

ADA-4643

+13.5 dBm Output P1dB Avago Darlington Amplifier



Application Note 1368

Description

Avago Technologies' