

## FEATURES

**Attenuation range: 0.5 dB (LSB) steps to 31.5 dB**

$\pm 0.5$  dB typical step error

**Low insertion loss: 2.8 dB at 4 GHz**

**High linearity at  $V_{EE} = -3$  V**

Input P0.1dB: 22 dBm typical

Input IP3: 45 dBm typical

**High RF input power handling: 25 dBm maximum**

**Low relative phase: 30° typical at 6.0 GHz**

**Single-supply operation:  $-3$  V to  $-5$  V**

**16-lead, 3 mm  $\times$  3 mm LFCSP package**

## APPLICATIONS

Cellular infrastructure

Microwave radios and very small aperture terminals (VSATs)

Test equipment and sensors

Intermediate frequency (IF) and RF designs

Military and space

## GENERAL DESCRIPTION

The HMC424ALP3E is a broadband, 6-bit, gallium arsenide (GaAs), digital attenuator in low cost, leadless surface-mount package with a 31.5 dB attenuation control range in 0.5 dB steps.

The HMC424ALP3E offers excellent attenuation accuracy of  $\pm(0.2$  dB + 4% of attenuation state) and high input linearity with a typical insertion loss of less than 4 dB over the specified frequency range from 0.1 GHz to 13.0 GHz. The attenuator bit values are 0.5 dB (LSB), 1 dB, 2 dB, 4 dB, 8 dB, and 16 dB for a total attenuation of 31.5 dB with a  $\pm 0.5$  dB typical step error.

## FUNCTIONAL BLOCK DIAGRAM

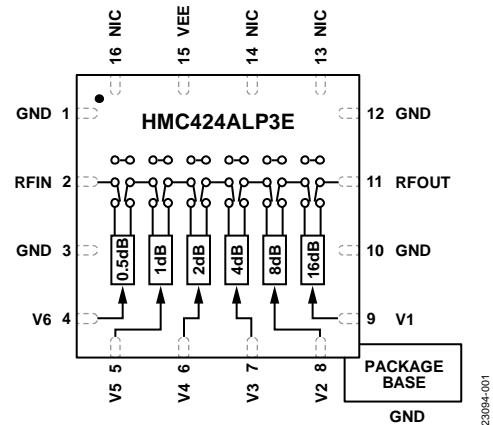


Figure 1.

The device allows a user to program the attenuation state via six parallel control inputs toggled between 0 V and  $V_{EE}$ .

The HMC424ALP3E operates with a single negative supply voltage from  $-3$  V to  $-5$  V, and requires an external level shifter to interface with a CMOS/transistor to transistor logic (TTL) interface.

The HMC424ALP3E comes in a RoHS compliant, compact, 3 mm  $\times$  3 mm, 16-lead lead frame chip scale package (LFCSP).

**TABLE OF CONTENTS**

Features ..... 1  
 Applications..... 1  
 Functional Block Diagram ..... 1  
 General Description ..... 1  
 Revision History ..... 2  
 Specifications..... 3  
 Absolute Maximum Ratings..... 4  
     Thermal Resistance ..... 4  
     ESD Caution..... 4  
 Pin Configuration and Function Descriptions..... 5  
     Interface Schematics..... 5  
 Typical Performance Characteristics ..... 6

Insertion Loss, Return Loss, State Error, Step Error, and  
 Relative Phase .....6  
 Input Power Compression and Third-Order Intercept.....8  
 Theory of Operation ..... 10  
     Power Supply..... 10  
     RF Input and Output ..... 10  
 Applications Information ..... 11  
     Evaluation Board ..... 11  
 Outline Dimensions ..... 13  
     Ordering Guide ..... 13

**REVISION HISTORY**

**9/2020—Rev. 00.1113 to Rev. A**

This Hittite Microwave Products data sheet has been reformatted to meet the styles and standards of Analog Devices, Inc.

Changed N/C to NIC ..... Throughout  
 Changes to Title, Features Section, Applications Section, and  
 General Description Section ..... 1  
 Changes to Table 1 ..... 3  
 Deleted Bias Voltage & Current Table and Control Voltage  
 Table; Renumbered Sequentially ..... 3  
 Changes to Table 2..... 4  
 Added Figure 2, Thermal Resistance Section, and Table 3;  
 Renumbered Sequentially..... 4  
 Added Figure 3 and Figure 4..... 5  
 Deleted GND Interface Schematic and N/C Interface Schematic... 5  
 Changes to Table 4 and Figure 5..... 5  
 Added Insertion Loss, Return Loss, State Error, Step Error, and  
 Relative Phase Section..... 6  
 Changes to Figure 7 to Figure 12..... 6

Added Figure 13 and Figure 14 .....7  
 Changes to Figure 15 and Figure 16 .....7  
 Added Input Power Compression and Third-Order Intercept  
 Section.....8  
 Added Figure 17 to Figure 22 .....8  
 Added Figure 23 to Figure 28 .....9  
 Added Theory of Operation Section, Power Supply Section, and  
 RF Input and Output Section..... 10  
 Changes to Figure 29 and Table 5 ..... 10  
 Added Applications Information Section ..... 11  
 Changed Evaluation PCB Section to Evaluation Board Section ... 11  
 Changes to Evaluation Board Section..... 11  
 Added Figure 31 ..... 12  
 Changes to Table 6..... 12  
 Updated Outline Dimensions ..... 13  
 Changes to Ordering Guide ..... 13

## SPECIFICATIONS

Supply voltage ( $V_{EE}$ ) = -3 V to -5 V, control input voltage ( $V_{CTL}$ ) = 0 V or  $V_{EE}$ ,  $T_{CASE}$  = 25°C, 50  $\Omega$  system, unless otherwise noted.

