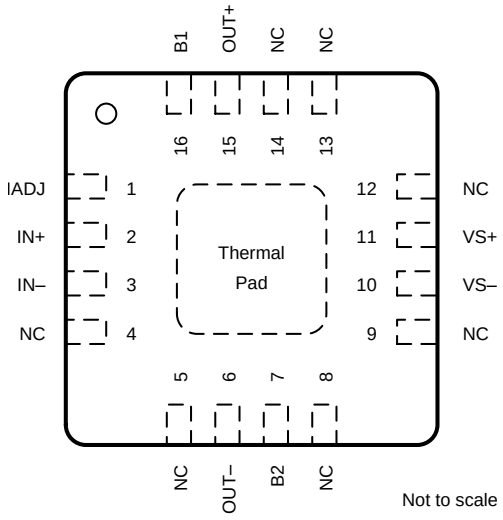
4 Revision History

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

Changes from Original (April 2018) to Revision A	Page
• Released to production	1

5 Pin Configuration and Functions

RSA Package
16-Pin VQFN
Top View



Not to scale

Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
B1	16	I	Most significant bit (MSB), logic level referenced to VS–
B2	7	I	Least significant bit (LSB), logic level referenced to VS–
IADJ	1	—	Bias current reference pin
IN–	3	I	Negative input
IN+	2	I	Positive input
NC	4	—	No internal connection to device (VS– recommended)
NC	5, 8, 9, 12, 13, 14	—	Not connected
OUT–	6	O	Negative output
OUT+	15	O	Positive output
VS–	10	—	Negative supply voltage connection
VS+	11	—	Positive supply voltage connection
Thermal pad		—	The thermal pad is connected to pin 4 via a downbond connection. The pad must be at the same potential as pin 4.

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage(2)	VS pin to GND (all modes)		13.2	V
Digital inputs to GND	B1, B2	–0.3	5.5	V
Analog inputs to GND	VIN+, VIN–	2	10	V
Differential analog inputs	(VIN+ – VIN–)	–6	6	V
Continuous power dissipation		See Thermal Information		
T_{stg}	Storage temperature	–65	150	°C
T_J	Junction temperature		150	°C

(1) Stresses beyond those listed under *Absolute Maximum Rating* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Condition*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Supply bypass capacitor type, value and location relative to the device are critical to prevent damage to the device when the device is turned on. See Power Supply Recommendations.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, allpins(1)	±3000	V
		Charged device model (CDM), per JEDEC specificationJESD22-C101, all pins(2)	±1000	

(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.

6.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
VS	Supply voltage	11.4	12	12.6	V
		±5.7	±6	±6.3	
T_A	Ambient temperature	–40		85	°C
T_J	Junction temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC(1)		THS6301 RSA (VQFN) 16 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	39	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	38.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	18	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	1	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	17.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	7.7	°C/W

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

6.5 Electrical Characteristics

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, drive mode 5 (B1B2 = 01, G.Fast mid power)(1) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	TEST LEVEL(2)
AC PERFORMANCE							
SSBW	Small-signal bandwidth	V_{OUT} = 1 V_{PP}, drive mode 1 (0Z, ADSL2+)		500		MHz	C
		V_{OUT} = 1 V_{PP}, drive mode 2 (Z1, VDSL low power)		565			C
		V_{OUT} = 1 V_{PP}, drive mode 3 (11, G.Fast low power and VDSL mid power)		635			C
		V_{OUT} = 1 V_{PP}, drive mode 4 (1Z, VDSL high power)		540			C
		V_{OUT} = 1 V_{PP}, drive mode 5 (01, G.Fast mid power)		670			C
		V_{OUT} = 1 V_{PP}, drive mode 6 (10, G.Fast high power)		618			C
LSBW	Large-signal bandwidth	V_{OUT} = 15 V_{PP}, drive mode 1 (0Z, ADSL2+)		160		MHz	C
		V_{OUT} = 15 V_{PP}, drive mode 2 (Z1, VDSL low power)		200			C
		V_{OUT} = 15 V_{PP}, drive mode 3 (11, G.Fast low power and VDSL mid power)		260			C
		V_{OUT} = 15 V_{PP}, drive mode 4 (1Z, VDSL high power)		270			C
		V_{OUT} = 15 V_{PP}, drive mode 5 (01, G.Fast mid power)		275			C
		V_{OUT} = 15 V_{PP}, drive mode 6 (10, G.Fast high power)		300			C
SR	Slew rate down	Drive mode 1 (0Z), 10%-90% 15-V_{PP} pulse		3200		V/µs	C
		Drive mode 2 (Z1), 10%-90% 15-V_{PP} pulse		4000			C
		Drive mode 3 (11), 10%-90% 15-V_{PP} pulse		6400			C
		Drive mode 4 (1Z), 10%-90% 15-V_{PP} pulse		7100			C
		Drive mode 5 (01), 10%-90% 15-V_{PP} pulse		8200			C
		Drive mode 6 (10), 10%-90% 15-V_{PP} pulse		10500			C
	Slew rate up	Drive mode 1 (0Z), 10%-90% 15-V_{PP} pulse		2500		V/µs	C
		Drive mode 2 (Z1), 10%-90% 15-V_{PP} pulse		3200			C
		Drive mode 3 (11), 10%-90% 15-V_{PP} pulse		4400			C
		Drive mode 4 (1Z), 10%-90% 15-V_{PP} pulse		5400			C
		Drive mode 5 (01), 10%-90% 15-V_{PP} pulse		6500			C
		Drive mode 6 (10), 10%-90% 15-V_{PP} pulse		8000			C
e_n	Input-referred voltage noise	f > 1 MHz, drive mode 1 (0Z)		4.3		nV/√Hz	C
		f > 1 MHz, drive mode 2 (Z1)		3.9			C
		f > 1 MHz, drive mode 3 (11)		3.9			C
		f > 1 MHz, drive mode 4 (1Z)		3.9			C
		f > 1 MHz, drive mode 5 (01)		3.7			C
		f > 1 MHz, drive mode 6 (10)		3.5			C
	Noise floor, line termination mode	Line-termination modes, referred to R_{SERIES}		–154		dBm/Hz	C
		Power-down mode, referred to R_{SERIES}		–166			C
		Line-termination mode 00, output referred (f > 1 MHz)		5.6		nV/√Hz	C
		Line-termination mode Z0, output referred (f > 1 MHz)		6			C
		Power-down mode, output referred (f > 1 MHz)		1.6			C

(1) See Table 1 for the different Bias Modes of the device
(2) Test levels (all values set by characterization and simulation): (A) 100% tested at T_A ≈ 25°C. (B) Not tested in production; limits set by characterization and simulation. (C) Typical value only for information. (D) Simulated value only for information

Electrical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, drive mode 5 (B1B2 = 01, G.Fast mid power)(1) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	TEST LEVEL(2)
	ADSL2+ MTPR(3)	Line power = 8 dBm, f ≤ 552 kHz, PAR = 15 dB		67		dB	C
		Line power = 8 dBm, f ≤ 1.104 MHz, PAR = 15 dB		69			C
		Line power = 8 dBm, f ≤ 2.208 MHz, PAR = 15 dB		67			C
	VDSL2-17a MTPR(3)	Line power = 8 dBm, f ≤ 14 MHz, PAR = 15 dB, bias = 11		73		dB	C
		Line power = 8 dBm, f ≤ 17.6 MHz, PAR = 15 dB, bias = 11		71.5			C
	VDSL2-30a MTPR(3)	Line power = 8 dBm, f ≤ 30 MHz, PAR = 15 dB, bias = 11		69		dB	C
	VDSL2-35b MTPR(3)	Line power = 8 dBm, f ≤ 35 MHz, PAR = 15 dB, bias = 11		66		dB	C
	G.Fast 106-MHz MTPR(3)	Line power = 4 dBm, f ≤ 106 MHz, PAR = 15 dB, bias 01		68		dB	C
		Line power = 8 dBm, f ≤ 106 MHz, PAR = 15 dB, bias 10		62			C
		Line-termination mode, line power = 8 dBm, PAR = 15 dB		60		dB	D
	G.Fast 212-MHz MTPR(3)	Line power = 4 dBm, f ≤ 212 MHz, PAR = 15 dB, bias 10		63		dB	C
		Line power = 8 dBm, f ≤ 212 MHz, PAR = 15 dB, bias 10		55			C
		Line-termination mode, line power = 4 dBm, PAR = 15 dB		50			D
	Differential output impedance	Drive mode 6 (10, G.Fast high power), f = 100 kHz		1.2		Ω	D
		Drive mode 6 (10, G.Fast high power), f = 50 MHz		1.7			D
		Drive mode 6 (10, G.Fast high power), f = 106 MHz		2.8			D
		Drive mode 6 (10, G.Fast high power), f = 212 MHz		5.3			D
		Power-down bias mode		2400			D
		Line-termination modes		1.3			D
DC PERFORMANCE							
A_V	Differential gain	At dc, no load, all modes	8.3	8.6	8.9	V/V	A
	Differential output offset		–100		100	mV	A
	Output swing	Differential, at dc, 200-Ω load at amplifier output	18			V_{PP}	A
$R_{IN-DIFF}$	Differential input resistance		8	10	12	kΩ	A
R_{IN-SE}	Single-ended input resistance		4	5	6	kΩ	A

(3) ADSL2+, VDSL2-17a and VDSL2-30a profiles are specified with 1-in-4 missing tones; VDSL2-35b and G.Fast profiles are specified with 1-in-64 missing tones

Electrical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, drive mode 5 (B1B2 = 01, G.Fast mid power)(1) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	TEST LEVEL(2)
	Linear output current	Drive mode 1 (0Z), sourcing, output offset < 20-mV deviation	40	75		mA	A
		Drive mode 1 (0Z), sinking, output offset < 20-mV deviation	40	70			A
		Drive mode 6 (10), sourcing, output offset < 20-mV deviation	80	160			A
		Drive mode 6 (10), sinking, output offset < 20-mV deviation	80	160			A
		High power termination mode (00), sourcing, output offset <20-mV deviation	50	95			A
		High power termination mode (00), sinking, output offset <20-mV deviation	50	90			A
		Low power termination mode (Z0), sourcing, output offset <20-mV deviation	40	77			A
		Low power termination mode (Z0), sinking, output offset <20-mV deviation	40	74			A
COMMON MODE							
	Input CM bias voltage		5.9	6	6.1	V	A
	Output CM bias voltage		5.9	6	6.1	V	A
POWER SUPPLY							
	Maximum supply voltage range	All modes			12.6	V	A
PSRR	Power-supply rejection ratio	f = dc	61			dB	A
I_Q	Quiescent current	Drive mode 1 (0Z, ADSL2+)	13	15.9	18.9	mA	A
		Drive mode 2 (Z1, VDSL low power)	16.7	20.1	24.3		A
		Drive mode 3 (11, G.Fast low power and VDSL mid power)	22.5	27.2	33.1		A
		Drive mode 4 (1Z, VDSL high power)	24	29.8	36.5		A
		Drive mode 5 (01, G.Fast mid power)	32.1	38.9	47.8		A
		Drive mode 6 (10, G.Fast high power)	36.7	45.3	56		A
		High power line termination mode (00)	13.6	16	18.9		A
		Low power line termination mode (Z0)	8.3	10.2	11.6		A
		Power-down mode		1.9	2.4		A

Electrical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, drive mode 5 (B1B2 = 01, G.Fast mid power)(1) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	TEST LEVEL(2)
	Dynamic power consumption	Drive mode 1 (0Z, ADSL2+), line power = 8 dBm		220		mW	D
		Drive mode 2 (Z1, VDSL low power), line power = 8 dBm		280			D
		Drive mode 3 (11, G.Fast low power and VDSL mid power), line power = 8 dBm		310			D
		Drive mode 4 (1Z, VDSL high power), line power = 8 dBm		340			D
		Drive mode 5 (01, G.Fast mid power), line power = 4 dBm		480			D
		Drive mode 6 (10, G.Fast high power), line power = 8 dBm		590			D
		High power line termination mode (00), line power = 4 dBm		220			D
		Low power line termination mode (Z0), line power = 4 dBm		120			D
		Power-down mode		23			D

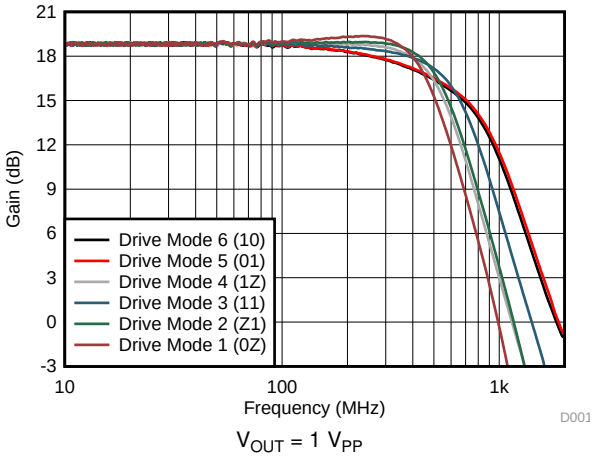
6.6 Switching Characteristics

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IH}	Minimum logic high level	All digital pins, high	2.3			V
V_{IL}	Maximum logic low level	All digital pins, low			0.6	V
V_{MID}	Logic mid range	All digital pins, driven externally	1.2		1.6	V
V_{Float}	Logic self-bias voltage	All digital pins, floating	1.3	1.4	1.5	V
I_{IH}	Logic high-level leakage current	All digital pins, logic level = 3.6 V		110	135	µA
I_{IL}	Logic low-level leakage current	All digital pins, logic level = ground	–85	–75		µA
	Turn-on switching time	High power line termination mode (00) to drive mode 6 (10, G.Fast high power)		64		ns
		Low power line termination mode (Z0) to drive mode 6 (10, G.Fast high power)		50		
		Power down mode (ZZ) to Drive mode 6 (10, G.Fast high power)		60		
	Turn-off switching time	Drive mode 6 (10, G.Fast high power) to high power line termination mode (00)		76		ns
		Drive mode 6 (10, G.Fast high power) to low power line termination mode (Z0)		400		
		Drive mode 6 (10, G.Fast high power) to power-down mode (ZZ)		380		

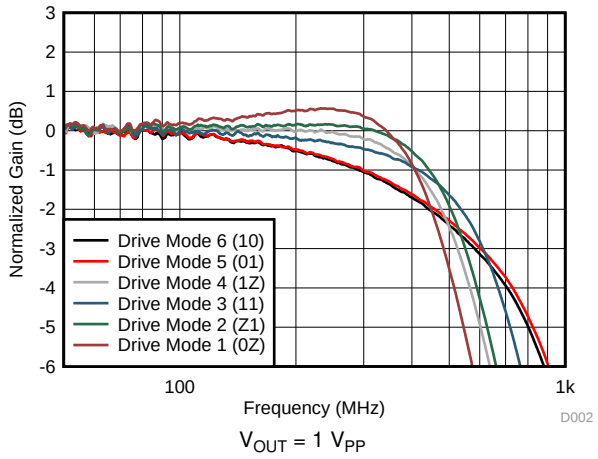
6.7 Typical Characteristics

at $T_A \approx 25°C$, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)



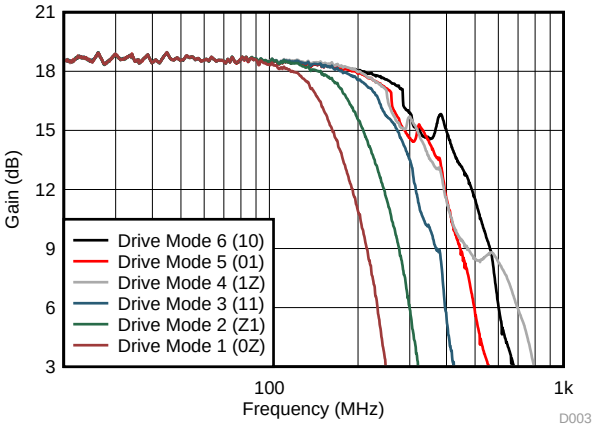
V_{OUT} = 1 V_{PP}

Figure 1. Small-Signal Bandwidth



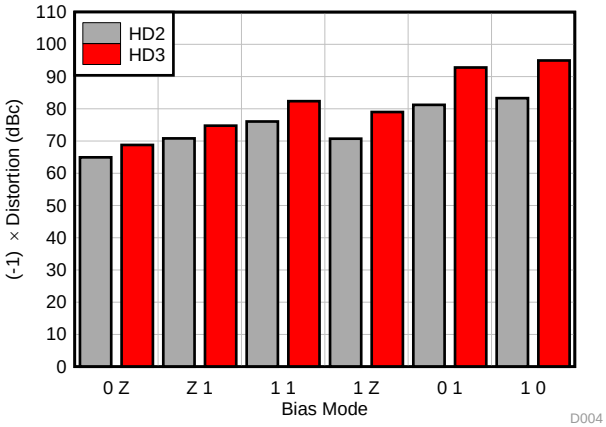
V_{OUT} = 1 V_{PP}

Figure 2. 3-dB Normalized Gain Small-Signal Bandwidth



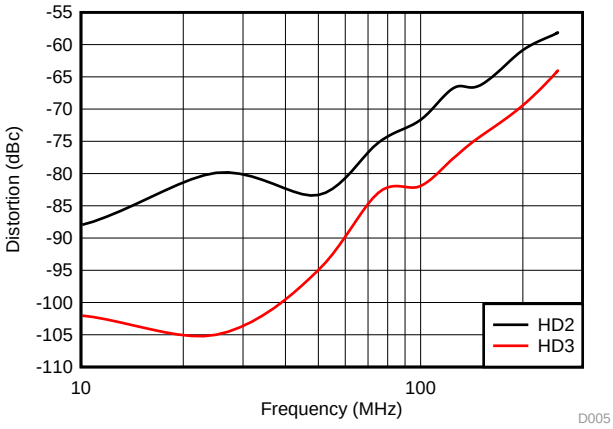
V_{OUT} = 15 V_{PP}

Figure 3. Large-Signal Bandwidth



Frequency = 50 MHz, V_{OUT} = 1 V_{PP}

Figure 4. Bias Modes vs Distortion



V_{OUT} = 1 V_{PP}

Figure 5. Distortion vs Frequency Drive Mode 6 (Bias 10)

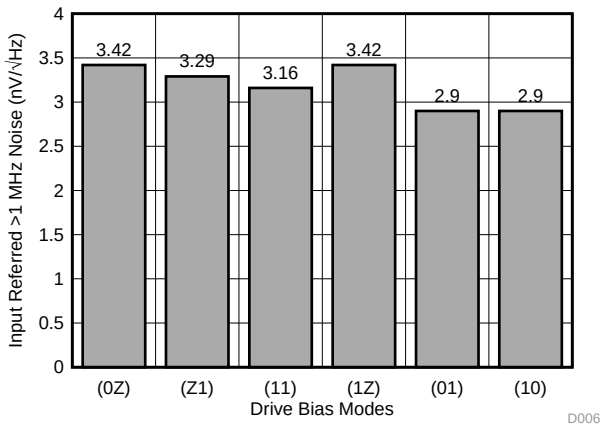


Figure 6. Input Voltage Noise

Typical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

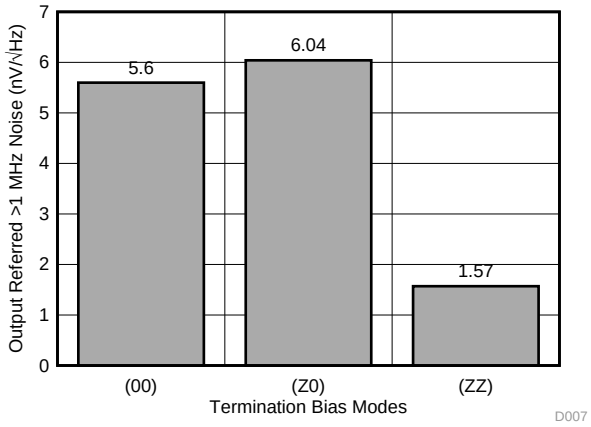
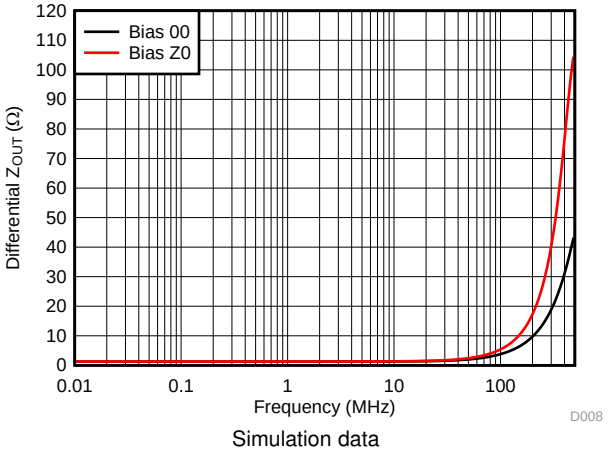
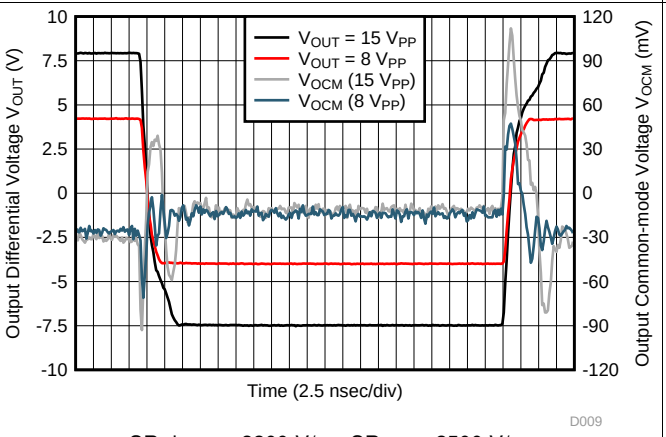


Figure 7. Termination Mode Noise Floor



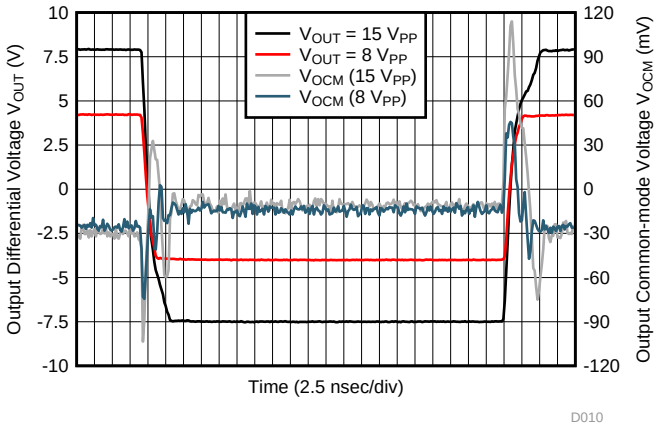
Simulation data

Figure 8. Termination Mode Differential Output Impedance



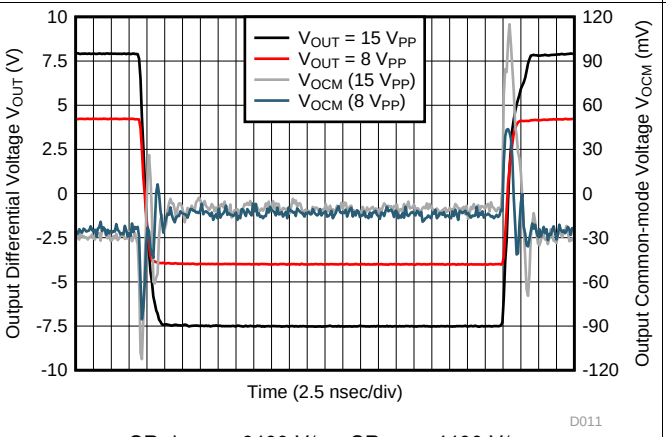
SR down = 3200 V/µs, SR up = 2500 V/µs

Figure 9. Pulse Response Drive Mode 1 (Bias 0Z)



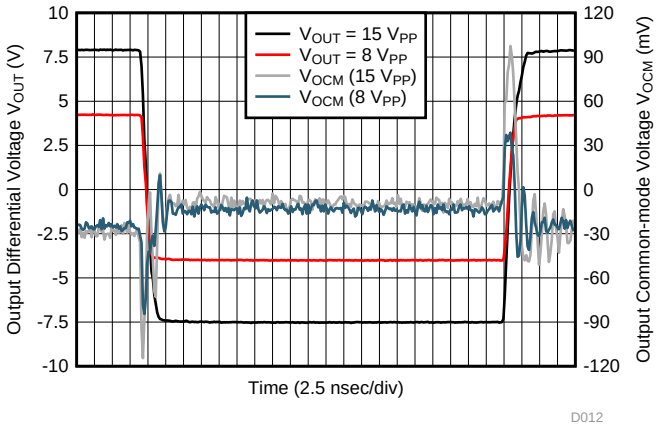
SR down = 4000 V/µs, SR up = 3200 V/µs

Figure 10. Pulse Response Drive Mode 2 (Bias Z1)



SR down = 6400 V/µs, SR up = 4400 V/µs

Figure 11. Pulse Response Drive Mode 3 (Bias 11)

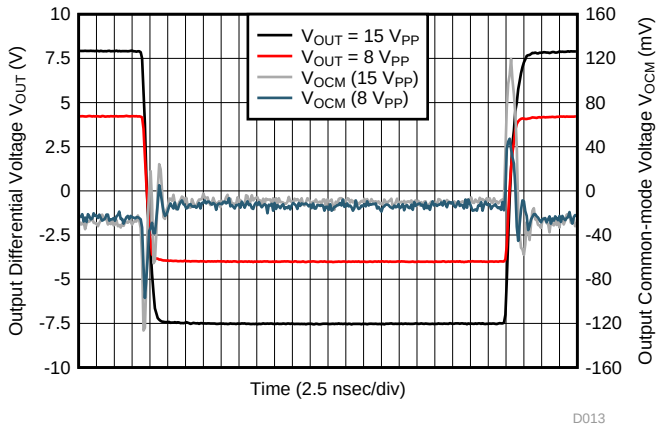


SR down = 7100 V/µs, SR up = 5400 V/µs

Figure 12. Pulse Response Drive Mode 4 (Bias 1Z)

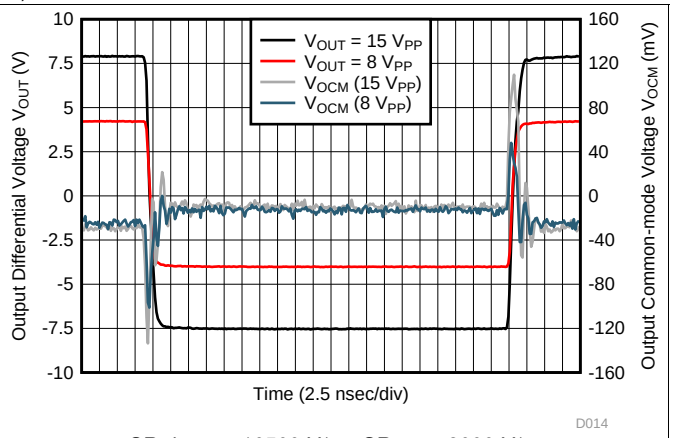
Typical Characteristics (continued)

at $T_A \approx 25°C$, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)



SR down = 8200 V/µs, SR up = 6500 V/µs

Figure 13. Pulse Response Drive Mode 5 (Bias 01)



SR down = 10500 V/µs, SR up = 8000 V/µs

Figure 14. Pulse Response Drive Mode 6 (Bias 10)

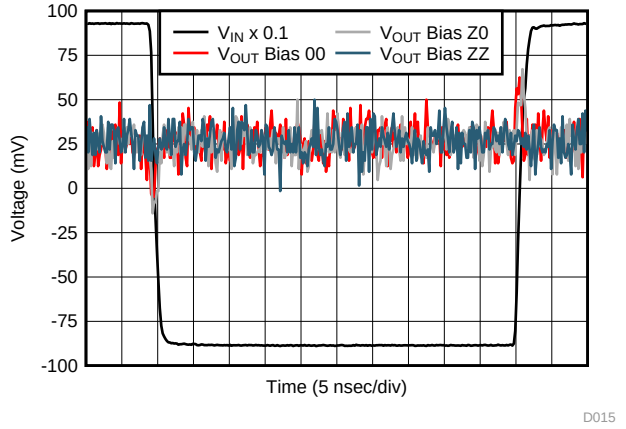
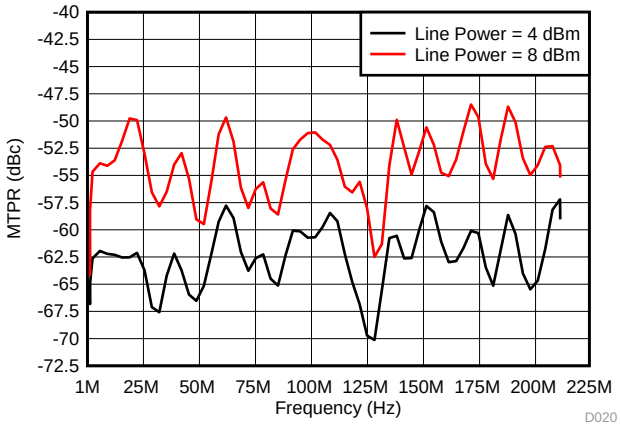
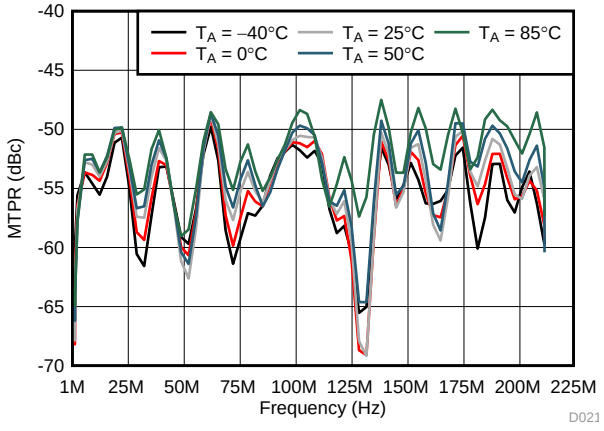


Figure 15. Pulse Response Termination and Power-Down Modes



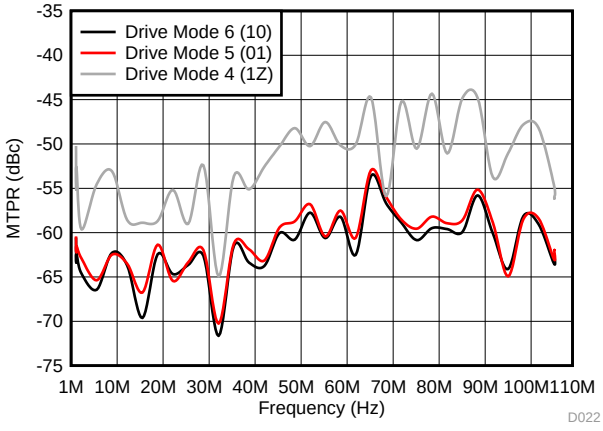
PAR = 15 dB, 1-in-64 missing tones

Figure 16. MTPR G.Fast 212-MHz Profile (Bias 10)



PAR = 15 dB, 1-in-64 missing tones, Line power = 8 dBm

Figure 17. MTPR Over Temperature G.Fast 212-MHz Profile (Bias 10)

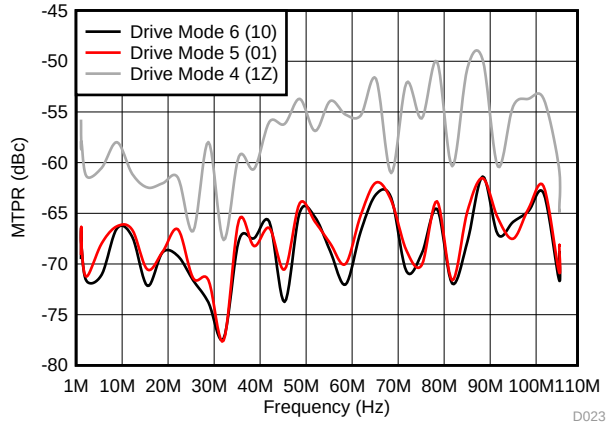


PAR = 15 dB, 1-in-64 missing tones, line power = 8 dBm

Figure 18. MTPR G.Fast 106-MHz Profile

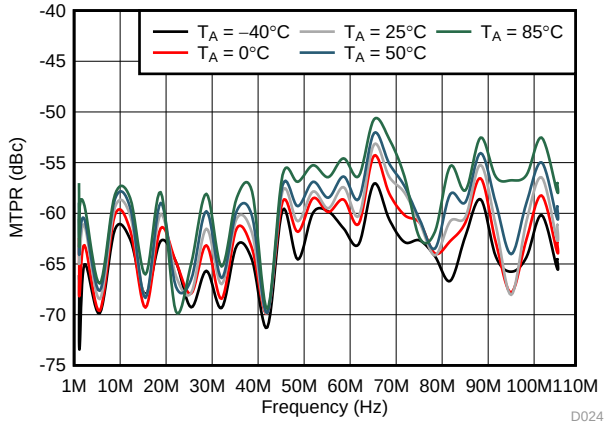
Typical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)



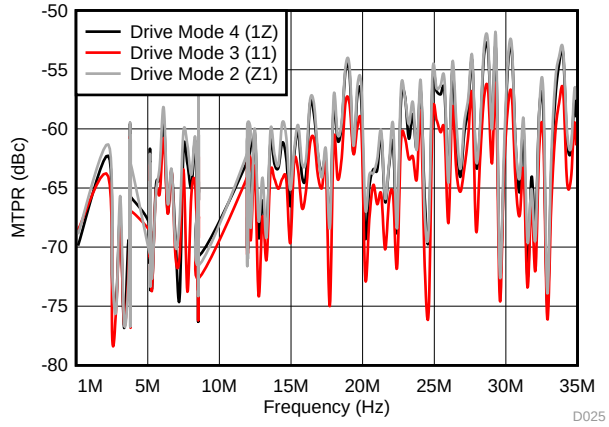
PAR = 15 dB, 1-in-64 missing tones, line power = 4 dBm

Figure 19. MTPR G.Fast 106-MHz Profile



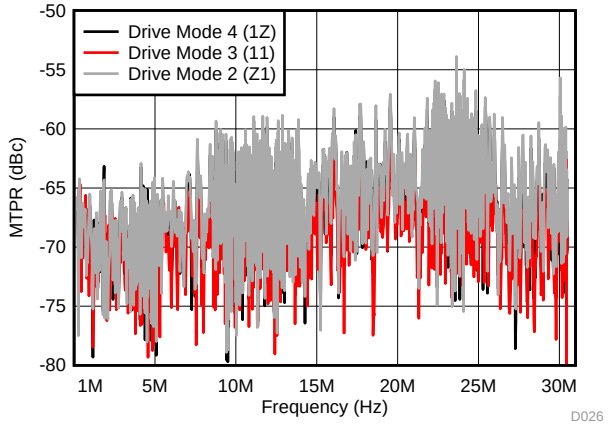
Line power = 8 dBm, PAR = 15 dB, 1-in-64 missing tones

Figure 20. MTPR Over Temperature G.Fast 106-MHz Profile (Bias 01)



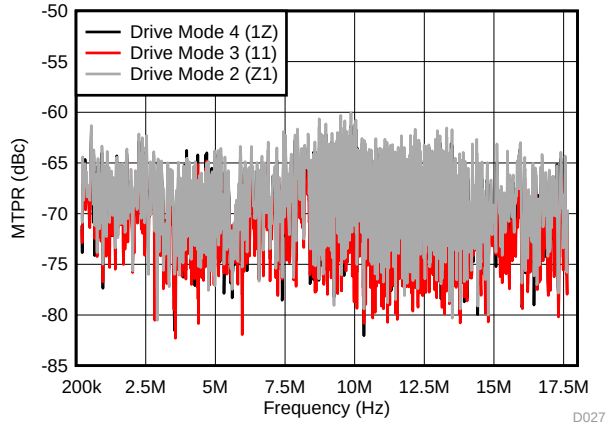
PAR = 15 dB, 1-in-64 missing tones, line power = 8 dBm

Figure 21. MTPR VDSL2-35b Profile



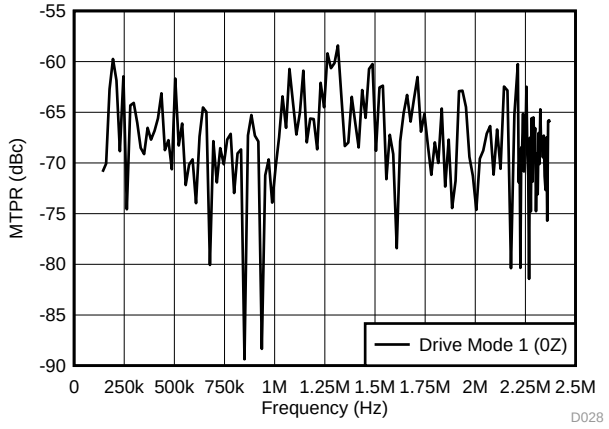
PAR = 15 dB, 1-in-4 missing tones, line power = 8 dBm

Figure 22. MTPR VDSL2-30a Profile



PAR = 15 dB, 1-in-4 missing tones, line power = 8 dBm

Figure 23. MTPR VDSL2-17a Profile

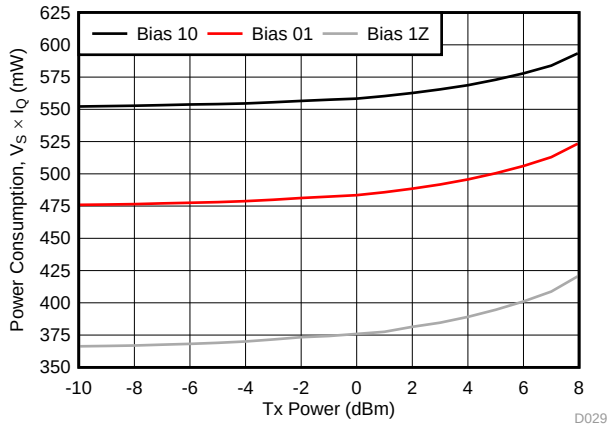


PAR = 15 dB, 1-in-4 missing tones, line power = 8 dBm

Figure 24. MTPR ADSL2+ Profile

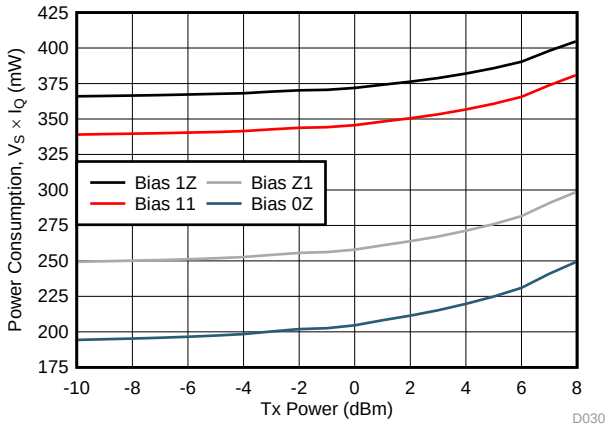
Typical Characteristics (continued)

at $T_A \approx 25°C$, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)



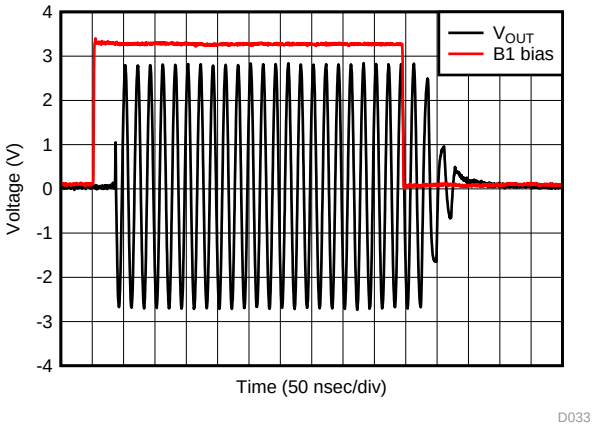
G.Fast 106-MHz profile used

Figure 25. G.Fast Modes Power Consumption



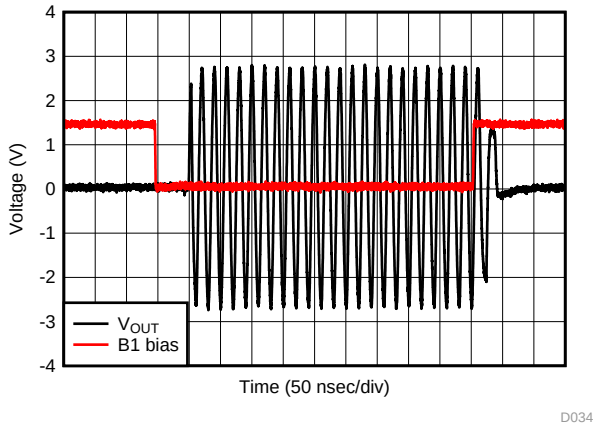
VDSL2-30a profile used

Figure 26. xDSL Modes Power Consumption



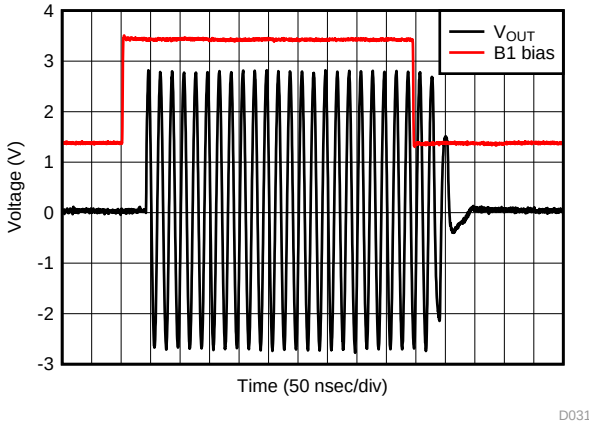
Bias mode 00 to 10 and 10 to 00

Figure 27. Mode Switch Time 00 to 10



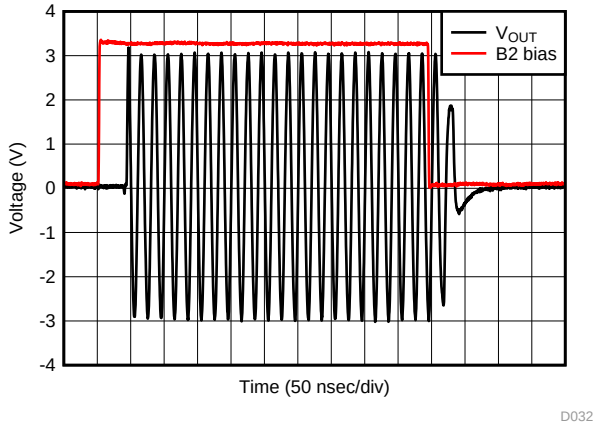
Bias mode ZZ to 0Z and 0Z to ZZ

Figure 28. Mode Switch Time ZZ to 0Z



Bias mode ZZ to 1Z and 1Z to ZZ

Figure 29. Mode Switch Time ZZ to 1Z



Bias mode Z0 to Z1and Z1 to Z0

Figure 30. Mode Switch Time Z0 to Z1

Typical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

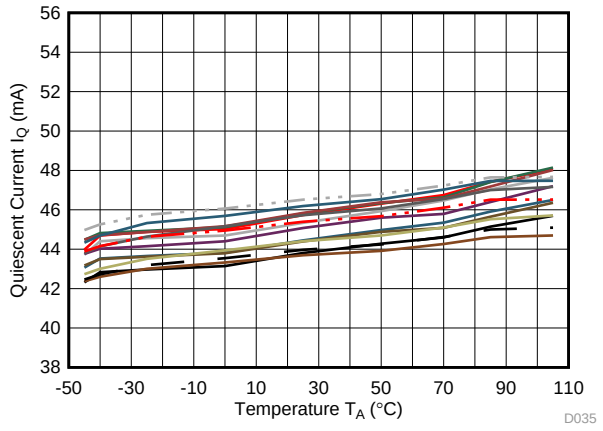


Figure 31. I_Q vs Temperature Drive Mode 6 (Bias 10)

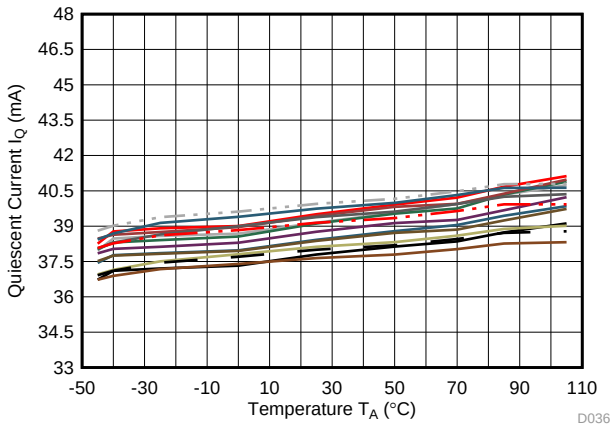


Figure 32. I_Q vs Temperature Drive Mode 5 (Bias 01)

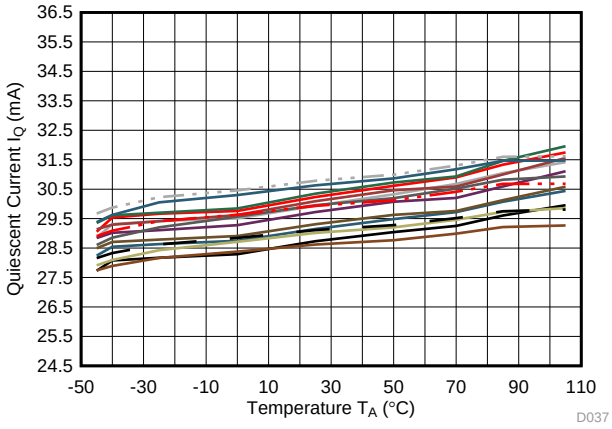


Figure 33. I_Q vs Temperature Drive Mode 4 (Bias 1Z)

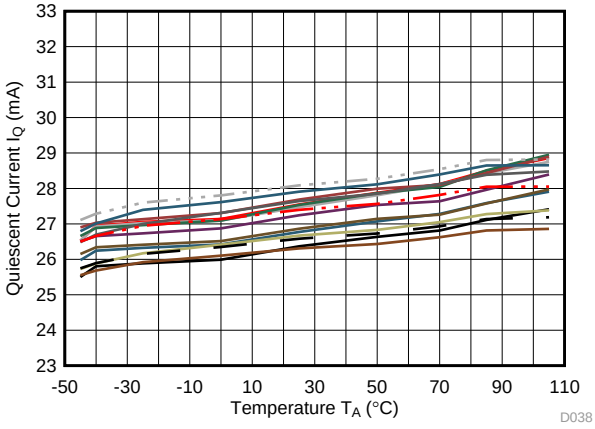


Figure 34. I_Q vs Temperature Drive Mode 3 (Bias 11)

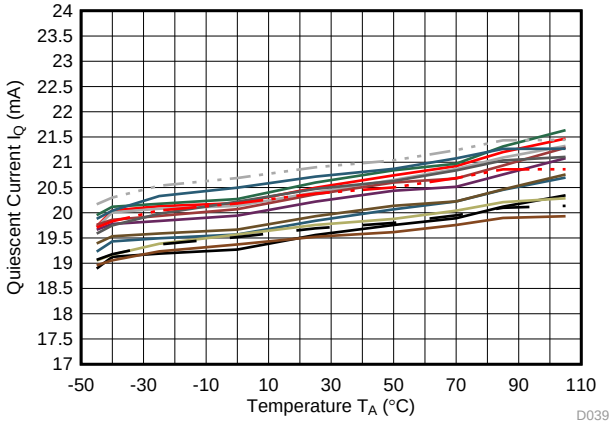


Figure 35. I_Q vs Temperature Drive Mode 2 (Bias Z1)

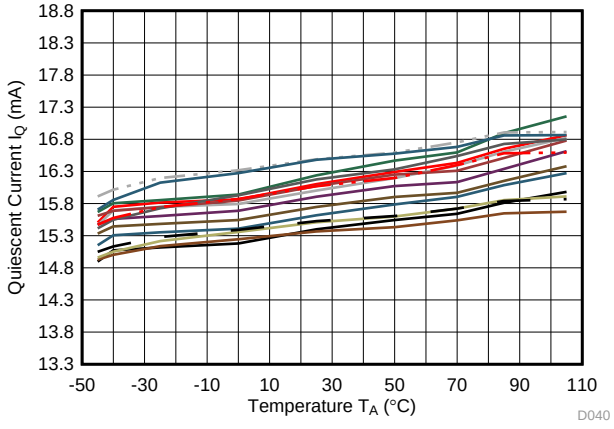


Figure 36. I_Q vs Temperature Drive Mode 1 (Bias 0Z)

Typical Characteristics (continued)

at T_A ≈ 25°C, VS+ = 12 V, VS– = 0 V, voltage gain (A_V) = 8.5 V/V, 100-Ω load, R_{SERIES} = 47.5 Ω, R_{IADJ} = 75 kΩ, C_{IADJ} = 100 pF, and drive mode 5 (B1B2 = 01, G.Fast mid power mode) and output power measured at input of transformer (1:1) with no assumed transformer insertion losses (unless otherwise noted)

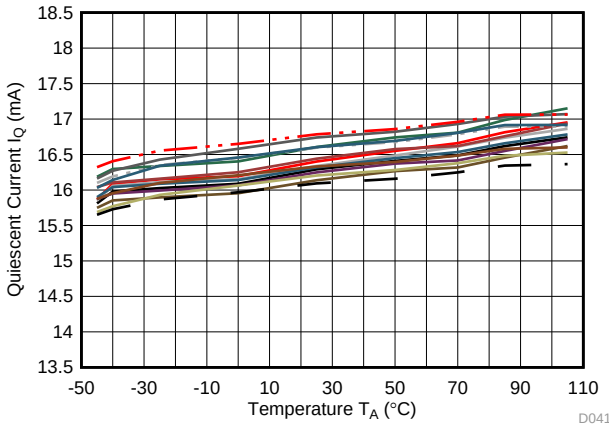


Figure 37. I_Q vs Temperature High-Power Termination Mode (Bias 00)

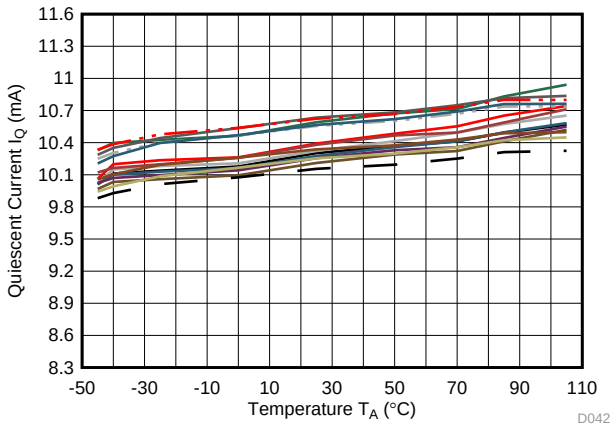


Figure 38. I_Q vs Temperature Low-Power Termination Mode (Bias Z0)

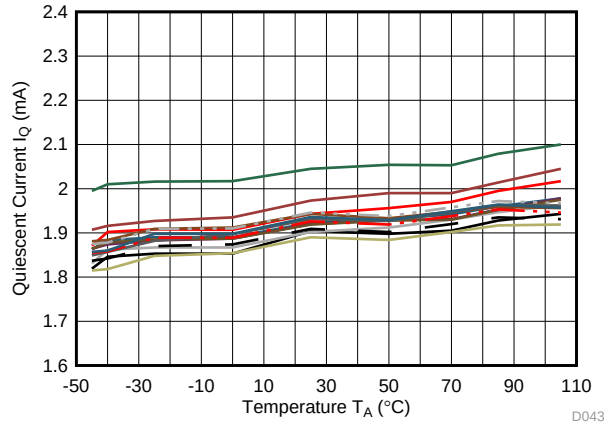


Figure 39. I_Q vs Temperature Power-Down Mode (Bias ZZ)

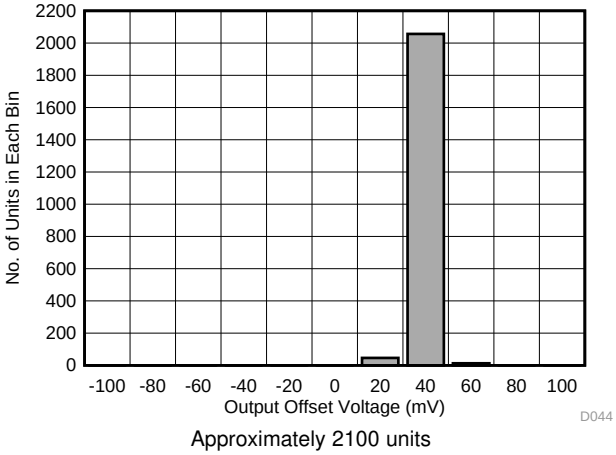


Figure 40. Output Offset Voltage Histogram

7 Detailed Description

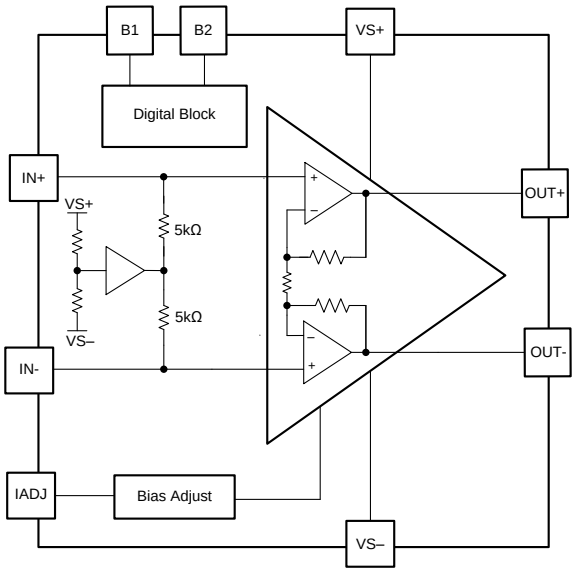
7.1 Overview

The THS6301 is a current-feedback architecture, differential line driver designed for G.Fast and xDSL systems. The device is targeted for use in G.Fast digital subscriber line (DSL) systems that enable native discrete multitone modulation (DMT) signals and supports an 8-dBm line power up to 212 MHz with good linearity.

The device consists of a unique architecture consisting of an amplifier in a noninverting configuration with an internally-fixed gain of 8.5 V/V. The THS6301 is designed to drive the high-performance G.Fast 212-MHz DSL profile, but is also backwards-compatible to drive lower frequency profiles. The device features selectable bias modes for the G.Fast 106-MHz profile, VDSL profiles, and ADSL profiles. These modes reduce the quiescent current of the device based on the frequency requirements of the various DSL profiles to maximize power efficiency. Along with adjustable bias modes, the device features two line-termination modes that maintain an output impedance match with low power consumption. The line-termination modes allow for the device to be in a low-power state without causing distortion on a shared signal line.

For further flexibility, the THS6301 features an IADJ pin that is used to further adjust the quiescent current of the device. A resistor connected to this pin can be changed to increase or decrease the device current to meet performance requirements and uses the lowest amount of power possible.

7.2 Functional Block Diagram



7.3 Feature Description

The THS6301 is a line driver that has a high current drive and a differential input and output. Figure 41 shows an example circuit of the THS6301 configured to drive the G.Fast 212-MHz DSL profile. The bias control pins B1 and B2 are set to 3.3 V and ground, respectively, to put the device in the G.Fast 212-MHz bias mode. This bias mode optimizes the internal power consumption of the device to meet performance specifications of the G.Fast 212-MHz profile and can be changed to meet several different DSL profiles and other modes listed in Table 1. The IADJ pin is biased with a 75-kΩ (R_{IADJ}) resistor that adjusts the device quiescent current to a nominal state. R_{IADJ} can be increased to lower the quiescent current or decreased to raise the quiescent current of the device for fine-tuning. C_{IADJ} provides decoupling for the IADJ pin and is typically 100 pF.

The THS6301 has a 10-kΩ, internally-set differential input impedance and low output impedance. In Figure 41 the input impedance is matched to 100 Ω by using a 100-Ω resistor connected differentially across the inputs. This value can easily be changed by using a different resistor to create the desired impedance at the input. Remember that the impedance in the device is actually the parallel combination of 10 kΩ and the external input resistor. For low impedances, this effect is minimal, but must be considered if the matched input impedance is increased. The output impedance of the THS6301 in Figure 41 is set by the two R_{SERIES} resistors to match 100 Ω. The internal output resistance is very low (< 2 Ω per output), so the output impedance is primarily set by the R_{SERIES} resistors. These resistors can be adjusted to match various output impedance values.

