LMH9135 3.2 – 4.2 GHz Differential to Single-Ended Amplifier with Integrated Balun

1 Features

- Single-Channel, Narrow-Band Differential Input to Single-Ended Output RF Gain Block Amplifier
- Supports 3.2 – 4.2 GHz 1-dB BW Typical
- 18 dB Typical Gain Across the Band
- 3.8 dB Noise Figure
- 31.5 dBm OIP3
- 18 dBm Output P1dB
- 395 mW Power Consumption on Single +3.3 V Supply
- Up to 105°C T_C Operating Temperature

2 Applications

- Differential DAC Output Driver for GSPS DACs
- Differential to Single-Ended Conversions
- Balun Alternatives
- Small Cell or m-MIMO Base Stations
- 5G Active Antenna Systems (AAS)
- Wireless Cellular Base Station

3 Description

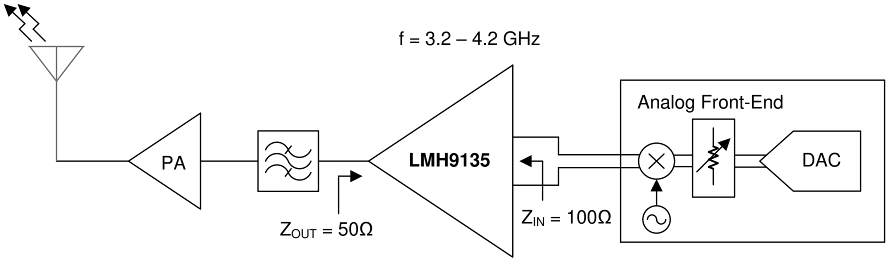
LMH9135 are high-performance, single-channel, differential input to single-ended output transmit radio frequency (RF) gain block amplifiers that support 3.2 – 4.2 GHz frequency band. The device can support the requirements for next generation 5G active antenna systems (AAS) or small-cell applications while driving the input of a power amplifier (PA). The RF amplifier provides 18 dB typical gain with good linearity performance of +31.5 dBm Output IP3, while maintaining less than 4 dB noise figure across the whole 1 dB bandwidth. The device is internally matched for 100-Ω differential input impedance providing easy interface with an RF-sampling or Zero-IF analog front-end (AFE) at the input. Also, the device is internally matched for 50-Ω single-ended output impedance that is required to easily interface with a post-amplifier, surface acoustic wave (SAW) filter, or power amplifier (PA).

Operating on a single 3.3 V supply, the device consumes about 395 mW typical active power making it suitable for high-density 5G massive MIMO applications. Also, the device is available in a space saving 2 mm x 2 mm, 12-pin QFN package. The device is rated for an operating temperature of up to 105°C to provide a robust system design. There is a 1.8-V JEDEC compliant power down pin available for fast power down and power up of the device suitable for time division duplex (TDD) systems.

Device Information (1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LMH9135	WQFN (12)	2.00 mm × 2.00 mm

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



LMH9135: Differential to Single Ended Amplifier

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4 Revision History

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

DATE	REVISION	NOTES
August 2020	*	Initial Release

5 Pin Configuration and Functions

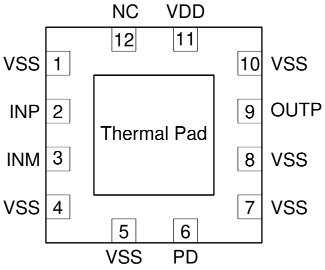


Figure 5-1. RRL Package 12-Pin WQFN Top View

Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	VSS	Power	Ground
2	INP	Input	RF differential positive input into amplifier
3	INM	Power	RF differential negative input into amplifier
4	VSS	Power	Ground
5	VSS	Power	Ground
6	PD	Input	Power down connection. PD = 0 V = normal operation; PD = 1.8 V = power off mode
7	VSS	Power	Ground
8	VSS	Output	Ground
9	OUTP	Output	RF single-ended output from amplifier
10	VSS	Power	Ground
11	VDD	Power	Positive supply voltage (3.3 V)
12	NC	—	Do not connect this pin
Thermal Pad		—	Connect the thermal pad to Ground

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage	VDD	–0.3	3.6	V
RF Pins	INP, INM, OUTP	–0.3	VDD	V
Digital Input PIN	PD	–0.3	VDD	V
Continuous wave (CW) input	T = 25 °C		18	dBm
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	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.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/ JEDEC JS-001, allpins[1]	±1000	V
		Charged device model (CDM), per JEDEC specificationJESD22-C101, all pins[2]	±500	

(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
VDD	Supply voltage	3.15	3.3	3.45	V
T_C	Case (bottom) temperature	–40		105	°C
T_J	Junction temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC[1]		DEVICE	UNIT
		PKG DES (PKG FAM)	
		PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	74.8	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	72.4	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	37.1	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	3.2	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	37.1	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	14.2	°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

T_A = +25°C, VDD = 3.3V, Frequency (f_{in}) = 3.5 GHz, Differential Input Impedance (Z_{IN}) = 100 Ω, Output Load (Z_{LOAD}) = 50 Ω (unless otherwise noted)

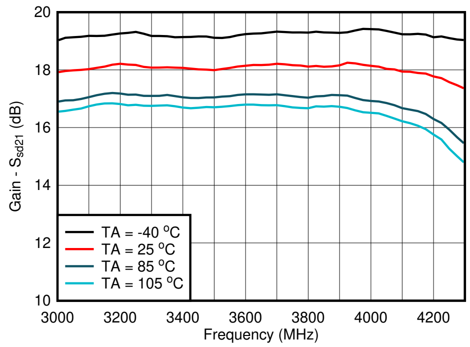
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
RF PERFORMANCE - LMH9135						
F_{RF}	RF frequency range		3200		4200	MHz
BW_{1dB}	1dB Bandwidth			1000		MHz
S21	Gain			18		dB
NF	Noise Figure	R_S = 100 Ω differential		3.8		dB
OP1dB	Output P1dB	Z_{LOAD} = 50 Ω		18		dBm
OIP3	Output IP3	f_{in} = 3.5 GHz ± 5 MHz Spacing, $P_{OUT/TONE}$ = 2 dBm		31.5		dBm
	Differential Input Gain Imbalance			±0.5		dB
	Differential Input Phase Imbalance			±4		degree
S11	Input return loss (1)	$_{fin}$ = 3.3 - 3.8 GHz		-10		dB
		$_{fin}$ = 3.3 - 4.2 GHz		-10		dB
S22	Output return loss (1)	$_{fin}$ = 3.3 - 3.8 GHz		-10		dB
		$_{fin}$ = 3.3 - 4.2 GHz		-10		dB
S12	Reverse isolation			35		dB
CMRR	Common Mode Rejection Ratio (2)			30		dB
Switching and Digital input characteristics						
t_{ON}	Turn-ON time	50% VPD to 90% RF		0.2		µs
t_{OFF}	Tun-OFF time	50% VPD to 10% RF		0.2		µs
V_{IH}	High-Level Input Voltage	PD pin	1.4			V
V_{IL}	Low-Level Input Voltage	PD pin			0.5	V
DC current and Power Consumption						
I_{VDD_ON}	Supply Current			120		mA
I_{VDD_PD}	Power Down Current			10		mA
P_{dis}	Power Dissipation			395		mW

(1) Reference impedance: Input = 100 Ω differential, Output = 50 Ω single-ended

(2) CMRR is calculated using (S_{12} - S_{13})/(S_{12} + S_{13}) for Transmit (1 is output port, 2 & 3 are differential input ports)

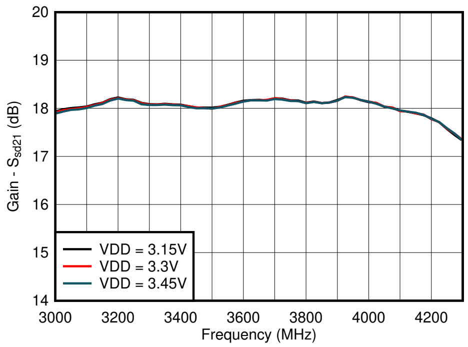
6.6 Typical Characteristics

At T_A = 25°C, VDD = 3.3 V, differential input impedance (Z_{IN}) = 100 Ω, single-ended output impedance (Z_{LOAD}) = 50 Ω (unless otherwise noted).



P_{OUT} = 2 dBm

Figure 6-1. Gain vs Frequency and Temperature



P_{OUT} = 2 dBm

Figure 6-2. Gain vs Frequency and Supply Voltage

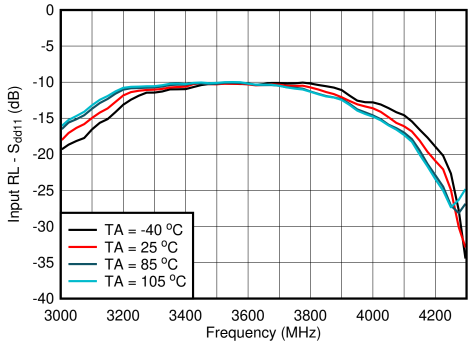


Figure 6-3. Input Return Loss vs Frequency

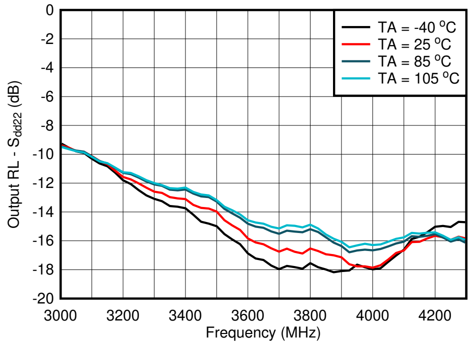


Figure 6-4. Output Return Loss vs Frequency

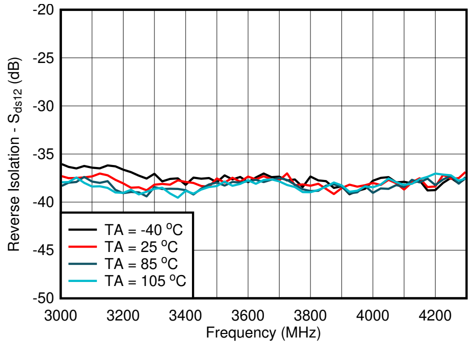
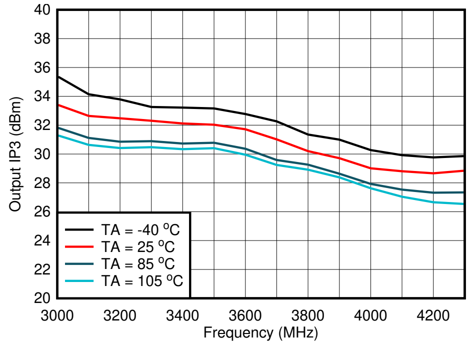
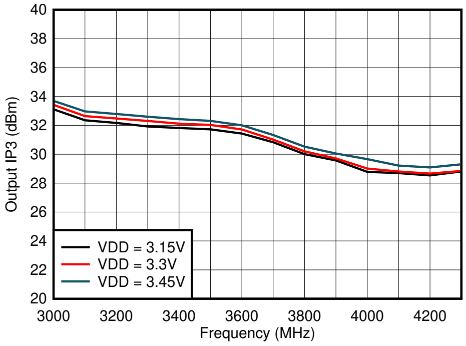