Table 1.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
FREQUENCY RANGE			0.1		13.0	GHz
INSERTION LOSS	IL	0.1 GHz to 4.0 GHz		2.8	3.3	dB
		4.0 GHz to 8.0 GHz		3.3	3.8	
		8.0 GHz to 13.0 GHz		3.9	4.4	dB
ATTENUATION		0.1 GHz to 13.0 GHz				
Range		Between minimum and maximum attenuation states		31.5		dB
Step Size		Between any successive attenuation states		0.5		dB
Step Error		Between any successive attenuation states		$\pm 0.5$		dB
State Error		All attenuation states, referenced to insertion loss state				
		0.1 GHz to 8.0 GHz	$-(0.2 + 4\%$ of attenuation state)		$+(0.2 + 4\%$ of attenuation state)	dB
		8.0 GHz to 13.0 GHz	$-(0.3 + 5\%$ of attenuation state)		$+(0.3 + 5\%$ of attenuation state)	dB
RETURN LOSS ( $R_{FIN}$ and $R_{FOUT}$ )		All attenuation states, 0.1 GHz to 13.0 GHz		13		dB
RELATIVE PHASE		Between minimum and maximum attenuation states				
		0.1 GHz to 6.0 GHz		30		Degrees
		6.0 GHz to 13.0 GHz		70		Degrees
SWITCHING CHARACTERISTICS		Between all attenuation states				
Rise and Fall Time	$t_{RISE}, t_{FALL}$	10% to 90% of RF output		30		ns
On and Off Time	$t_{ON}, t_{OFF}$	50% $V_{CTL}$ to 90% of RF output		50		ns
INPUT LINEARITY <sup>1</sup>		All attenuation states, 500 MHz to 6.0 GHz				
0.1 dB Compression	P0.1dB	$V_{EE} = -3$ V		22		dBm
		$V_{EE} = -5$ V		23		dBm
Third-Order Intercept	IP3	$V_{EE} = -3$ V to -5 V, 10 dBm per tone, 1 MHz spacing		45		dBm
SUPPLY CURRENT	$I_{DD}$	$V_{EE} = -3$ V to -5 V		2	5	mA
DIGITAL CONTROL INPUTS		V1 to V6				
Voltage						
Low	$V_{INL}$	$V_{EE} = -3$ V	-1.0		0	V
		$V_{EE} = -5$ V	-3.0		0	V
High	$V_{INH}$	$V_{EE} = -3$ V	-3.0		-2.2	V
		$V_{EE} = -5$ V	-5.0		-4.2	V
Current		$V_{EE} = -3$ V to -5 V				
Low	$I_{INL}$			35		$\mu$ A
High	$I_{INH}$			1		$\mu$ A

<sup>1</sup> Input linearity performance degrades at frequencies less than 250 MHz; see Figure 17 to Figure 28.

# ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Supply Voltage, $V_{EE}$	-7 V
Digital Control Input Voltage	$V_{EE} - 0.5$ V
RF Input Power <sup>1</sup> (All Attenuation States, $f = 800$ MHz to 13.0 GHz, $T_{CASE} = 85^{\circ}\text{C}$ , $V_{EE} = -3$ V to $-5$ V)	25 dBm
Continuous Power Dissipation, $P_{DISS}$ ( $T_{CASE} = 85^{\circ}\text{C}$ )	0.56 W
Temperature	
Junction, $T_J$	150°C
Storage	-65°C to +150°C
Reflow <sup>2</sup> ((Moisture Sensitivity Level 3 (MSL3) Rating)	260°C
ESD Sensitivity	
Human Body Model (HBM)	250 V (Class 1A)

<sup>1</sup> For power derating at frequencies less than 800 MHz, see Figure 2.

<sup>2</sup> See the Ordering Guide for more information.

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

Only one absolute maximum rating can be applied at any one time.

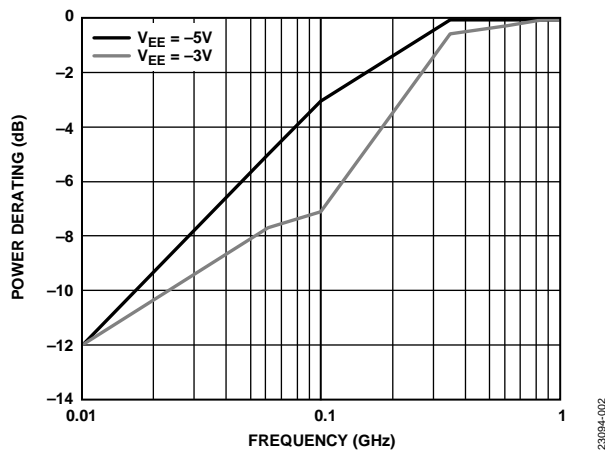


Figure 2. Power Derating at Frequencies Less than 0.8 GHz

## THERMAL RESISTANCE

Thermal performance is directly linked to printed circuit board (PCB) design and operating environment. Careful attention to PCB thermal design is required.

$\theta_{JC}$  is the junction to case thermal resistance.

Table 3. Thermal Resistance

Package Type	$\theta_{JC}$	Unit
CP-16-50 <sup>1</sup>	330	°C/W

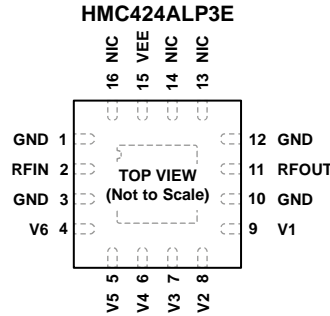
<sup>1</sup> Thermal impedance simulated values are based on a JEDEC 2S2P thermal test board with nine thermal vias. See JEDEC JESD51.

## ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

# PIN CONFIGURATION AND FUNCTION DESCRIPTIONS



**NOTES**  
 1. NIC = NOT INTERNALLY CONNECTED. NIC CAN BE CONNECTED TO GROUND.  
 2. EXPOSED PAD. THE EPAD MUST BE CONNECTED TO GROUND.