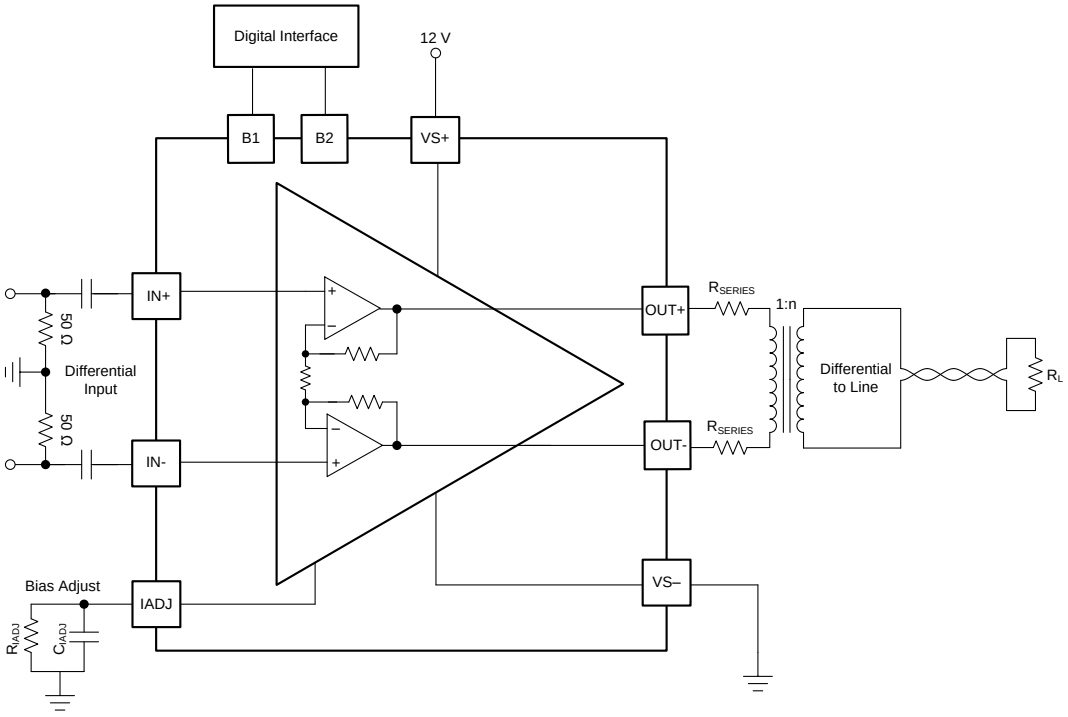


Figure 41. G.Fast, 212-MHz Driving Mode Example Circuit

7.4 Device Functional Modes

The THS6301 features nine different device operational modes, as listed in Table 1, to accommodate the G.Fast, xDSL, line termination, and power-down scenarios. The device is controlled by a 2-pin parallel interface that uses three-level logic to control the device state. The G.Fast and xDSL modes change the quiescent current of the device to meet signal performance requirements and maintain the lowest power possible, which allows for legacy DSL compatibility with maximum power efficiency. The two line-termination modes maintain a low impedance at the output and place the device in a low-power state. The line-termination modes allow for the muxing of multiple devices to one output line by putting the non-driving devices in a state that does not add distortion to the line. A power-down mode is also included to digitally shut down the device for the highest level of power savings. Table 1 lists the device power modes and the typical quiescent currents for each mode.

Table 1. Bias Modes Truth Table

MODE DESCRIPTION	BIAS CONTROL PINS		RECOMMENDED DSL PROFILE	TYPICAL QUIESCENT CURRENT (R_{IADJ} = 75 KΩ	SSBW (V_{OUT} = 1.7 V_{PP})
	B1	B2			
Power down	Z	Z	Power down	1.9 mA	N/A
Low-power termination	Z	0	Line termination (low power)	10.2 mA	N/A
High-power termination	0	0	Line termination (high power)	16 mA	N/A
Drive mode 1	0	Z	ADSL2+	15.9 mA	564 MHz
Drive mode 2	Z	1	VDSL (low power)	20.1 mA	659 MHz
Drive mode 3	1	1	G.Fast (low power) and VDSL (mid power)	27.2 mA	755 MHz
Drive mode 4	1	Z	VDSL (high power)	29.8 mA	605 MHz
Drive mode 5	0	1	G.Fast (mid power)	38.9 mA	864 MHz
Drive mode 6	1	0	G.Fast (high power)	45.3 mA	814 MHz

7.5 Programming

The THS6301 programming is controlled by two parallel pins, B1 and B2. These pins use three-level logic to create nine different combinations for each pair of pins. The pins have a high state (*1*) when the pin voltage is greater than 2.3 V, a low state (*0*) when the pin voltage is less than 0.6 V, and an open state (*Z*) where the pin floats at approximately 1.4 V or can be driven between 1.2 V and 1.6 V. Table 1 lists the logic combinations for the two pins and the corresponding power modes.

8 Application and Implementation

NOTE

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

8.1 Application Information

The device is a single-port, very-high-bit-rate linear xDSL, G.Fast differential line driver where the device drives a twisted pair cable. The signal is generated by a high-speed, digital-to-analog converter (DAC) at low signal swings that is amplified by the G.Fast line driver.

The G.Fast system is ac-coupled when transmitting information above the audio band. On the input of the line driver, this ac-coupling translates into the series capacitors to isolate the dc voltage coming from the DAC output common-mode voltage. On the output, a transformer is used to help isolate the 48 V present between the tip and ring of the telephone line.

The transformer can be set to any useful ratio. In practice, the transformer-turn ratio is set between 1:1 and 1:1.4 for the device. The output transformer usually has the active impedance synthesis factor set to 5. This synthesis factor means that the termination resistor (R_T) is 1/5th of the load impedance reflected to the transformer secondary. Thus, the correct termination can be selected based on the transformer-turn ratio.

Note that the resulting load detected by the amplifier may affect the amplifier linearity or output voltage swing capabilities.

8.2 Typical Application

Figure 42 shows a typical application circuit for this device.

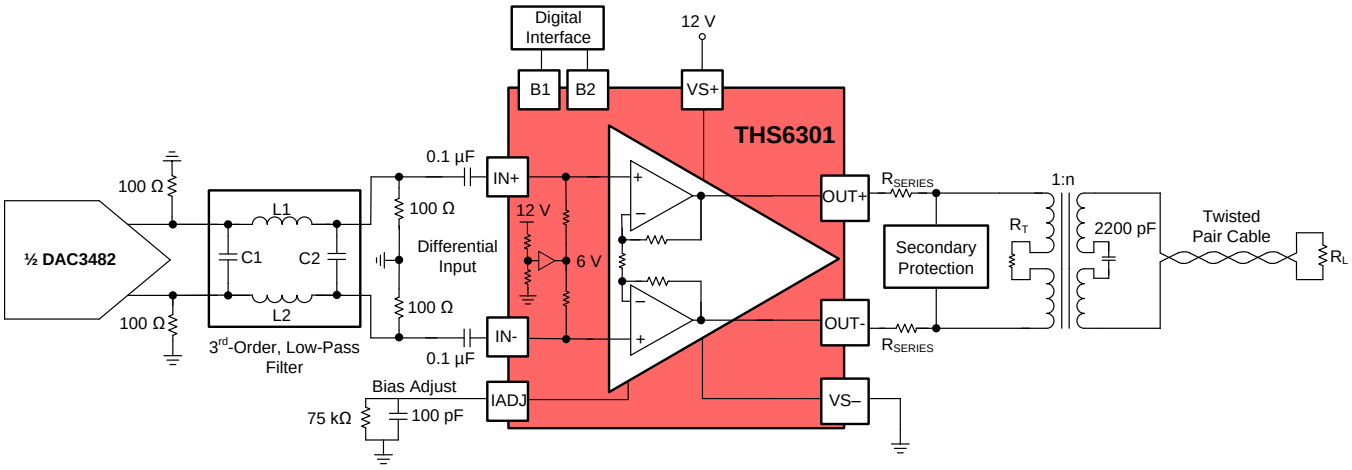


Figure 42. Typical G.FAST Line Driver Configuration

Typical Application (continued)

8.2.1 Design Requirements

Table 2 provides the design requirements for a G.Fast line driver, which is met by the THS6301 device.

Table 2. Design Requirements

DESIGN REQUIREMENT	CONDITION
G.Fast, 106-MHz, 212-MHz transmit profile	Yes, using the bias control pins for line power = 8 dBm and PAR = 15 dBm
Legacy DSL profile support	Yes
Supply voltage	12 V
Output current drive	±80 mA, each output
Power-down functionality	High isolation from input to output
Input interface	AC coupled
Output transformer ratio	1:1.5
Surge protection	External needed

8.2.2 Detailed Design Procedure

The G.Fast signal input to the THS6301 comes from a high-speed DAC whose interleaving spurs are filtered out using either a 3rd- or 5th-order filter. Digital pre-emphasis can be employed in the DAC output such that the differential line driver compensates for the transmission line cable losses at long distance and high frequency. The THS6301 is operated on a 12-V single supply. Resulting from the single-supply operation, the device input is AC-coupled using a capacitor that blocks any DC current flowing out of the inputs to the adjacent circuitry. The AC-coupling capacitor forms a high-pass filter with the device input impedance. This pole must be set at a frequency low enough to not interfere with the desired xDSL or G.Fast signal.

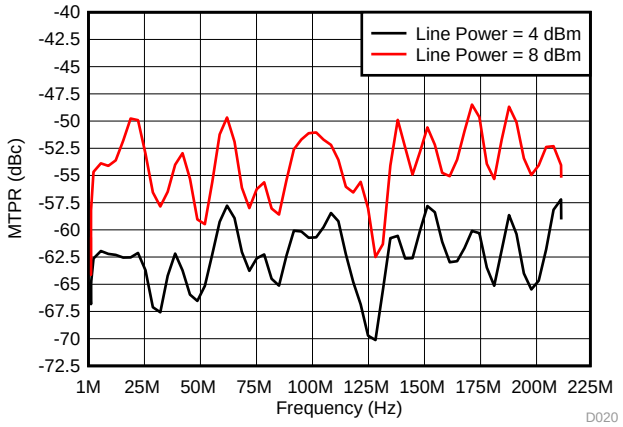
The THS6301 differential outputs usually drive a 1:n output transformer with a transformer turns ratio that can be changed depending upon the application. The output transformer selected must have low insertion loss in the desired frequency band in order to maintain good multi-tone power rejection (MTPR) for a given line power. The load is expected to be a transmission line with 100-Ω characteristic impedance on the primary side of the transformer. Referred to the transformer secondary, the load detected by the amplifier is $1 / n^2$ with 1:n being the transformer turn ratio. Practical limitations force the transformer-turn ratio to be between 1:1 and 1:1.6. At the lighter load detected by the amplifier (1:1), the voltage swing is limited by the class AB output stage and the maximum achievable swing of the amplifier. At the heaviest load (1:1.6), the voltage swing is limited by the current drive capability of the amplifier. To satisfy the synthesis impedance factor and the loading, the termination resistance (R_T) can be set to $R_T = R_L / 5 = 100\ \Omega / (5 \times n^2)$.

For surge protection, consider adding a gas discharge tube (GDT) on the primary side of the output transformer. The gas discharge tube is required to shunt the large current that could flow through the cables during lightning surge, and protect the device outputs. The secondary protection is also normally added after the series resistance on the secondary transformer side. The secondary protection could be in the form of back to back switching diodes, which also help limit the residual surge current flowing into the device outputs.

For the power-supply bypass, consider using X7R or X5R because of the better stability of these materials over temperature.

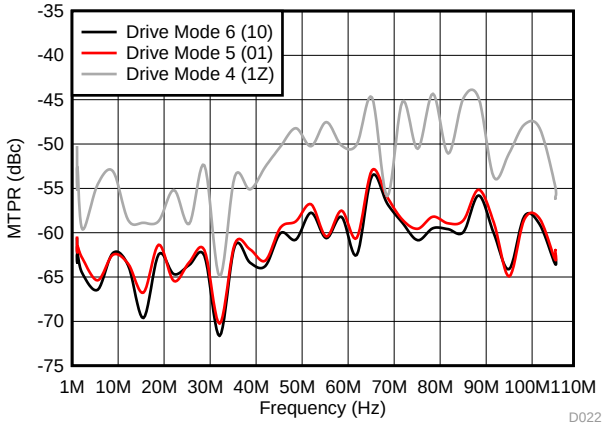
8.2.3 Application Curves

Figure 43 and Figure 44 show the MTPR results for 212-MHz and 160-MHz G.Fast profiles, respectively.



PAR = 15 dB, 1-in-64 missing tones

Figure 43. MTPR G.Fast 212-MHz Profile



PAR = 15 dB, 1-in-64 missing tones, line power = 8 dBm

Figure 44. MTPR G.Fast 106-MHz Profile

9 Power Supply Recommendations

The THS6301 is recommended to operate using a total supply voltage of 12 V. If a lower or higher supply voltage is required, select one that is between 11.4 V and 12.6 V for optimal performance. Use supply-decoupling capacitors on the power-supply pins to minimize distortion caused by parasitic signals on the power supply. This usage is especially important in applications where many devices share a single power-supply bus.

The device can be operated on split supplies (such as ±6 V). However, the bias adjust resistor must be tied to the negative supply for proper device operation. When operating the device on split supply, pins 4 and 10 act as the negative supply voltage pin. The thermal pad must be tied to either GND or the negative supply voltage in split-supply operation. The device bias mode pins are now referenced to the negative supply voltage for the different logic levels.