Figure 6-5. Reverse Isolation vs Frequency



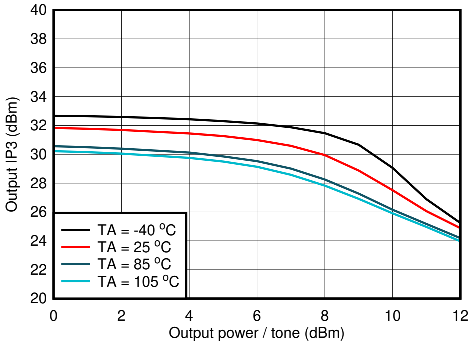
$P_{OUT/TONE}$ = 2 dBm, 10-MHz tone spacing

Figure 6-6. Output IP3 vs Frequency and Temperature



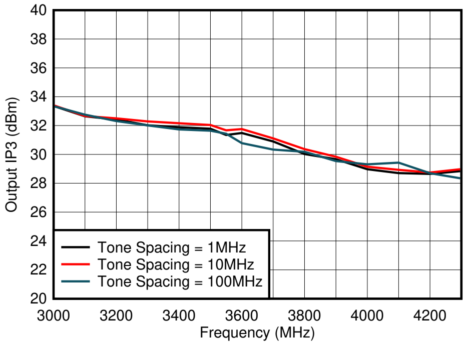
$P_{OUT/TONE}$ = 2 dBm, 10-MHz tone spacing

Figure 6-7. Output IP3 vs Frequency and Supply Voltage



f = 3.5 GHz, 10-MHz tone spacing

Figure 6-8. Output IP3 vs Output Power per Tone



$P_{OUT/TONE}$ = 2 dBm

Figure 6-9. Output IP3 vs Frequency and Tone Spacing

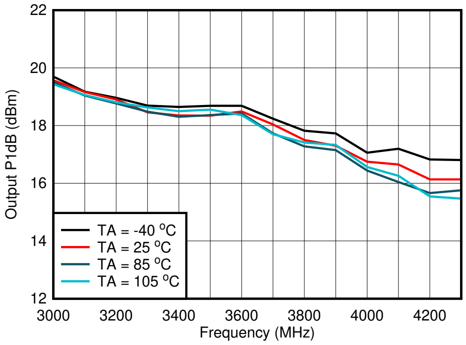


Figure 6-10. Output P1dB vs Frequency and Temperature

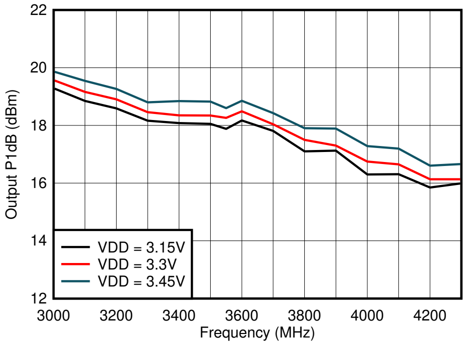
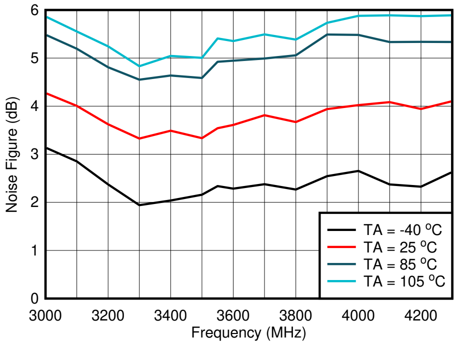


Figure 6-11. Output P1dB vs Frequency and Supply Voltage



Z_{SOURCE} = 100-Ω differential

Figure 6-12. Noise Figure vs Frequency and Temperature

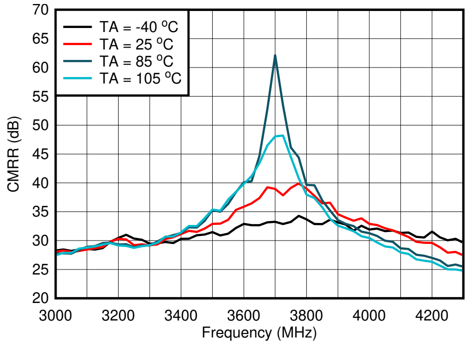


Figure 6-13. Common-mode Rejection Ratio vs Frequency

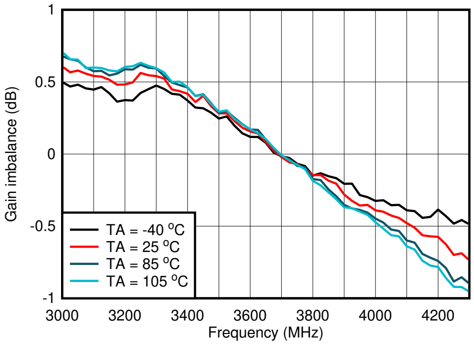


Figure 6-14. Gain Imbalance vs Frequency and Temperature

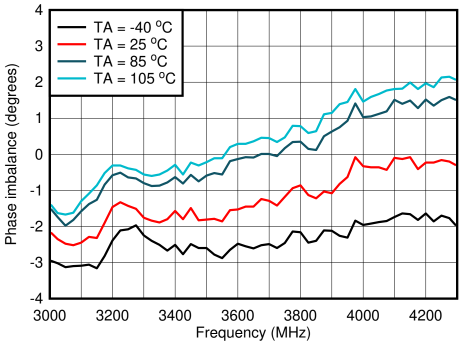


Figure 6-15. Phase Imbalance vs Frequency and Temperature

7 Detailed Description

7.1 Overview

The LMH9135 device is a differential input to single-ended output narrow-band RF amplifier used in transmitter applications. The device provides 18 dB fixed power gain with excellent linearity and noise performance across the frequency band 3.2 – 4.2 GHz. The device is internally matched for 100-Ω impedance at the differential input and 50-Ω impedance at the single-ended output, as shown in Figure 7-1.

LMH9135 have on-chip active bias circuitry to maintain device performance over a wide temperature and supply voltage range. The included power down function allows the amplifier to shut down saving power when the amplifier is not needed. Fast shut down and start up enable the amplifier to be used in a host of time division duplex applications.

Operating on a single 3.3 V supply and 120 mA of typical supply current, the devices are available in a 2 mm x 2 mm 12-pin QFN package.

7.2 Functional Block Diagram

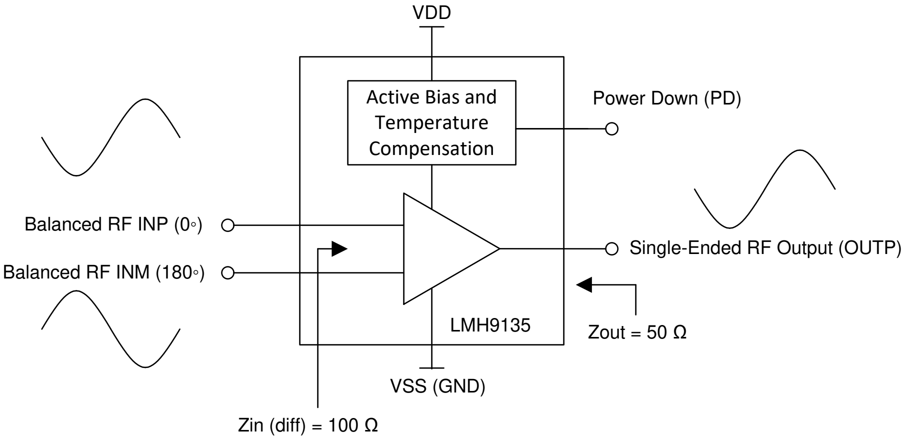


Figure 7-1. Functional Block Diagram

7.3 Feature Description

The LMH9135 device is a differential input to single-ended output RF amplifier for narrow band active balun implementation. The device integrates the functionality of a single-ended RF amplifier and passive balun in traditional transmitter applications achieving small form factor with comparable linearity and noise performance, as shown in Figure 7-2.

The active balun implementation coupled with higher operating temperature of 105°C allows for more robust receiver system implementation compared to passive balun that is prone to reliability failures at high temperatures. The robust operation is achieved by the on-chip active bias circuitry which maintains device performance over a wide temperature and supply voltage range.

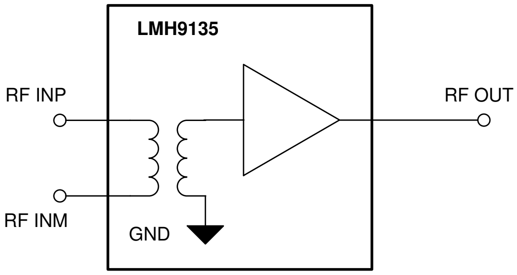


Figure 7-2. Differential Input to Single-Ended Output, Active Balun Implementation

7.4 Device Functional Modes

LMH9135 features a PD pin which should be connected to GND for normal operation. To power down the device, connect the PD pin to a logic high voltage of 1.8 V.

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

LMH9135 is a differential to single-ended RF gain block amplifier, which works as an active balun in the transmit path of a 3.3-GHz to 3.8-GHz 5G, TDD m-MIMO or small cell base station. The device replaces the traditional passive balun and single-ended RF amplifier offering a smaller footprint solution to the customer. TI recommends following good RF layout and grounding techniques to maximize the device performance.

8.2 Typical Application

LMH9135 is typically used in a four transmit and four receive (4T/4R) array of active antenna system for 5G, TDD, wireless base station applications. Such a system is shown in Figure 8-1, where the LMH9135 is used in the transmit path as an active balun that converts differential DAC output from Tx AFE to single-ended signal. Also shown in the figure is the application of LMH9235 chip, which is the counter-part of LMH9135 in the Receive path.