23094-003

Figure 3. Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1, 3, 10, 12	GND	Ground. These pins must be connected to ground.
2	RFIN	Attenuator RF Input. This pin is dc-coupled and ac matched to 50 Ω. An external dc blocking capacitor is required if the RF line potential is not equal to 0V.
4 to 9	V1 to V6	Parallel Control Voltage Inputs. These pins select the required attenuation (see Table 5). There is an internal pull-down resistor on these pins to V <sub>EE</sub> .
11	RFOUT	Attenuator RF Output. This pin is dc-coupled and ac matched to 50 Ω. An external dc blocking capacitor is required if the RF line potential is not equal to 0V.
13, 14, 16	NIC	Not Internally Connected. NIC can be connected to ground.
15	VEE	Power Supply.
	EPAD	Exposed Pad. The EPAD must be connected to ground.

## INTERFACE SCHEMATICS

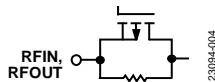


Figure 4. RFIN, RFOUT Interface Schematic

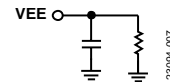


Figure 6. VEE Pin Interface

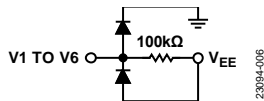


Figure 5. V1 to V6 Pin Interface Schematic

# TYPICAL PERFORMANCE CHARACTERISTICS

## INSERTION LOSS, RETURN LOSS, STATE ERROR, STEP ERROR, AND RELATIVE PHASE

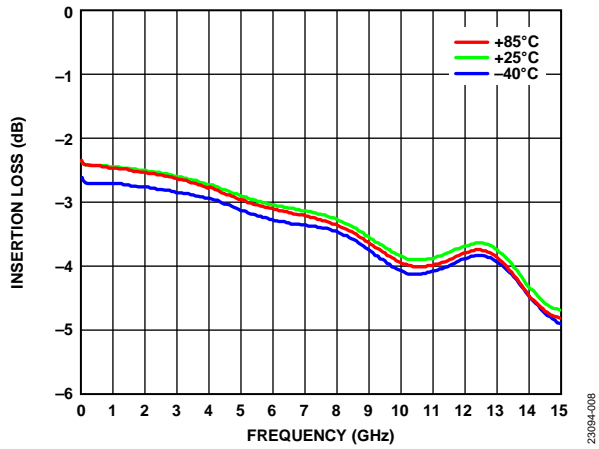


Figure 7. Insertion Loss vs. Frequency over Temperature

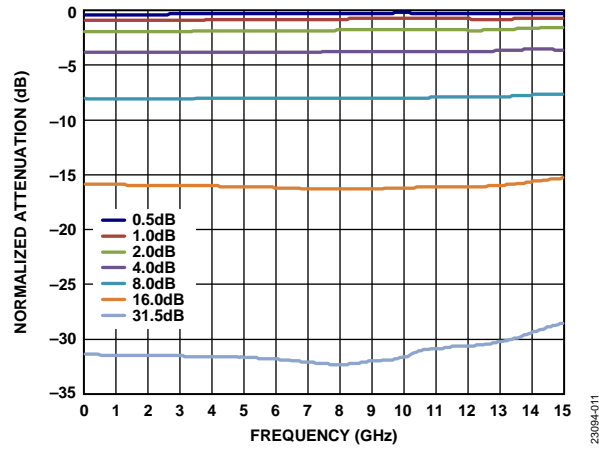


Figure 10. Normalized Attenuation vs. Frequency over Major Attenuation States

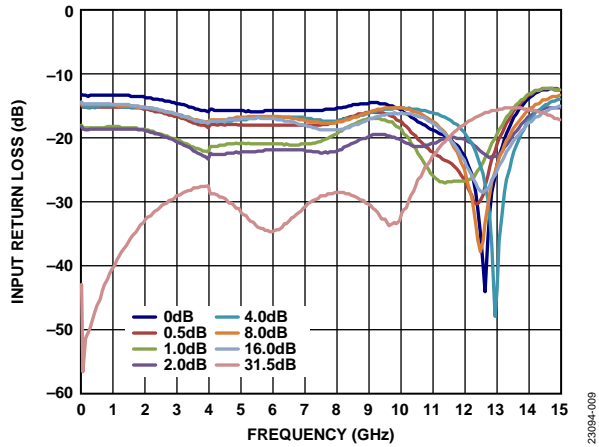


Figure 8. Input Return Loss vs. Frequency over Major Attenuation States

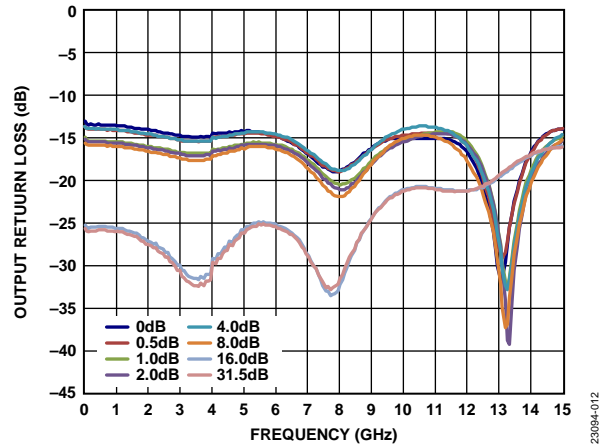


Figure 11. Output Return Loss vs. Frequency over Major Attenuation States

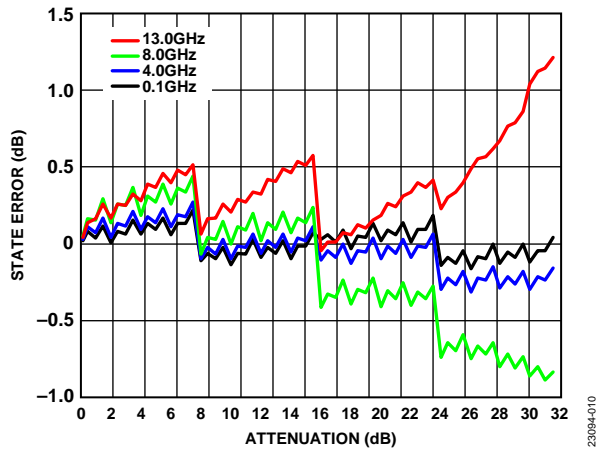


Figure 9. State Error vs. Attenuation over Frequency

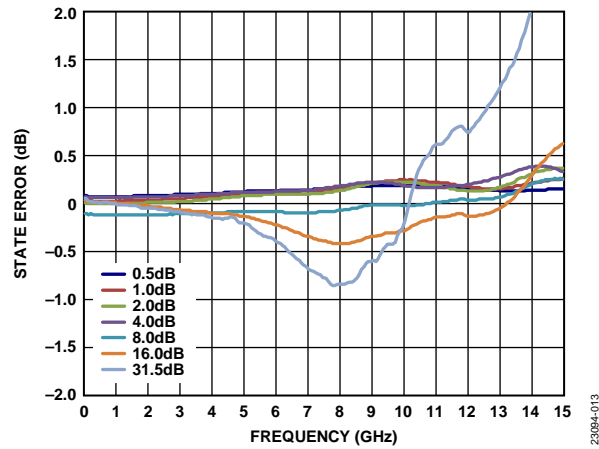


Figure 12. State Error vs. Frequency over Major Attenuation States

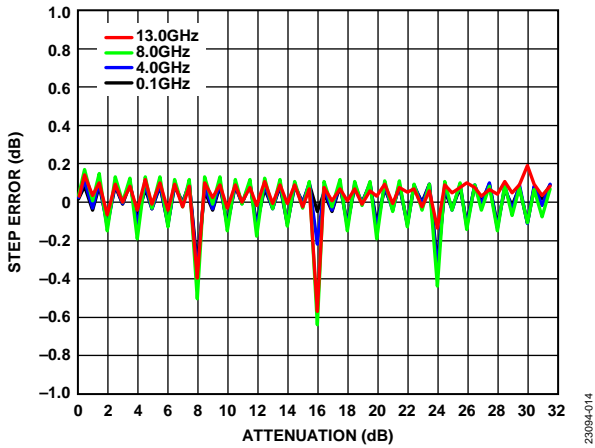


Figure 13. Step Error vs. Attenuation over Frequency

23094-014

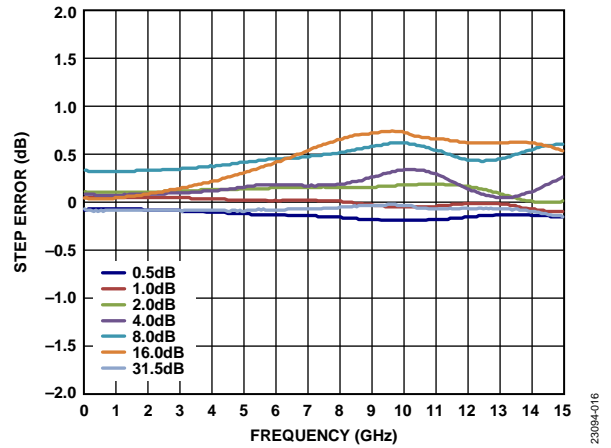


Figure 15. Step Error vs. Frequency over Major Attenuation States

23094-016

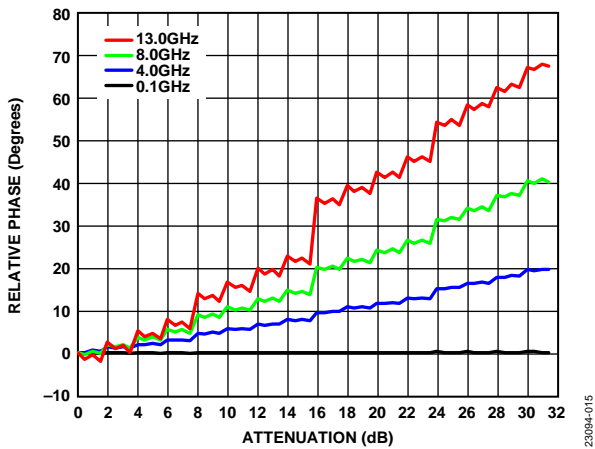


Figure 14. Relative Phase vs. Attenuation over Frequency

23094-015

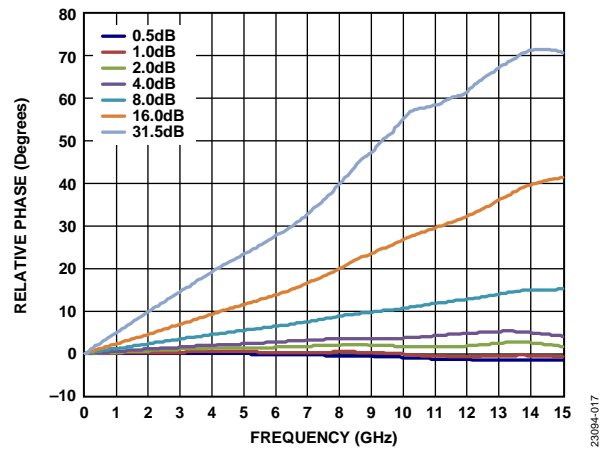
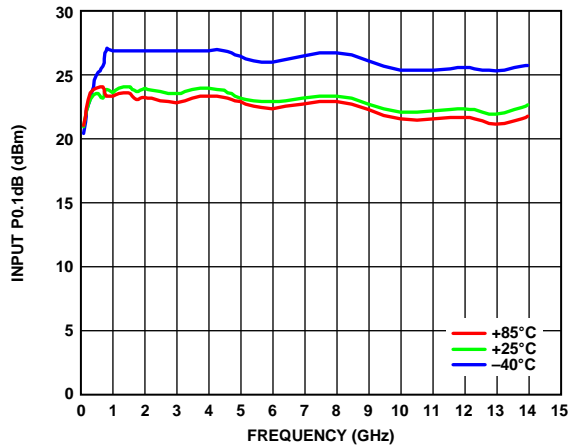