As with all high-speed amplifiers, supply bypass capacitors are required for operation of the THS6301. Multiple capacitors are required to cover the entire frequency range of the device. For low frequency bypassing use a 10 µF or larger tantalum capacitor (see the description of C1 in the *THS6301EVM User's Guide*). Place this capacitor within two or three centimeters of the amplifier. Use 0.1-µF and 1-nF high-frequency bypass capacitors (these capacitors are labeled C2 and C3 on the EVM). Place these capacitors within two to three millimeters of the amplifier and must be directly connected to the power-supply planes with low-impedance vias. Texas Instruments recommends using the capacitors shown in the bill of materials (BOM) that accompanies the *THS6301EVM User's Guide*. The capacitor part numbers are listed in the THS6301EVM user's guide.

10 Layout

10.1 Layout Guidelines

Achieving optimum performance with a high-frequency amplifier such as the THS6301 requires careful attention to board layout parasitics and external component types. Recommendations that optimize performance include:

a. Minimize parasitic capacitance to any ac ground for all signal I/O pins. Excessive parasitic capacitance on the input pin can cause instability. In the line driver application, the parasitic capacitance forms a pole with the load detected by the amplifier and can reduce the effective bandwidth of the application circuit, thus leading to degraded performance. To reduce unwanted capacitance, open a window around the signal I/O pins in all ground and power planes around those pins. Otherwise, make sure that ground and power planes are unbroken elsewhere on the board.

b. Minimize the distance (< 0.25") from the power-supply pins to high-frequency, 0.1-µF decoupling capacitors. At the device pins, make sure that the ground and power-plane layout are not in close proximity to the signal I/O pins. Avoid narrow power and ground traces to minimize inductance between the pins and decoupling capacitors. Always decouple the power-supply connections with these capacitors.

c. Make sure the bias adjust resistor connected to the IADJ pin is not routed close to the device inputs in-order to avoid any high-frequency noise coupling into the IADJ pin and result in unexpected device behavior.

d. Careful selection and placement of external components preserves the high-frequency performance of the device. Use very-low reactance-type resistors. Surface-mount resistors function best and allow a tighter overall layout. Metal-film or carbon composition, axially-leaded resistors also provide good high-frequency performance. Again, keep the leads and printed circuit board (PCB) traces as short as possible. Never use wire-wound type resistors in a high-frequency application.

e. Connections to other wideband devices on the board can be made with short, direct traces or through onboard transmission lines. For short connections, consider the trace and the input to the next device as a lumped capacitive load. Use relatively wide traces (50 mils to 100 mils), preferably with ground and power planes opened up around them.

f. Do not socket a high-speed part such as the THS6301. The additional lead length and pin-to-pin capacitance introduced by the socket can create an extremely troublesome parasitic network that makes achieving a smooth, stable frequency response almost impossible. Best results are obtained by soldering the device onto the board.

g. TI recommends soldering the thermal pad to the PCB in order to conduct heat out of the device package. Vias underneath the part help regulate the flow of free air and also help conduct heat out of the package.

Layout Guidelines (continued)

10.1.1 Power Dissipation and Thermal Considerations

For maximum performance and reliability, the designer must ensure that the design does not exceed a junction temperature of 125°C. Between 125°C and 150°C, damage does not occur, but the performance of the amplifier begins to degrade and long-term reliability suffers. The thermal characteristics of the device are dictated by the package and the PCB. Equation 1 calculates maximum power dissipation for a given package:

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / R_{\theta JA} \quad (1)$$

where

- $P_{D(MAX)}$ is the maximum power dissipation in the amplifier (W)
- $T_{J(MAX)}$ is the absolute maximum junction temperature (°C)
- T_A is the ambient temperature (°C)
- $R_{\theta JA} = R_{\theta JC} + R_{\theta CA}$
- $R_{\theta JC}$ is the thermal coefficient from silicon transistors to the case (°C/W)
- $R_{\theta CA}$ is the thermal coefficient from case to ambient temperature (°C/W)

For systems where heat dissipation is more critical, the THS6301 is offered in an 16-pin VQFN package with thermal pad. Because of the thermal pad, the thermal coefficient for the VQFN package is substantially improved over the traditional SOIC. The data for the VQFN packages with thermal pad assume a board layout that follows the thermal pad layout guidelines referenced in this section and detailed in the *Quad Flatpack No-Lead Logic Packages* application note. If the thermal pad is not soldered to the PCB, the thermal impedance increases substantially, which may cause serious heat and performance issues. Be sure to always solder the thermal pad to the PCB for optimum performance.

When determining whether or not the device satisfies the maximum power dissipation requirement, consider not only quiescent power dissipation, but also dynamic power dissipation. Often times, this dissipation is difficult to quantify because the signal pattern is inconsistent, but an estimate of the RMS power dissipation can provide visibility into a possible problem.

10.2 Layout Example

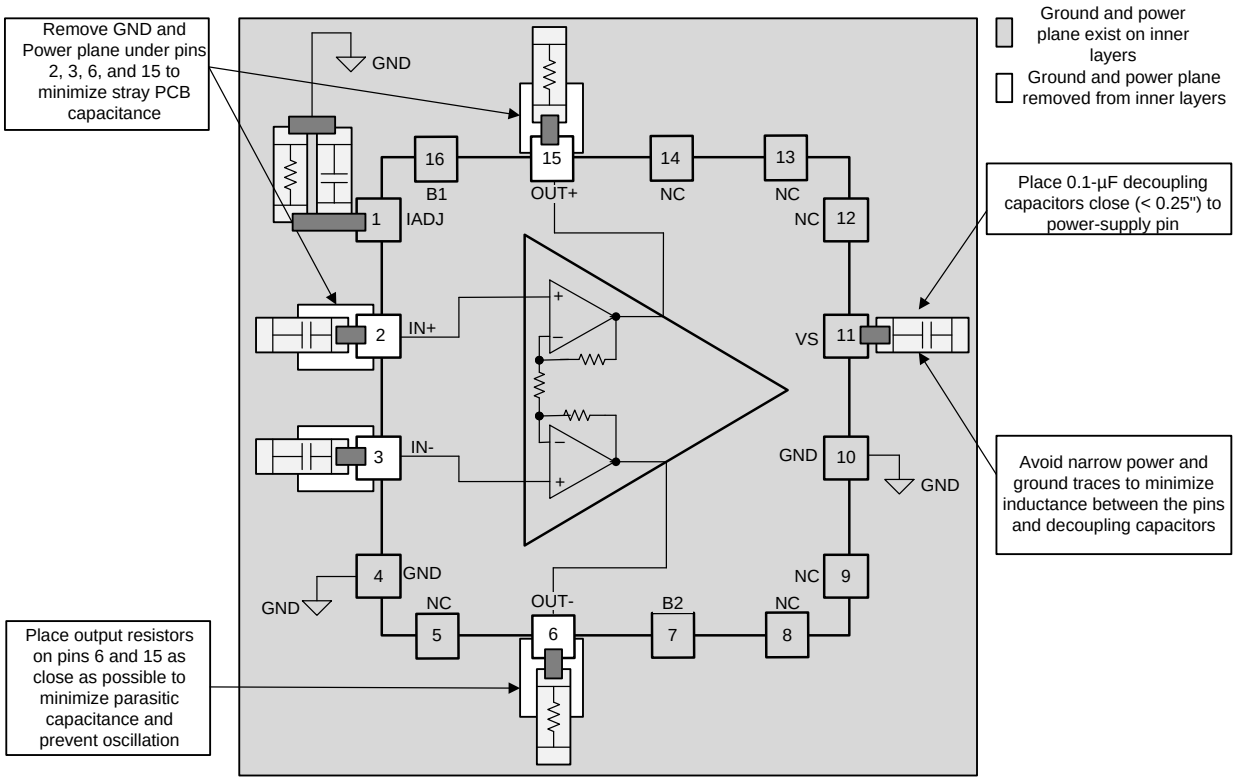


Figure 45. Example Layout

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- *Quad Flatpack No-Lead Logic Packages* Application Note
- *Active output impedance for ADSL line drivers* Application Note
- *THS6301EVM User's Guide*

11.2 Receiving Notification of Documentation Updates

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

11.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.4 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.5 Electrostatic Discharge Caution

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

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

11.6 Glossary

SLYZ022 — *TI Glossary*.

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

12 Mechanical, Packaging, and Orderable Information

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

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
THS6301IRSAR	ACTIVE	QFN	RSA	16	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	THS 6301	Samples
THS6301IRSAT	ACTIVE	QFN	RSA	16	250	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	THS 6301	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

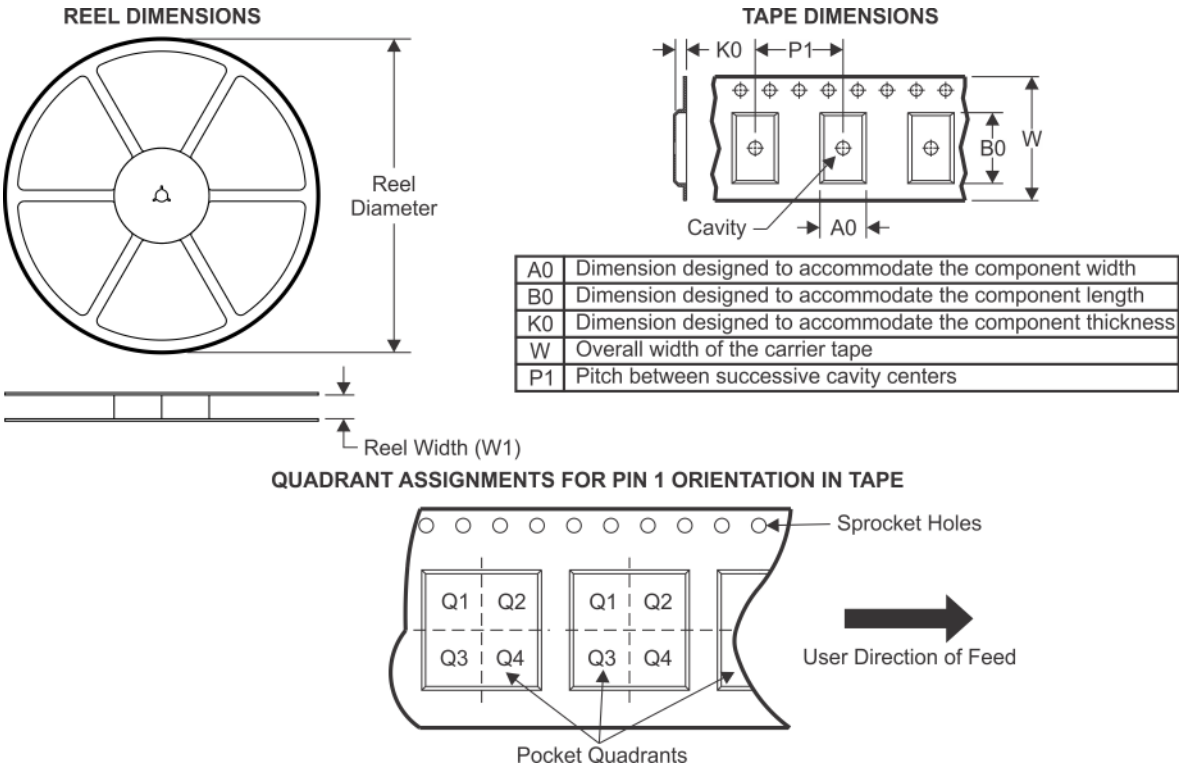
(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices 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.

