

### 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 typical at 4.0 GHz

**High linearity at  $V_{EE} = -5$  V**

**Input P0.1dB:** 25 dBm typical

**Input IP3:** 45 dBm typical

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

**Low relative phase:**  $30^\circ$  at 6.0 GHz

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

**Die size:** 1.390 mm  $\times$  0.770 mm  $\times$  0.102 mm

### APPLICATIONS

Cellular infrastructure

Microwave radios and very small aperture terminals (VSATs)

Test equipment and sensors

Intermediate frequency (IF) and RF designs

Military and space

### FUNCTIONAL BLOCK DIAGRAM

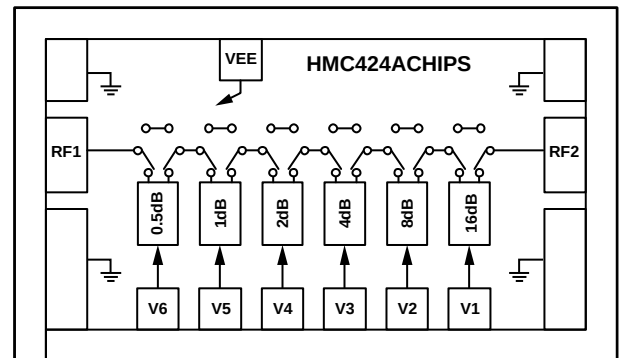


Figure 1.

### GENERAL DESCRIPTION

The HMC424ACHIPS is a broadband, 6-bit, gallium arsenide (GaAs), digital attenuator monolithic microwave integrated circuit (MMIC) chip with a 31.5 dB attenuation control range in 0.5 dB steps.

The HMC424ACHIPS offers excellent attenuation accuracy of  $\pm(0.2 \text{ dB} + 3\% \text{ of attenuation state})$  and high input linearity over the specified frequency range from 0.1 GHz to 13.0 GHz with a typical insertion loss of  $\leq 4.2$  dB. 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 of typical step error.

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

The HMC424ACHIPS operates with a single negative supply voltage from  $-3$  V to  $-5$  V, and requires an external driver to interface with a CMOS/transistor to transistor logic (TTL) interface.

The HMC424ACHIPS comes in a RoHS compliant, 9-pad bare die.

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## REVISION HISTORY

### 3/2020—Rev. 01.1115 to Rev. B

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

|                                                                                                                                 |   |
|---------------------------------------------------------------------------------------------------------------------------------|---|
| Changes to Title, Features Section, Applications Section, and General Description Section .....                                 | 1 |
| Changes to Table 1 .....                                                                                                        | 3 |
| Added Table 2, Figure 2, Thermal Resistance Section, and Table 3; Renumbered Sequentially .....                                 | 4 |
| Changes to Table 2 .....                                                                                                        | 4 |
| Deleted Bias Voltage & Current Table and Control Voltage Table; Renumbered Sequentially .....                                   | 5 |
| Added Figure 3, Table 4, and Figure 4 .....                                                                                     | 5 |
| Changes to Figure 5 .....                                                                                                       | 5 |
| Added Insertion Loss, Return Loss, State Error, Step Error, and Relative Phase Section, Figure 8, Figure 9, and Figure 12 ..... | 6 |
| Changes to Figure 7, Figure 10, and Figure 11 .....                                                                             | 6 |
| Added Figure 13, Figure 14, and Figure 16 .....                                                                                 | 7 |
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| Deleted Handling Precautions Section, Mounting Section, and Wire Bonding Section .....                                       | 7  |
| Added Input Power Compression and Third-Order Intercept Section, Figure 18 to Figure 20, and Figure 22 .....                 | 8  |
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## 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                                         |                                  | 3.4  | 4.0                              | dB      |
|                              |                      | 8.0 GHz to 13.0 GHz                                        |                                  | 4.2  | 4.6                              | 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                  |                                  | ±0.5 |                                  | dB      |
| State Error                  |                      | All attenuation states, referenced to insertion loss state |                                  |      |                                  |         |
|                              |                      | 0.1 GHz to 8.0 GHz                                         | -(0.2 + 3% of attenuation state) |      | +(0.2 + 3% of attenuation state) | dB      |
|                              |                      | 8.0 GHz to 13.0 GHz                                        | -(0.2 + 4% of attenuation state) |      | +(0.2 + 4% of attenuation state) | dB      |
| RETURN LOSS (RF1 AND RF2)    |                      | All attenuation states, 0.1 GHz to 13.0 GHz                |                                  | 12   |                                  | 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                                            |                                  | 23   |                                  | dBm     |
|                              |                      | $V_{EE} = -5$ V                                            |                                  | 25   |                                  | dBm     |
| Third-Order Intercept        | IP3                  | $V_{EE} = -5$ V, 10 dBm per tone, 1 MHz spacing            |                                  | 45   |                                  | dBm     |
|                              |                      | $V_{EE} = -3$ V, 10 dBm per tone, 1 MHz spacing            |                                  | 35   |                                  | 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, Figure 21, and Figure 22.