Figure 16. Relative Phase vs. Frequency over Major Attenuation States

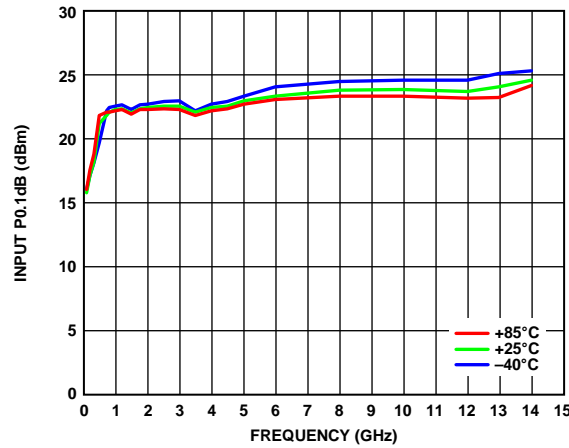
23094-017

INPUT POWER COMPRESSION AND THIRD-ORDER INTERCEPT



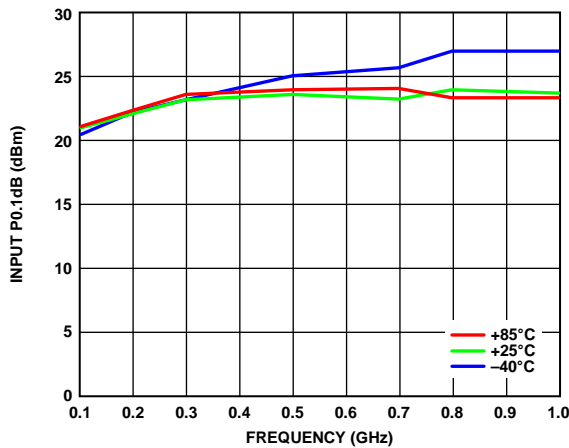
23094-018

Figure 17. Input P0.1dB vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -5 V$



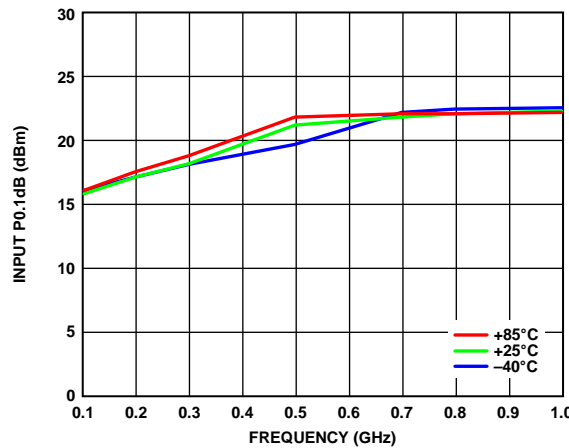
23094-101

Figure 20. Input P0.1dB vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -3 V$



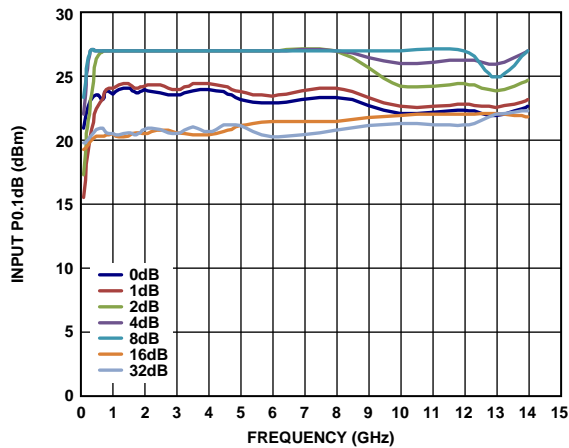
23094-019

Figure 18. Input P0.1dB vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -5 V$  (Low Frequency Detail)



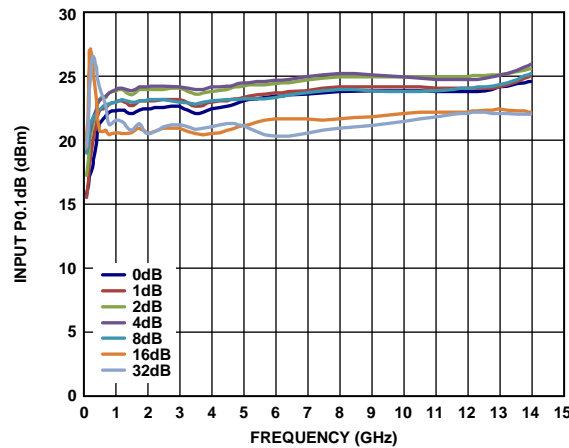
23094-102

Figure 21. Input P0.1dB vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -3 V$  (Low Frequency Detail)



23094-020

Figure 19. Input P0.1dB vs. Frequency over Major Attenuation States,  $V_{EE} = -5 V$



23094-023

Figure 22. Input P0.1dB vs. Frequency over Major Attenuation States,  $V_{EE} = -3 V$



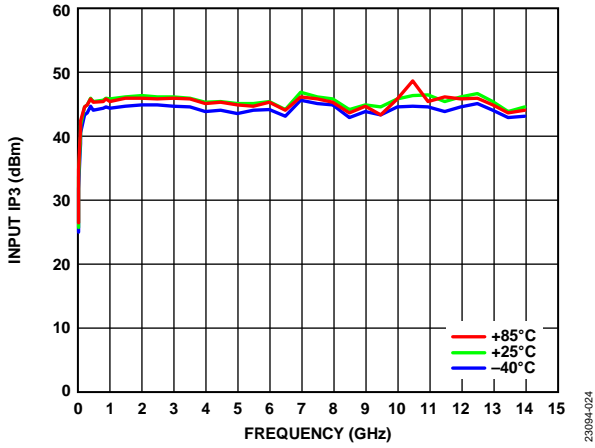


Figure 23. Input IP3 vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -5 V$

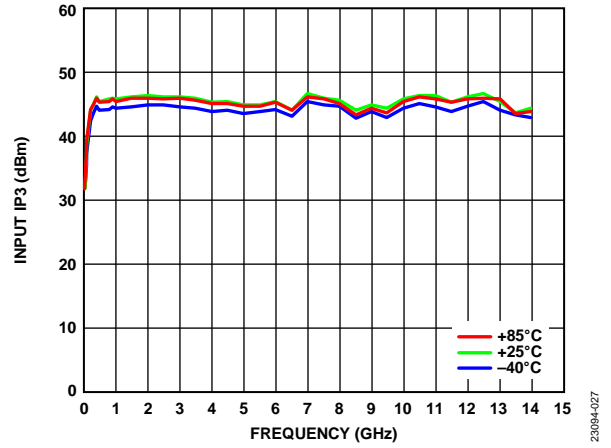


Figure 26. Input IP3 vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -3 V$

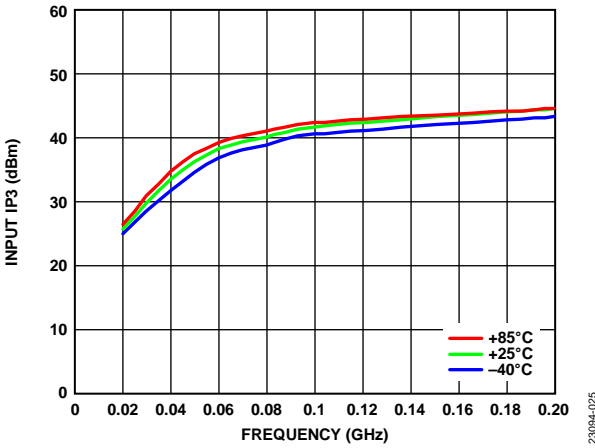


Figure 24. Input IP3 vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -5 V$  (Low Frequency Detail)

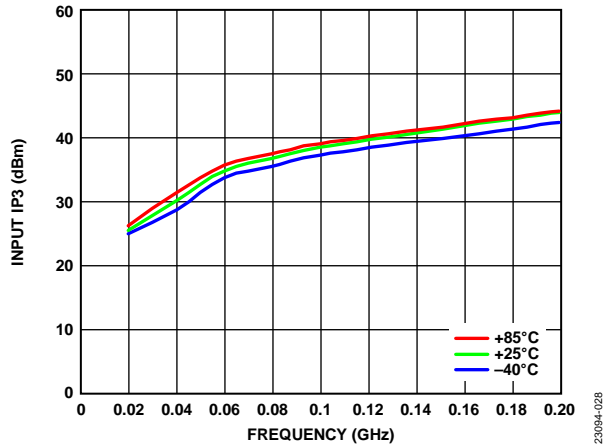


Figure 27. Input IP3 vs. Frequency at Minimum Attenuation State over Temperature,  $V_{EE} = -3 V$  (Low Frequency Detail)

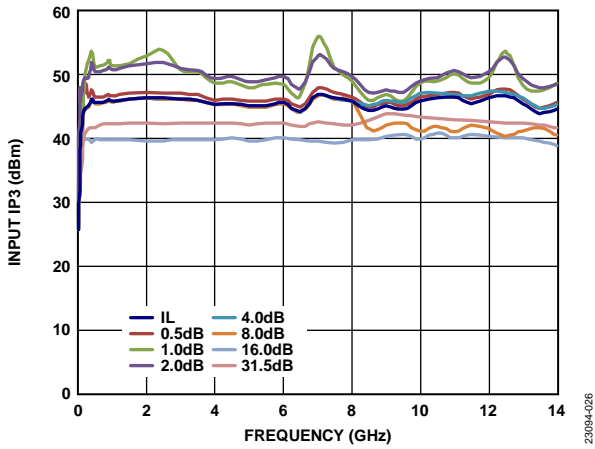


Figure 25. Input IP3 vs. Frequency over Major Attenuation States,  $V_{EE} = -5 V$

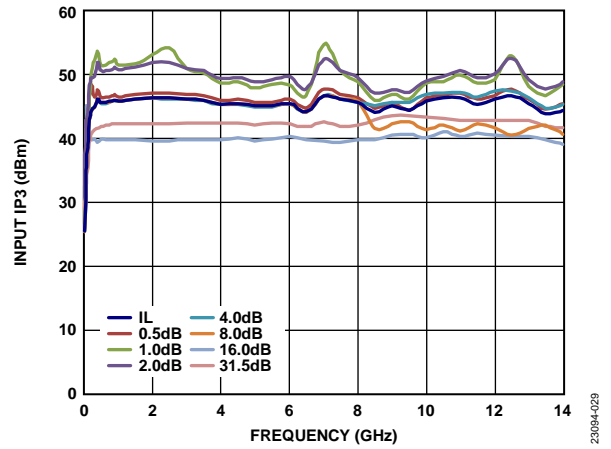


Figure 28. Input IP3 vs. Frequency over Major Attenuation States,  $V_{EE} = -3 V$

## THEORY OF OPERATION

The HMC424ALP3E incorporates a 6-bit attenuator die that offers an attenuation range of 31.5 dB in 0.5 dB steps. The attenuation state is changed by the parallel control voltage inputs (V1 to V6) directly (see Table 5).

The HMC424ALP3E allows the user to program the attenuation state via six parallel control inputs toggled between 0 V and V<sub>EE</sub>. When interfacing with a TTL/CMOS interface, an external level shifter is required. For example, a simple driver using standard logic ICs provides fast switching while using minimum dc current. The series resistance is recommended to suppress unwanted RF signals at the input of the V1 to V6 control lines.