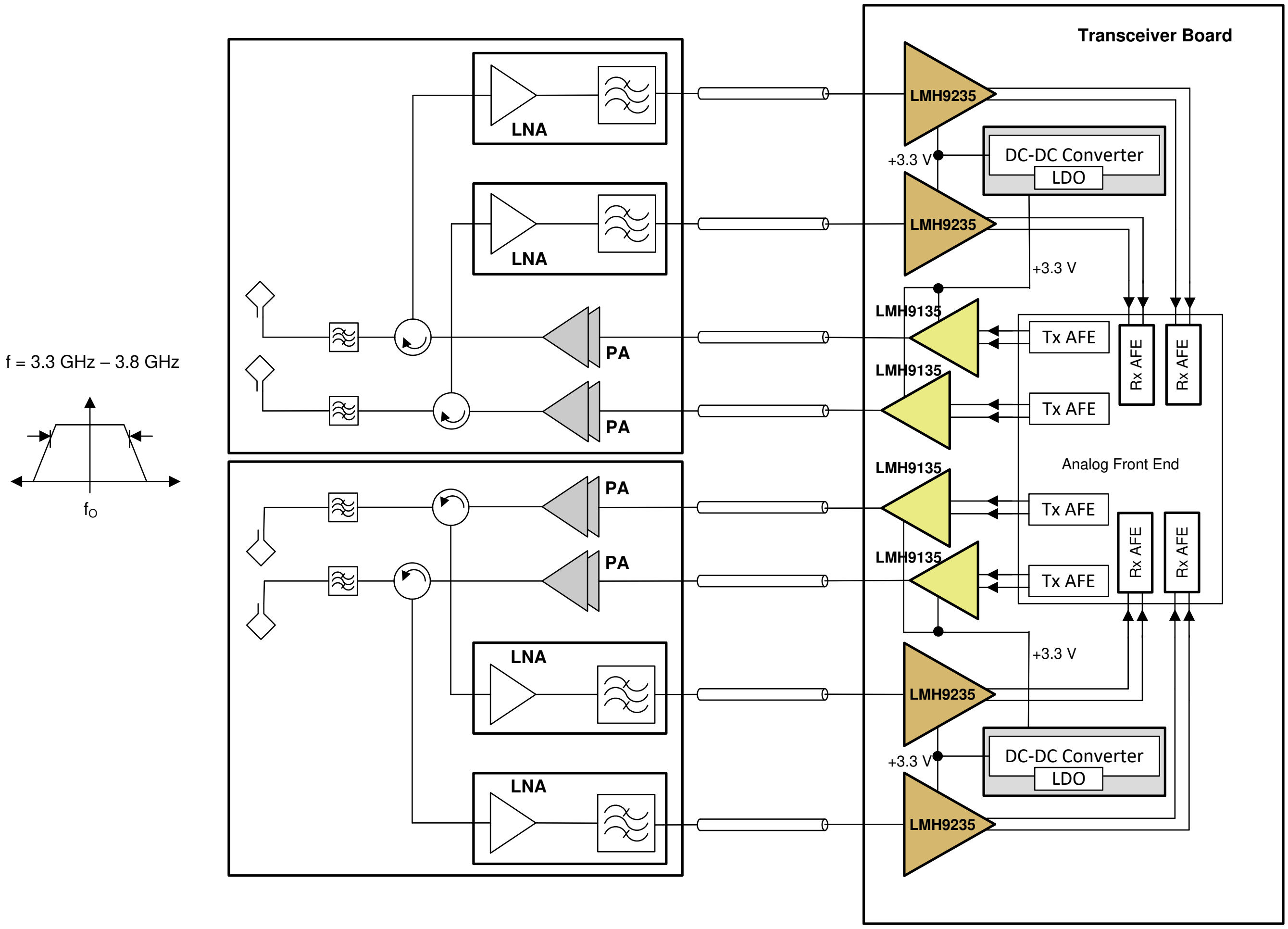


Figure 8-1. LMH9135 in a 4T/4R 5G Active Antenna System

The 4T/4R system can be scaled to 16T/16R, 64T/64R, or higher antenna arrays that result in proportional scaling of the overall system power dissipation. As a result of the proportional scaling factor for multiple channels in a system, the individual device power consumption must be reduced to dissipate less overall heat in the system. Operating on a single 3.3-V supply, the LMH9135 consumes only about 400 mW and therefore provides power saving to the customer. Multiple LMH9135 devices can be powered from a single DC/DC converter or a low-dropout regulator (LDO) operating on a 3.3-V supply. A DC/DC converter provides the most power efficient way of generating the 3.3-V supply. However, care must be taken when using the DC/DC converter to minimize the switching noise using inductor chokes and adequate isolation must be provided between the analog and digital power domains.

8.2.1 Design Requirements

Input of LMH9135 is matched to 100 Ω and therefore can be directly driven by a DAC that has 100 Ω source impedance without any external matching network. If a DAC with different impedance is used, then it should be appropriately matched to get the best RF performance.

The example in Figure 8-2 shows how LMH9135 can be matched to a DAC that has 200-Ω differential termination.

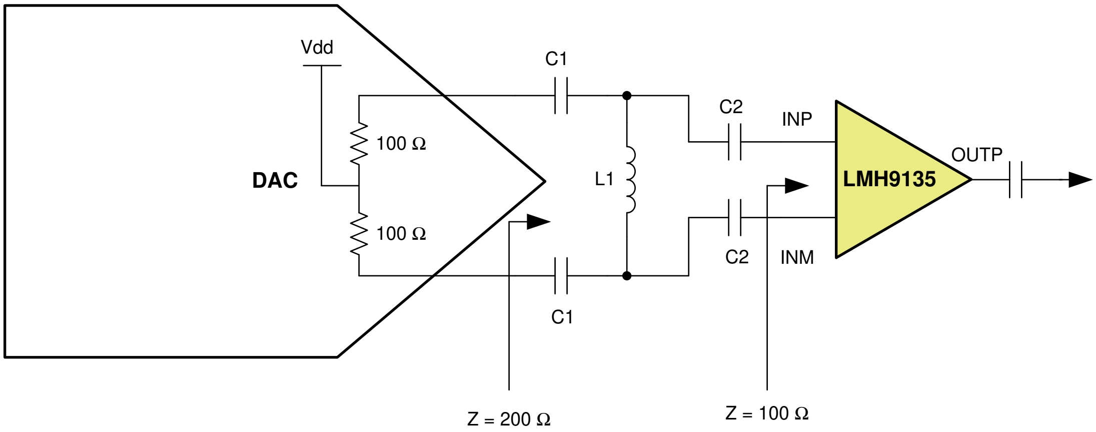


Figure 8-2. LMH9135 Driven by a DAC with 200-Ω Termination

8.2.2 Detailed Design Procedure

A simple differential LC network is used here as the matching network. In Figure 8-2, shunt inductor L1 and series capacitors C2 form the matching network. The series capacitors C1 act as the DC-blocking capacitors. Table 8-1 shows the matching network component values.

Table 8-1. Matching Network Component Values for 200-Ω Termination

COMPONENT	VALUE
C1	5.6 pF
L1	6.8 nH
C2	0.8 pF

8.2.3 Application Curves

The graphs given below show the gain, input return loss, and output return loss of the design with different DAC terminations.

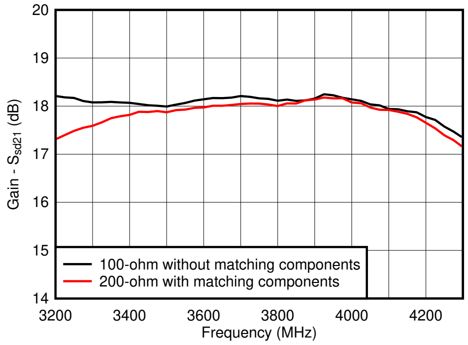


Figure 8-3. Gain vs Frequency for Different DAC Terminations

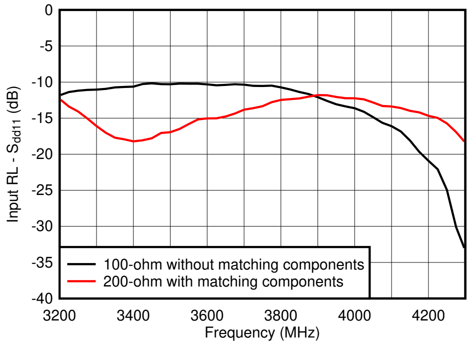


Figure 8-4. Input Return Loss vs Frequency for Different DAC Terminations

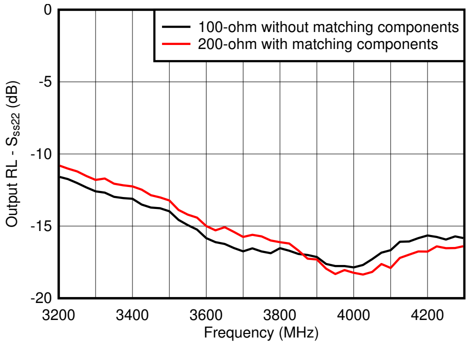


Figure 8-5. Output Return Loss vs Frequency for Different DAC Terminations

9 Power Supply Recommendations

The LMH9135 device operates on a common nominal 3.3 V supply voltage. It is recommended to isolate the supply voltage through decoupling capacitors placed close to the device. Select capacitors with self resonant frequency above the application frequency. When multiple capacitors are used in parallel to create a broadband decoupling network, place the capacitor with the higher self-resonant frequency closer to the device.

10 Layout

10.1 Layout Guidelines

When designing with an RF amplifier operating in the frequency range 3 GHz to 4.2 GHz with relatively high gain, certain board layout precautions must be taken to ensure stability and optimum performance. TI recommends that the LMH9135 board be multi-layered to improve thermal performance, grounding, and power-supply decoupling. Figure 10-1 shows a good layout example. In this figure, only the top signal layer is shown.

- Excellent electrical connection from the thermal pad to the board ground is essential. Use the recommended footprint, solder the pad to the board, and do not include a solder mask under the pad.
- Connect the pad ground to the device terminal ground on the top board layer.
- Ensure that ground planes on the top and any internal layers are well stitched with vias.
- Design the two input and one output RF traces for 50-Ω impedance. TI recommends grounded coplanar waveguide (GCPW) type transmission lines for the RF traces. Use a PCB trace width calculator tool to design the transmission lines.
- Avoid routing clocks and digital control lines near RF signal lines.
- Do not route RF or DC signal lines over noisy power planes.
- Place supply decoupling close to the device.
- The differential output traces must be symmetrical in order to achieve the best differential balance and linearity performance.

See the *LMH9135 Evaluation Module* user's guide for more details on board layout and design.

10.2 Layout Example

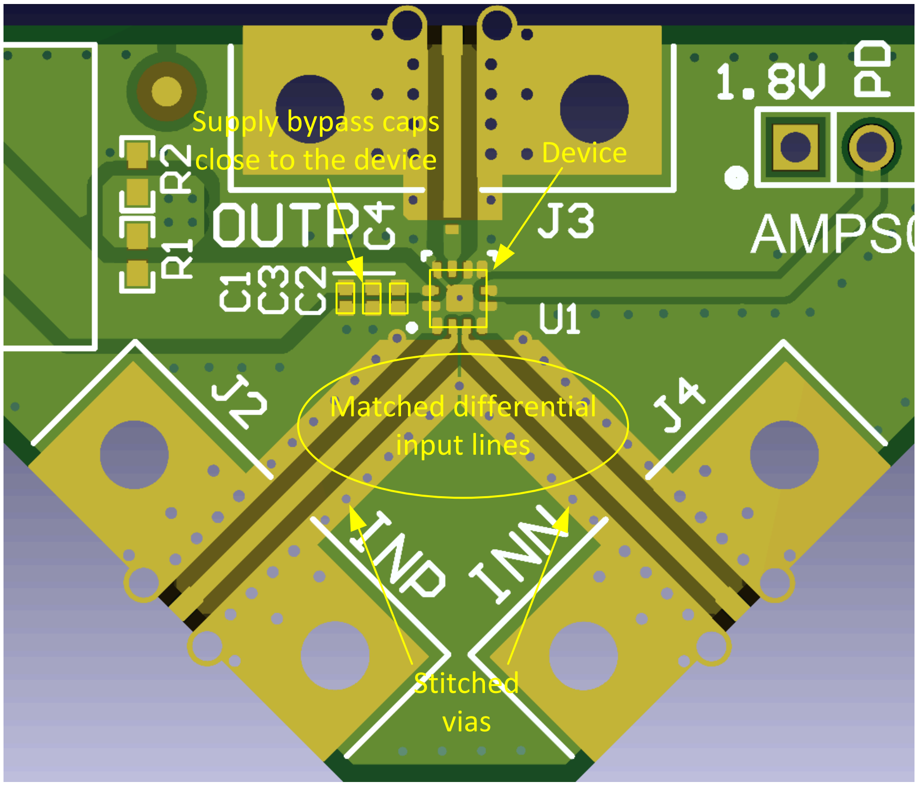


Figure 10-1. Layout Showing Matched Differential Traces and Supply Decoupling

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- Texas Instruments, LMH9135 Evaluation Module User's Guide
- Texas Instruments, LMH9135 S-parameter Models
- Texas Instruments, LMH9135RRLEVM EU Declaration of Conformity (DoC)

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 Support Resources

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

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

11.4 Trademarks

TI 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

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 part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LMH9135IRRLR	Active	Production	WQFN (RRL) | 12	3000 | LARGE T&R	Yes	NIPDAUAG	Level-2-260C-1 YEAR	-40 to 105	35AO
LMH9135IRRLR.B	Active	Production	WQFN (RRL) | 12	3000 | LARGE T&R	Yes	NIPDAUAG	Level-2-260C-1 YEAR	-40 to 105	35AO