## 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,<br>$f = 0.8$ to $13.0$ GHz, $T_{CASE} = 85^{\circ}\text{C}$ ,<br>$V_{EE} = -3$ V to $-5$ V) | 25 dBm           |
| Continuous Power Dissipation, $P_{DISS}$<br>( $T_{CASE} = 85^{\circ}\text{C}$ )                                                                  | 0.56 W           |
| Temperature                                                                                                                                      |                  |
| Junction, $T_J$                                                                                                                                  | 150°C            |
| Storage                                                                                                                                          | -65°C to +150°C  |
| ESD Sensitivity, Human Body Model<br>(HBM)                                                                                                       | 250 V (Class 1A) |

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

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.

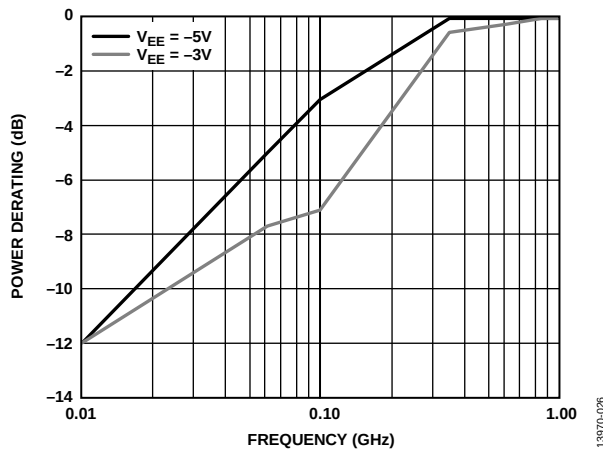


Figure 2. Power Derating at Frequencies Less than 0.8 GHz

## 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 |
|--------------------|---------------|------|
| C-9-2 <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

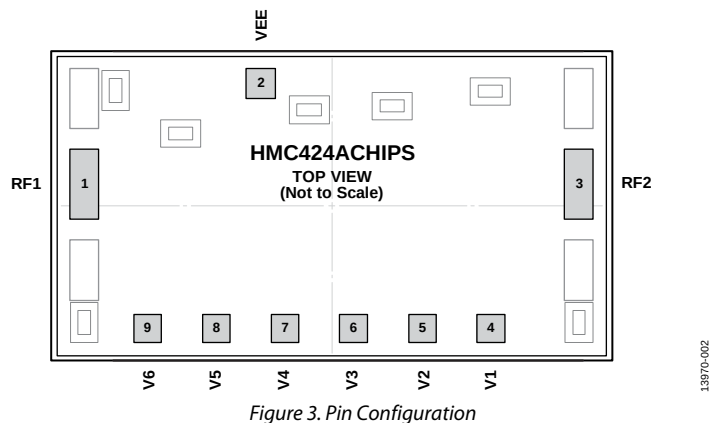


Figure 3. Pin Configuration

Table 4. Pin Function Descriptions

| Pad No. | Mnemonic | Description                                                                                                                                                              |
|---------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | RF1      | Attenuator RF Input. This pin is dc-coupled and ac matched to 50 $\Omega$ . An external dc blocking capacitor is required if the RF line potential is not equal to 0 V.  |
| 2       | VEE      | Power Supply.                                                                                                                                                            |
| 3       | RF2      | Attenuator RF Output. This pin is dc-coupled and ac matched to 50 $\Omega$ . An external dc blocking capacitor is required if the RF line potential is not equal to 0 V. |
| 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> .    |