### POWER SUPPLY

The HMC424ALP3E requires a single dc voltage applied to the VEE pin. The ideal power-up sequence is as follows:

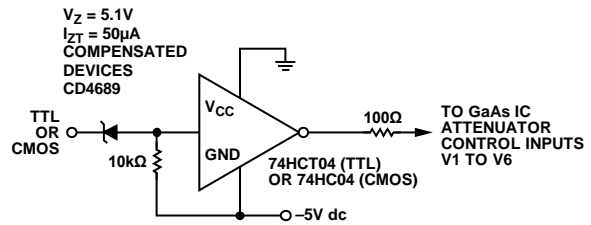
1. Connect the ground reference.
2. Apply a supply voltage to the VEE pin.
3. Power up the digital control inputs. The relative order of the digital control inputs is not important.
4. Apply an RF input signal to RFIN.

The power-down sequence is the reverse of the power-up sequence.

### RF INPUT AND OUTPUT

The attenuator in the HMC424ALP3E is bidirectional. The RFIN and RFOUT pins are interchangeable as the RF input and output ports. The attenuator is internally matched to 50 Ω at both the input and the output. Therefore, no external matching components are required.

The RF input and output pins of the HMC424ALP3E are internally dc biased to 0 V. Therefore, they require external dc blocking capacitors if the RF line potential is not equal to 0 V. Select the value of these dc blocking capacitors based on the minimum operating frequency. Use larger value capacitors to extend the operation to lower frequencies.



NOTE  
CD4689 IS A ZENER DIODE. V<sub>Z</sub> IS THE ZENER VOLTAGE, AND I<sub>ZT</sub> IS THE ZENER TEST CURRENT.

Figure 29. Suggested Driver Circuit

23094-030

Table 5. V1 to V6 Truth Table

Control Voltage Input <sup>1</sup>						Attenuation State, RFIN to RFOUT
V1 (16 dB)	V2 (8 dB)	V3 (4 dB)	V4 (2 dB)	V5 (1 dB)	V6 (0.5 dB)	
Low	Low	Low	Low	Low	Low	Reference insertion loss
Low	Low	Low	Low	Low	High	0.5 dB
Low	Low	Low	Low	High	Low	1 dB
Low	Low	Low	High	Low	Low	2 dB
Low	Low	High	Low	Low	Low	4 dB
Low	High	Low	Low	Low	Low	8 dB
High	Low	Low	Low	Low	Low	16 dB
High	High	High	High	High	High	31.5 dB

<sup>1</sup> Any combination of the control voltage input states shown in Table 5 provides an attenuation equal to the sum of the bits selected.

## APPLICATIONS INFORMATION

### EVALUATION BOARD

The HMC424ALP3E uses a 4-layer evaluation board. The copper thickness is 0.5 oz (0.7 mil) on each layer. The top dielectric material is 10 mil Rogers RO4350 for optimal high frequency performance, whereas the middle and bottom dielectric materials are FR4 type materials to achieve an overall board thickness of 62 mil. RF traces are routed on the top copper layer, and the bottom layer is a grounded plane that provides a solid ground for the RF transmission lines. The RF transmission lines are designed using a coplanar waveguide (CPWG) model with a width of 16 mil and ground spacing of 13 mil to have a characteristic impedance of 50  $\Omega$ . For enhanced RF and thermal grounding, as many plated through vias as possible are arranged around transmission lines and under the exposed pad of the package.

Figure 30 shows the top view of the populated HMC424ALP3E evaluation board, available from Analog Devices, Inc., upon request (see the Ordering Guide section).

The evaluation board is grounded from the dc pin, J3, and the dc supply must be connected to Pin 8 (GND) of J3. A 0.1 nF decoupling capacitor is placed on the supply trace to filter high frequency noise. The device can be supplied with either  $V_{EE} = -3$  V or  $V_{EE} = -5$  V. The control pins, V1 to V6, are also on the J3 connector, and they require 0 V or  $V_{EE}$  for programming. Series 100  $\Omega$  are placed between each control pin and the connector to suppress the unwanted RF signals.

The RF input and output ports (RFIN and RFOUT) are connected through 50  $\Omega$  transmission lines to the Subminiature Version A (SMA) connectors, J1 and J2, respectively. A thru calibration line is used to estimate the loss of the PCB over the environmental conditions being evaluated. A matching structure at the connector interface helps with matching of the connector.

Figure 31 and Table 6 show the evaluation board schematic and bill of materials, respectively.