TAPE AND REEL INFORMATION

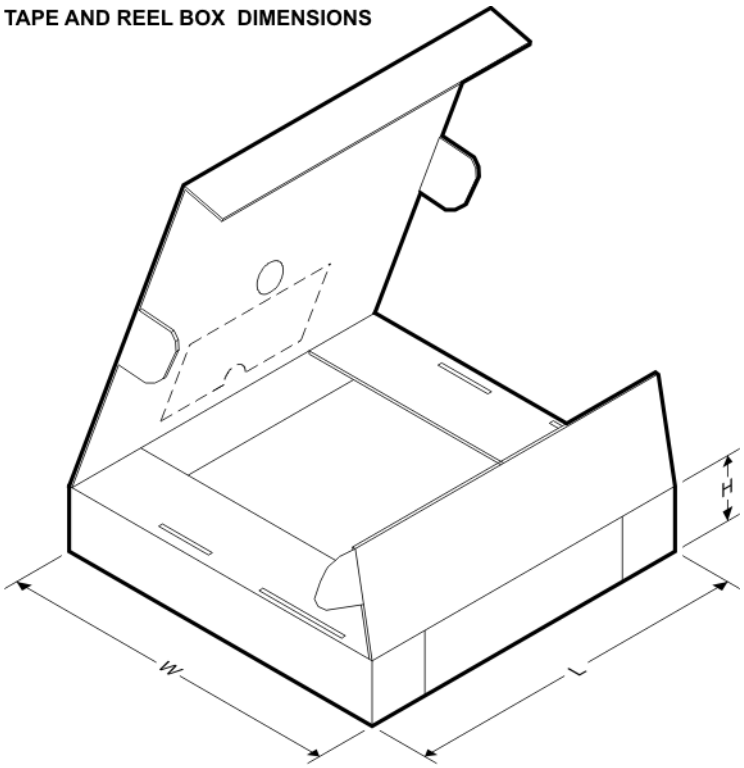


A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
THS6301IRSAR	QFN	RSA	16	3000	330.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
THS6301IRSAT	QFN	RSA	16	250	180.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2

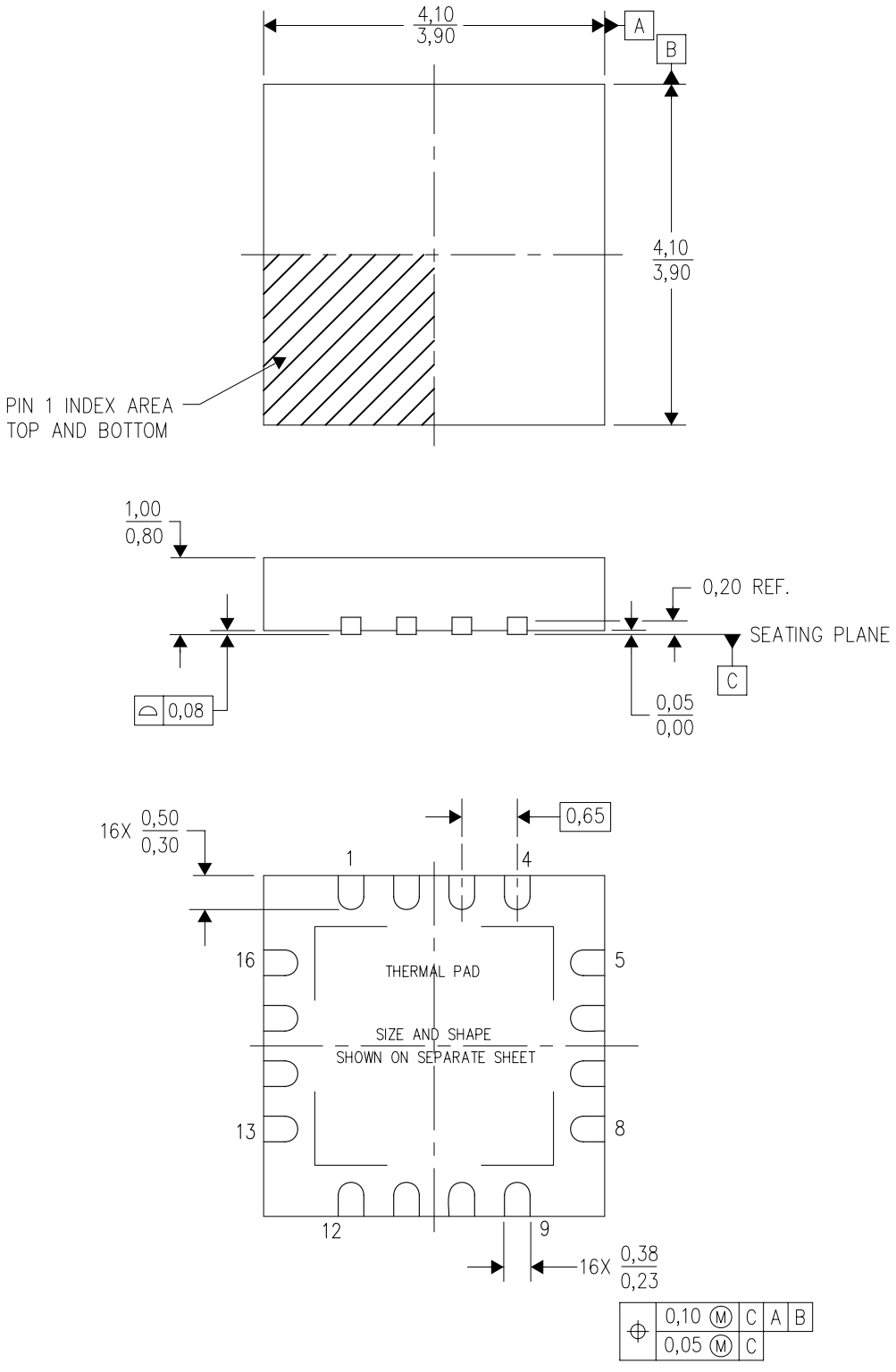
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
THS6301IRSAR	QFN	RSA	16	3000	367.0	367.0	35.0
THS6301IRSAT	QFN	RSA	16	250	210.0	185.0	35.0

RSA (S–PVQFN–N16) PLASTIC QUAD FLATPACK NO–LEAD



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. Quad Flatpack, No–leads (QFN) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Falls within JEDEC MO–220.

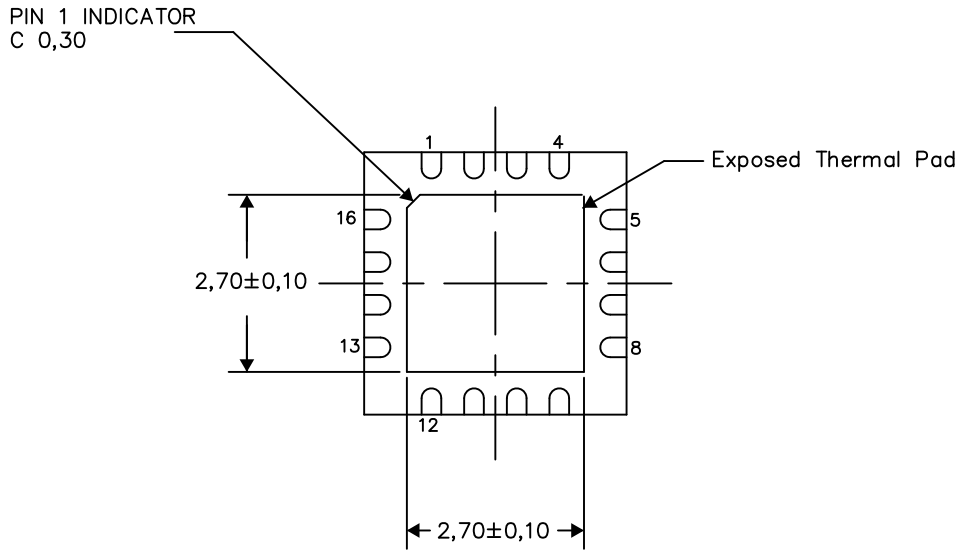
RSA (S–PVQFN–N16) PLASTIC QUAD FLATPACK NO–LEAD

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 the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to 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, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

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



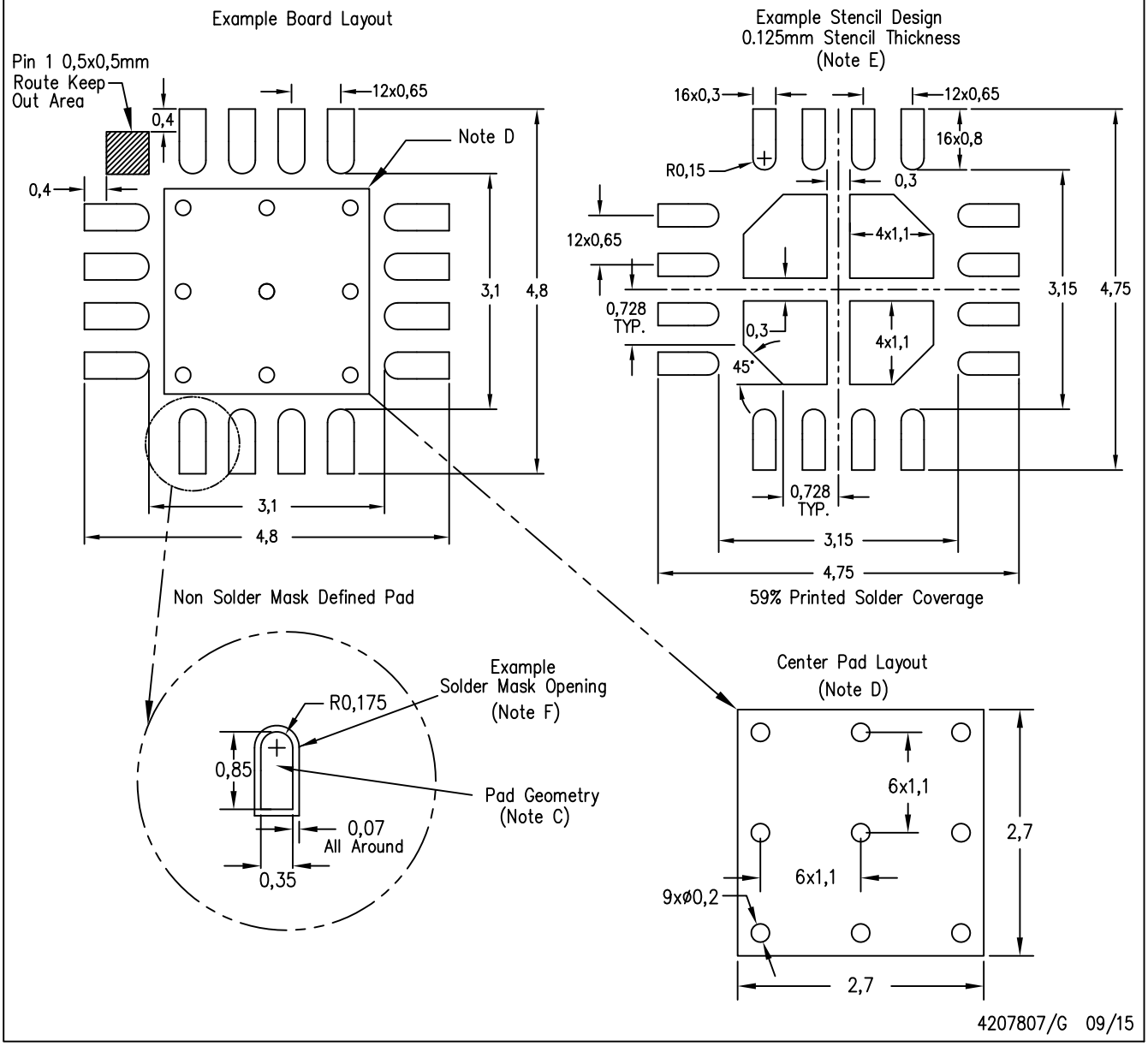
Bottom View

Exposed Thermal Pad Dimensions

4206364–2/0 09/15

NOTES:
A. All linear dimensions are in millimeters

RSA (S–PVQFN–N16) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, QFN Packages, Texas Instruments Literature No. 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>.
E. 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.
F. Customers should contact their board fabrication site for solder mask tolerances.

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