## INTERFACE SCHEMATICS

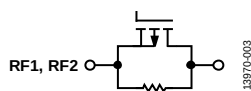


Figure 4. RF1 and RF2 Interface Schematic

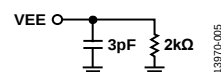


Figure 6. VEE Interface Schematic

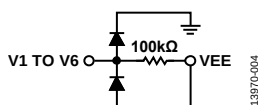
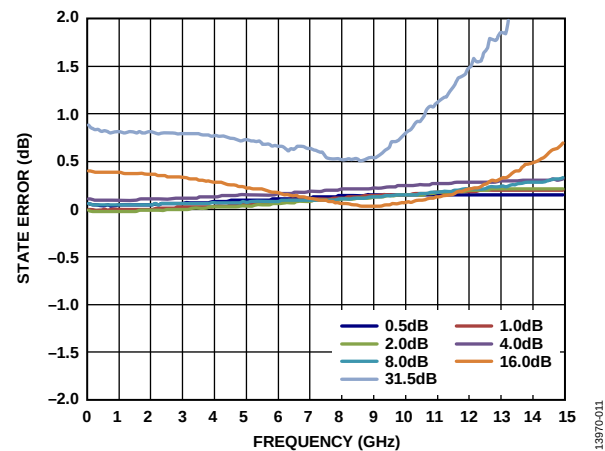
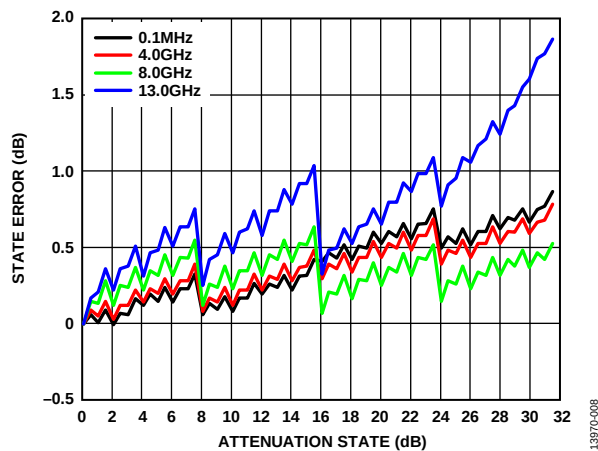
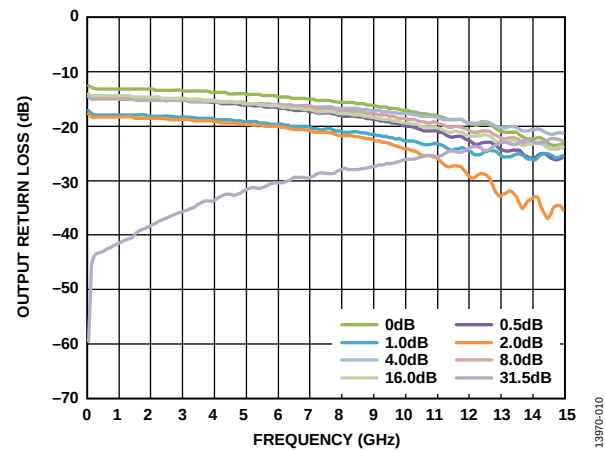
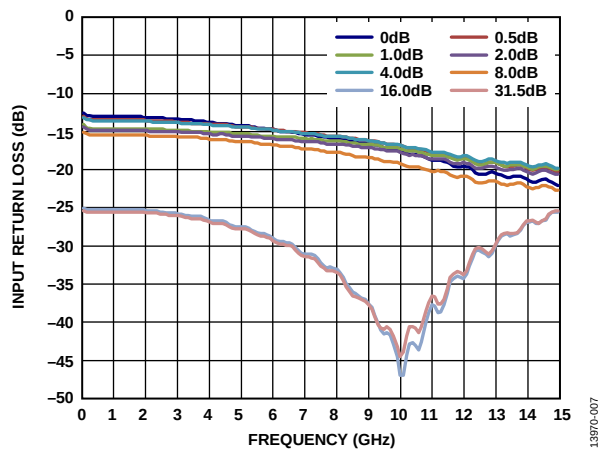
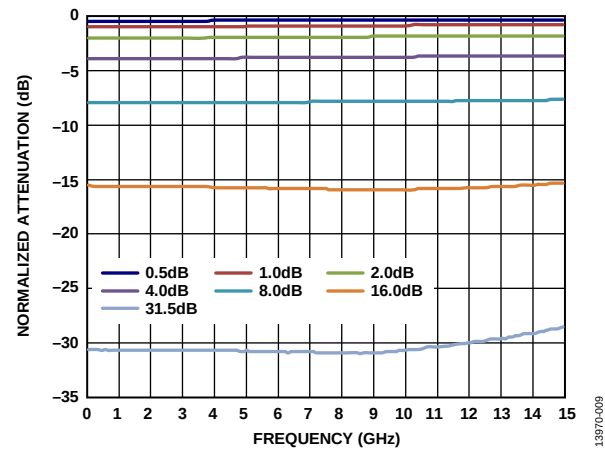
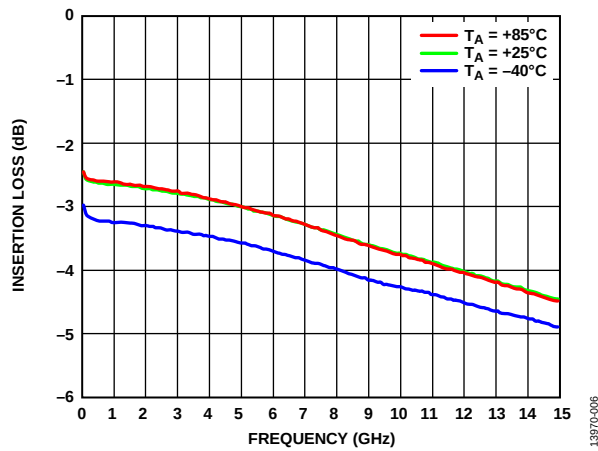