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

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

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

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

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

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

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

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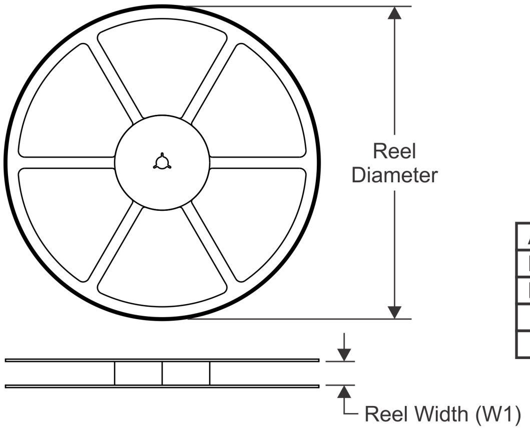
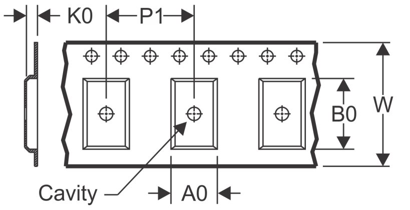
TAPE AND REEL INFORMATION

REEL DIMENSIONS

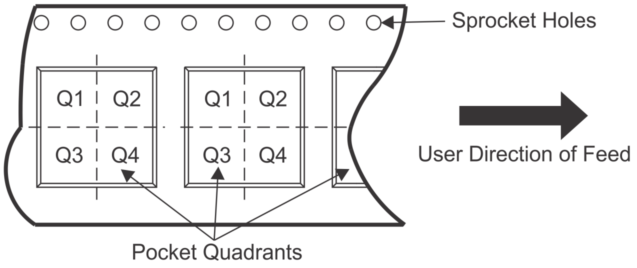


TAPE DIMENSIONS



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

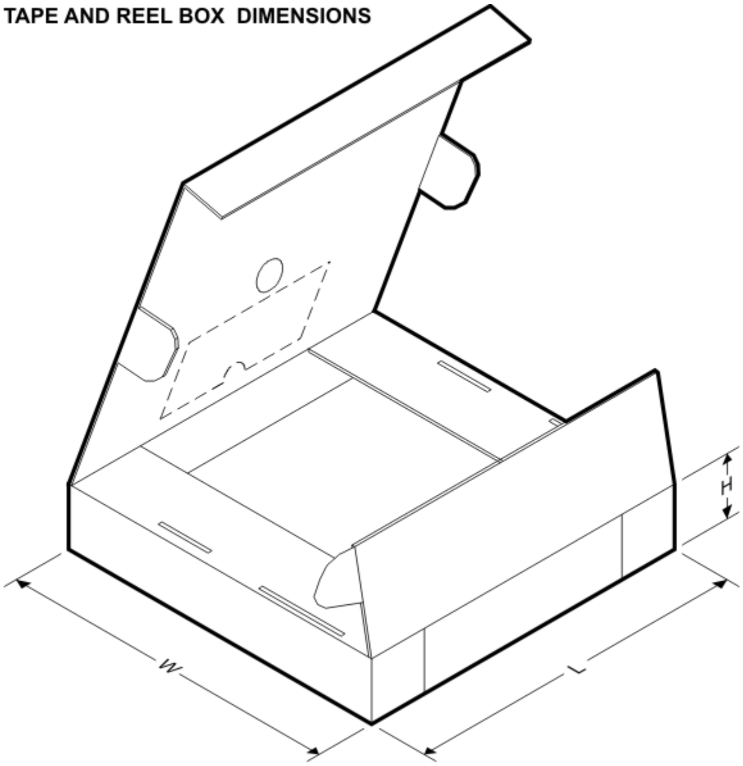
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

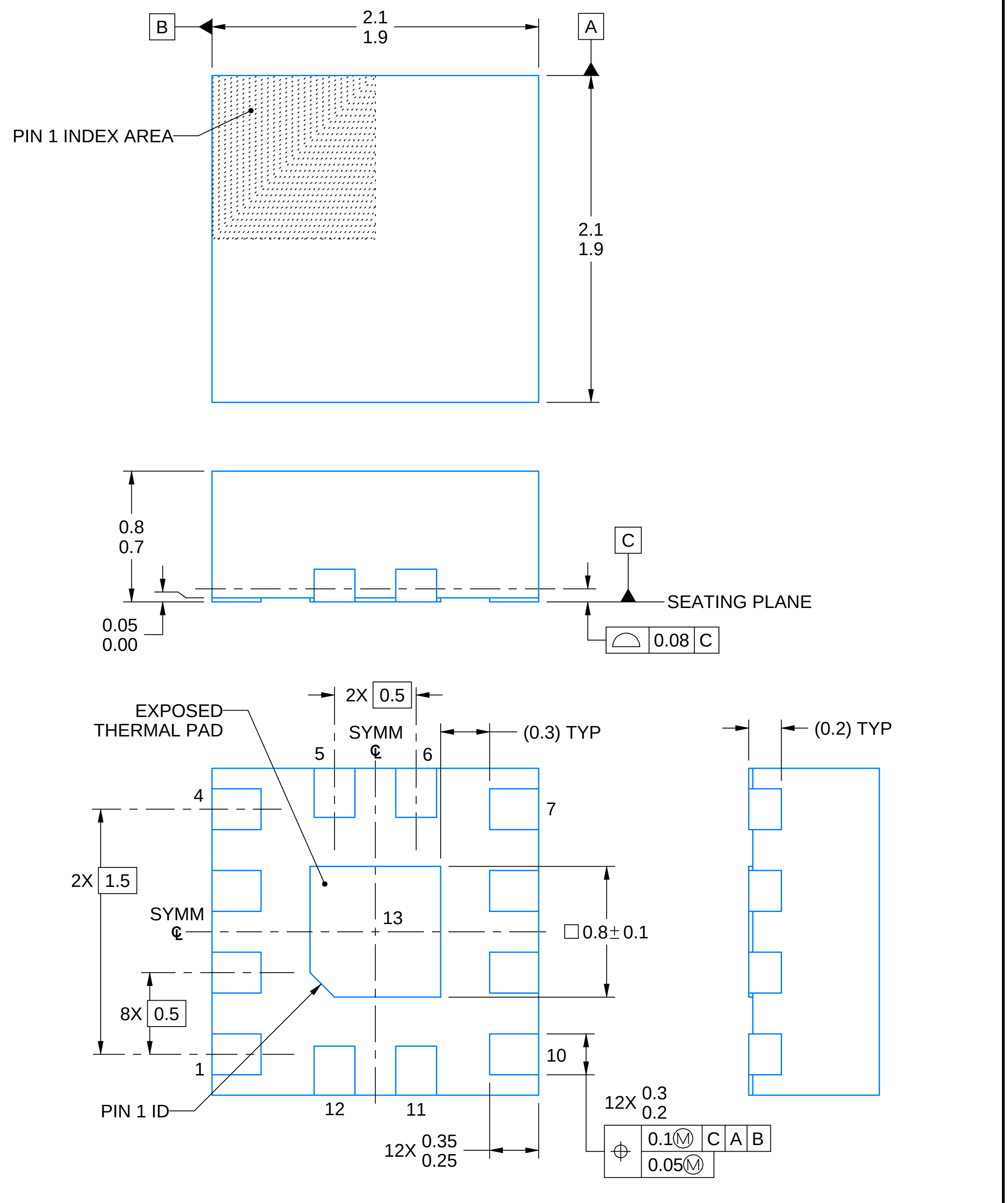
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LMH9135IRRLR	WQFN	RRL	12	3000	180.0	8.4	2.2	2.2	1.2	4.0	8.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMH9135IRRLR	WQFN	RRL	12	3000	213.0	191.0	35.0