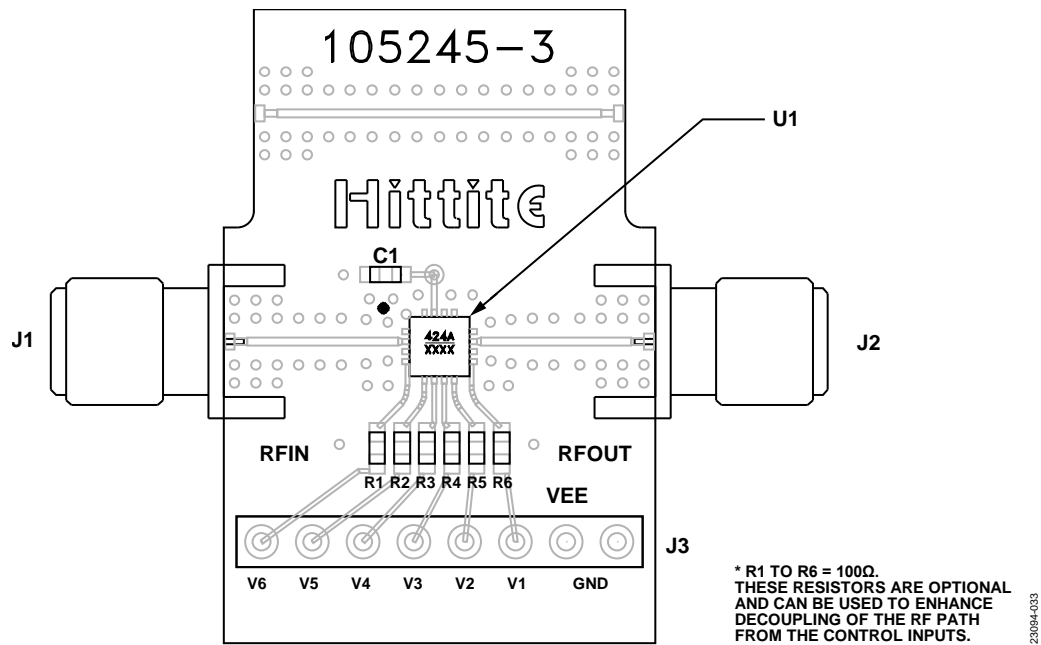


Figure 30. Populated Evaluation Board—Top View

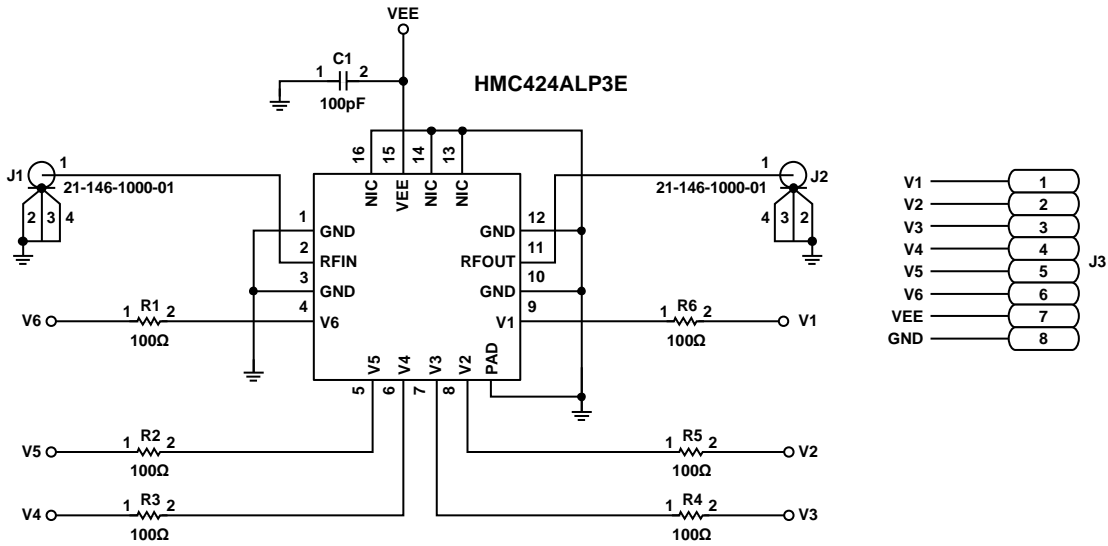


Figure 31. Evaluation Board Schematic

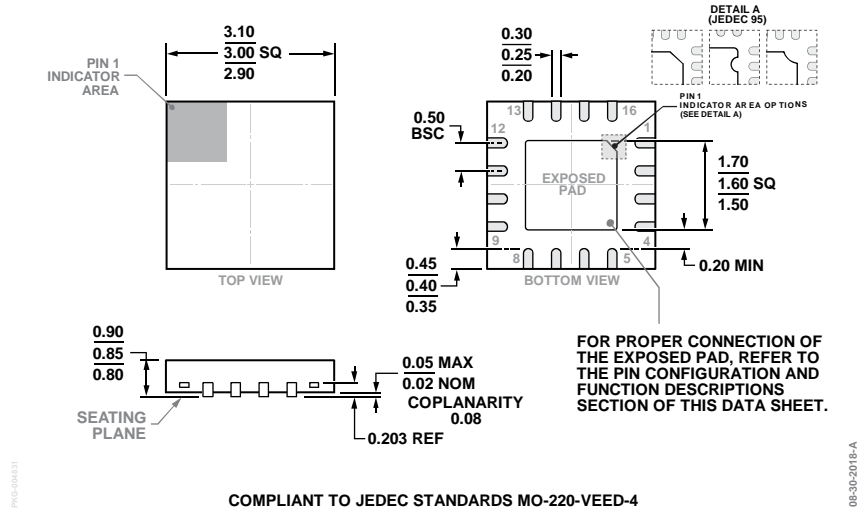
23094-034

Table 6. Evaluation Board Bill of Materials

Reference Designator	Description
J1, J2	PCB mount SMA connector
J3	8-pin dc connector
C1	0.1 μF capacitor, 0603 package
R1 to R6	100 Ω resistors, 0603 package
U1	HMC424ALP3E digital attenuator
PCB <sup>1</sup>	EV1HMC424ALP3 evaluation PCB

<sup>1</sup> Circuit board material: Rogers RO4350.

# OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-220-VEED-4

Figure 32. 16-Lead Lead Frame Chip Scale Package [LFCSP]  
 3 mm × 3 mm Body and 0.85 mm Package Height  
 (CP-16-50)  
 Dimensions shown in millimeters

## ORDERING GUIDE

Model <sup>1</sup>	Temperature Range	MSL Rating <sup>2</sup>	Package Description	Package Option	Marking Code <sup>3</sup>
HMC424ALP3E	-40°C to +85°C	MSL3	16-Lead Lead Frame Chip Scale Package [LFCSP]	CP-16-50	H424A XXXX
HMC424ALP3ETR	-40°C to +85°C	MSL3	16-Lead Lead Frame Chip Scale Package [LFCSP]	CP-16-50	H424A XXXX
EV1HMC424ALP3			Evaluation Board		

<sup>1</sup> The HMC424ALP3E, HMC424ALP3ETR, and EV1HMC424ALP3 are RoHS compliant.  
<sup>2</sup> See the Absolute Maximum Ratings section.  
<sup>3</sup> XXXX is the 4-digit lot number.