Figure 5. V1 to V6 Interface Schematic

# TYPICAL PERFORMANCE CHARACTERISTICS

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



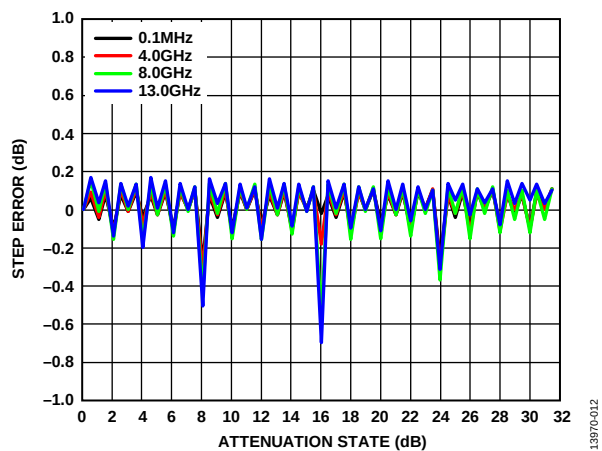


Figure 13. Step Error vs. Attenuation State over Frequency

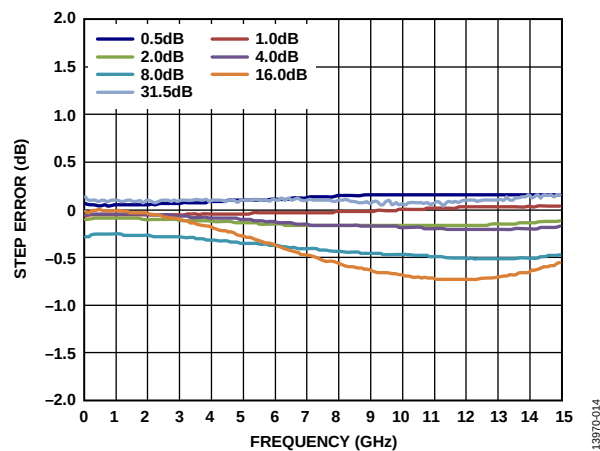


Figure 15. Step Error vs. Frequency over Major Attenuation States

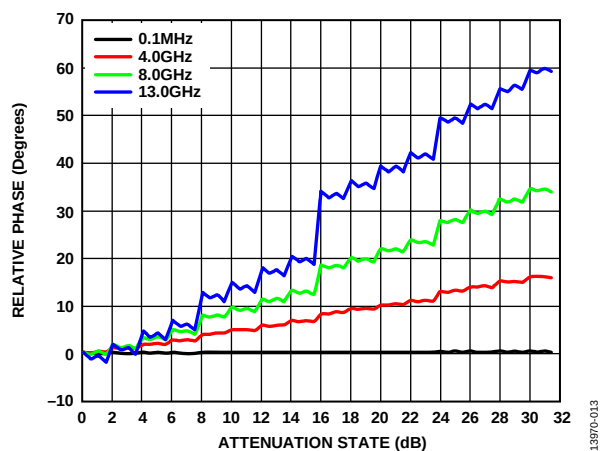


Figure 14. Relative Phase vs. Attenuation State over Frequency