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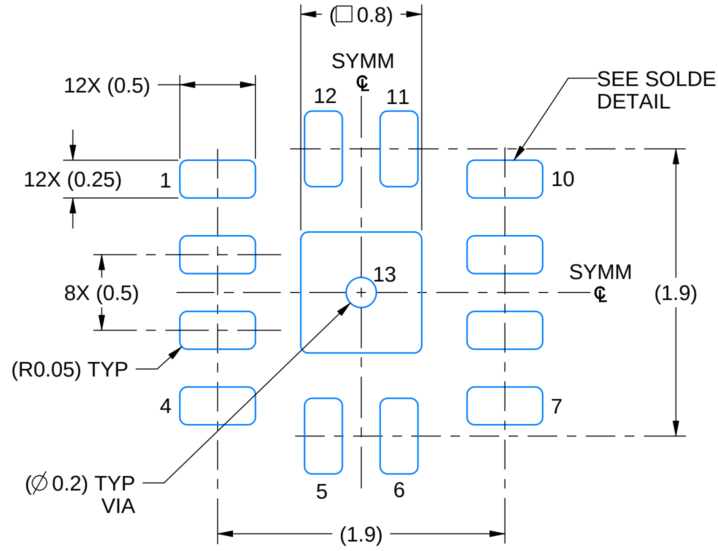
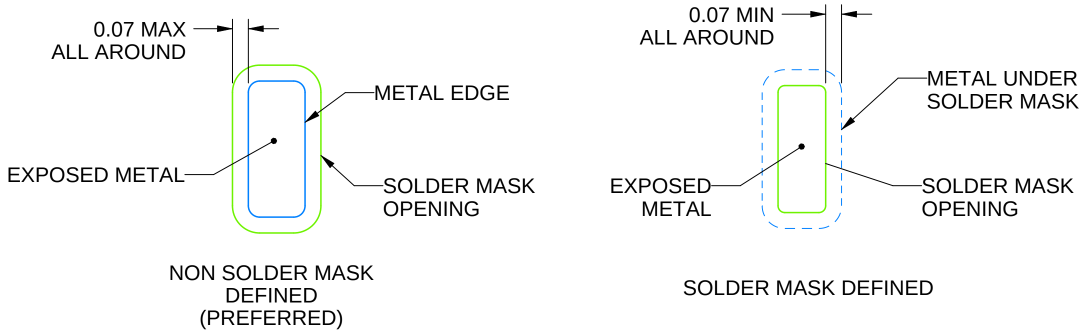
NOTES:

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



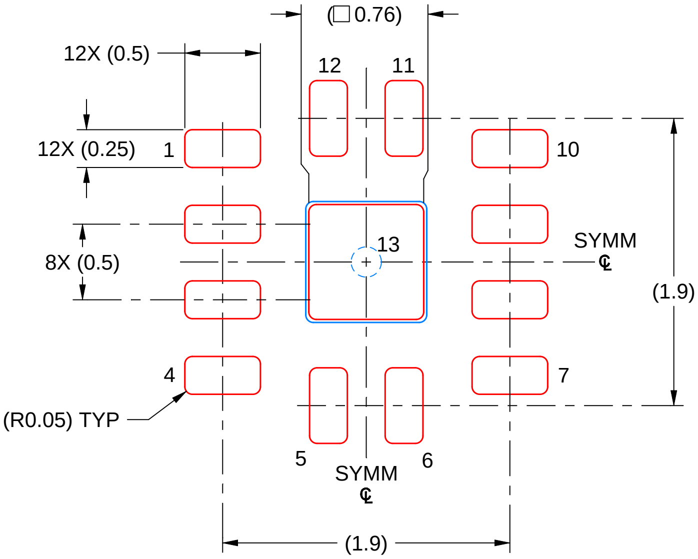
LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 20X



SOLDER MASK DETAILS

NOTES: (continued)

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



SOLDER PASTE EXAMPLE
BASED ON 0.125 MM THICK STENCIL
SCALE: 20X

EXPOSED PAD 13
90% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE

NOTES: (continued)

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

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