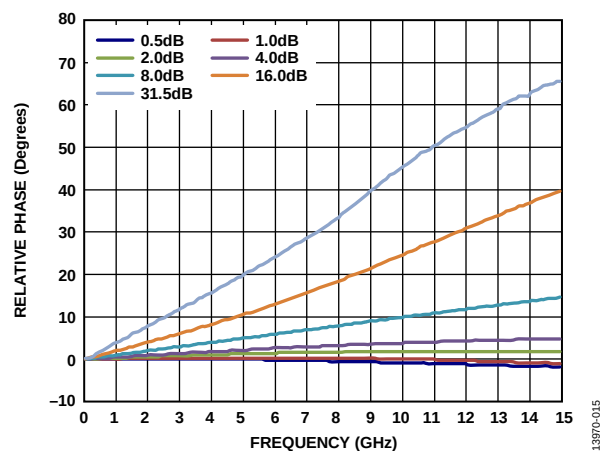


Figure 16. Relative Phase vs. Frequency over Major Attenuation States

## INPUT POWER COMPRESSION AND THIRD-ORDER INTERCEPT

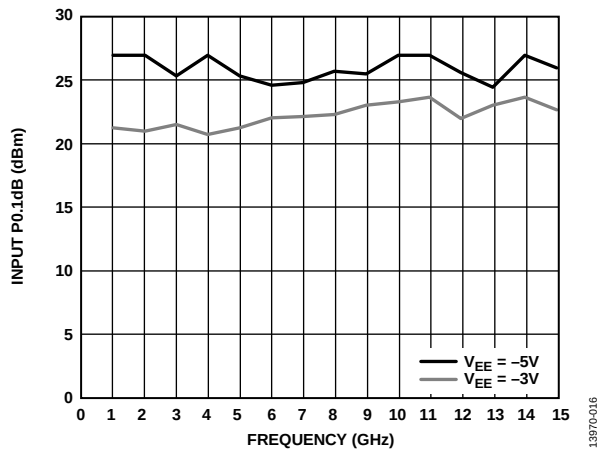


Figure 17. Input P0.1dB vs. Frequency at Minimum Attenuation State over  $V_{EE} = -5V$  and  $V_{EE} = -3V$

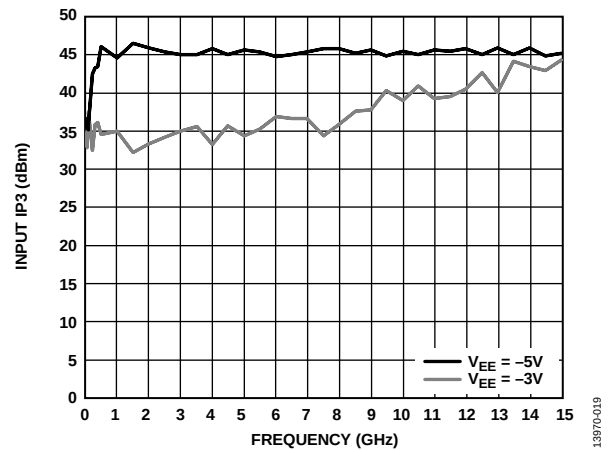


Figure 20. Input IP3 vs. Frequency at Minimum Attenuation State over  $V_{EE} = -5V$  and  $V_{EE} = -3V$

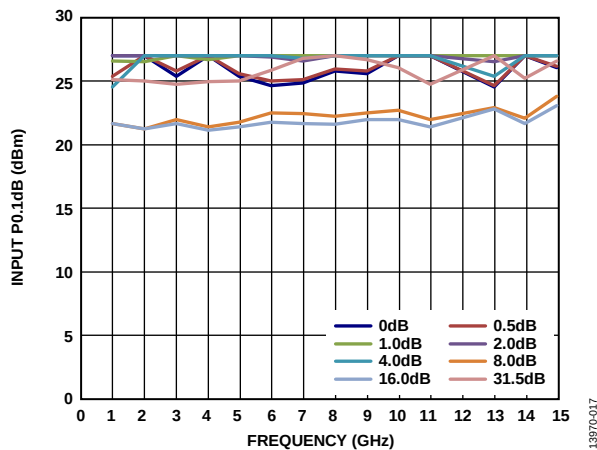


Figure 18. Input P0.1dB vs. Frequency over Major Attenuation States,  $V_{EE} = -5V$

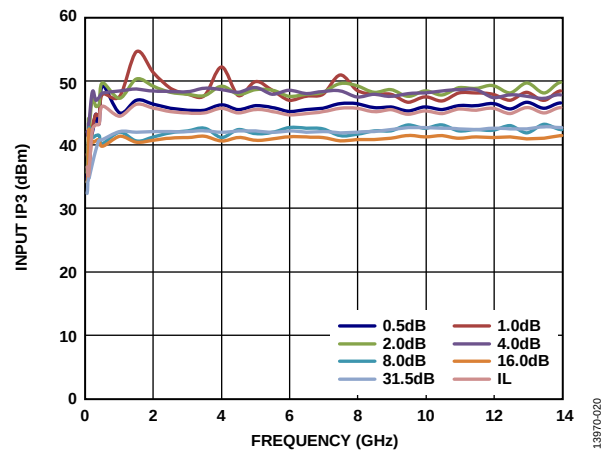


Figure 21. Input IP3 vs. Frequency over Major Attenuation States,  $V_{EE} = -5V$

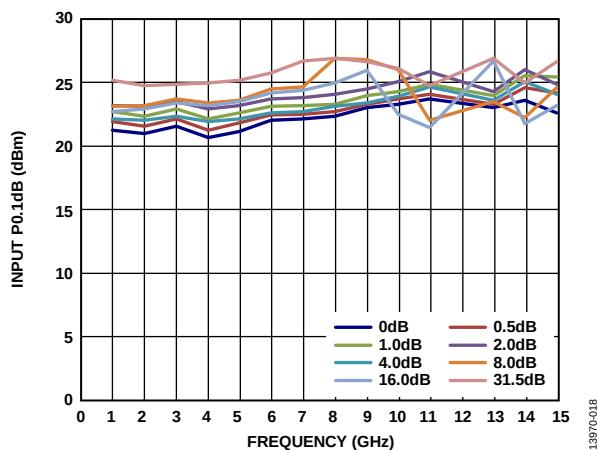


Figure 19. Input P0.1dB vs. Frequency over Major Attenuation States,  $V_{EE} = -3V$

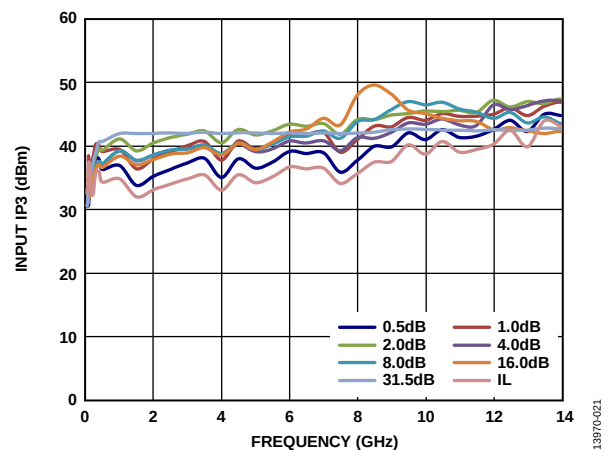


Figure 22. Input IP3 vs. Frequency over Major Attenuation States,  $V_{EE} = -3V$



## THEORY OF OPERATION

The HMC424ACHIPS 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 HMC424ACHIPS allows the user to program the attenuation state via six parallel control inputs toggled between 0 V and  $V_{EE}$ . When interfacing with a TTL/CMOS interface, an external level shifter is required. An example 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 HMC424ACHIPS requires a single dc voltage applied to the VEE pin. The ideal power-up sequence is as follows:

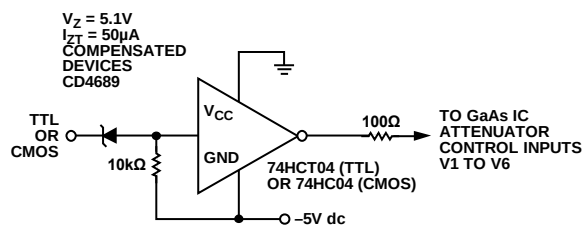
1. Connect the ground reference.
2. Apply a supply voltage to the VEE pin.
3. Power up the digital control inputs. The relative order of the digital control inputs is not important.
4. Apply an RF input signal to RF1.

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

## RF INPUT AND OUTPUT

The attenuator in the HMC424ACHIPS is bidirectional. The RF1 and RF2 pins are interchangeable as the RF input and output ports. The attenuator is internally matched to 50  $\Omega$  at both the input and the output. Therefore, no external matching components are required.

The RF input and output pins of the HMC424ACHIPS 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.  $V_Z$  IS THE ZENER VOLTAGE, AND  $I_{ZT}$  IS THE ZENER TEST CURRENT.

Figure 23. Suggested Driver Circuit

Table 5. V1 to V6 Truth Table

| Control Voltage Input |           |           |           |           |             | Attenuation State, RF1 to RF2 |
|-----------------------|-----------|-----------|-----------|-----------|-------------|-------------------------------|
| 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

### MOUNTING AND BONDING TECHNIQUES

The HMC424ACHIPS is back metallized and must be attached directly to the ground plane with gold tin (AuSn) eutectic preforms or with electrically conductive epoxy.

The die thickness is 0.102 mm (4 mil). The 50  $\Omega$  microstrip transmission lines on 0.127 mm (5 mil) thick alumina thin film substrates are recommended for bringing RF to and from the HMC424ACHIPS (see Figure 24).

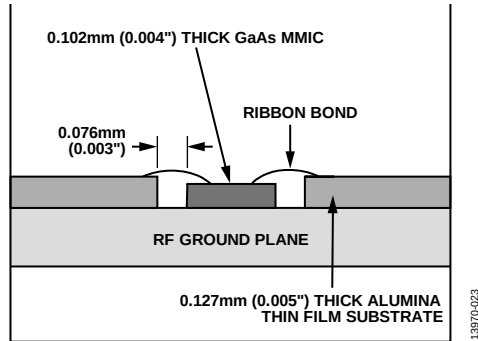


Figure 24. Bonding RF Pads to 5 mil Substrate

When using 0.254 mm (10 mil) thick alumina thin film substrates, the HMC424ACHIPS must be raised 0.150 mm (6 mil) so that the surface of the HMC424ACHIPS is coplanar with the surface of the substrate. One way to accomplish this is by attaching the 0.102 mm

(4 mil) thick die to a 0.150 mm (6 mil) thick molybdenum heat spreader (moly tab), which is then attached to the ground plane (see Figure 25).

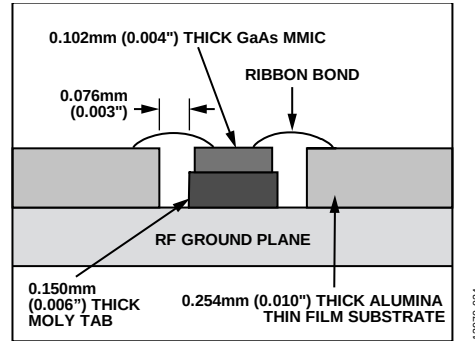


Figure 25. Bonding RF Pads to 10 mil Substrate

Microstrip substrates are placed as close to the HMC424ACHIPS as possible to minimize bond length. Typical die to substrate spacing is 0.076 mm (3 mil).

RF bonds made with 3 mil  $\times$  5 mil ribbon are recommended. DC bonds made with 1 mil diameter wire are recommended. All bonds must be as short as possible.

### ASSEMBLY DIAGRAM

An assembly diagram of the HMC424ACHIPS is shown in Figure 26.

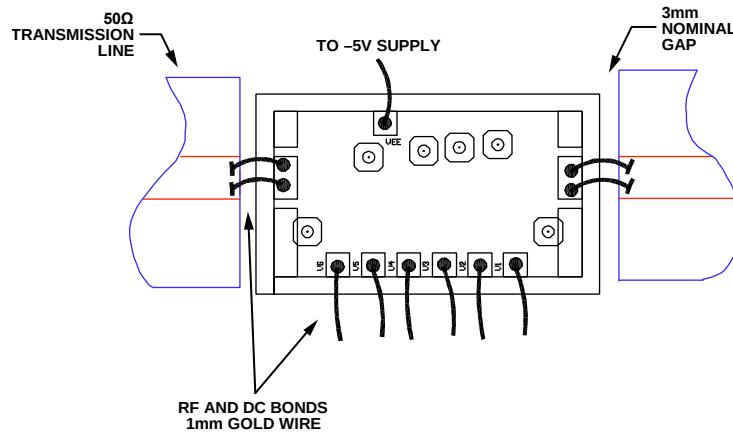


Figure 26. Assembly Diagram

## OUTLINE DIMENSIONS

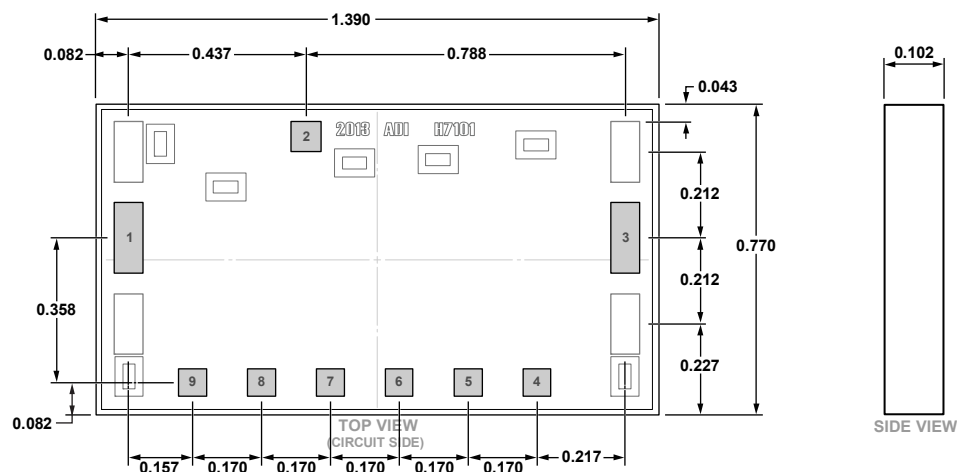


Figure 27. 9-Pad Bare Die [CHIP]  
(C-9-2)  
Dimensions shown in millimeters

07-19-2019-A

## ORDERING GUIDE

| Model <sup>1</sup> | Temperature Range | Package Description   | Package Option | Marking Code <sup>2</sup> |
|--------------------|-------------------|-----------------------|----------------|---------------------------|
| HMC424A            | −40°C to +85°C    | 9-Pad Bare Die [CHIP] | C-9-2          | H424A<br>XXXX             |
| HMC424A-SX         | −40°C to +85°C    | 9-Pad Bare Die [CHIP] | C-9-2          | H424A<br>XXXX             |

<sup>1</sup> All models are RoHS compliant.

<sup>2</sup> XXXX is the 4-digit lot number.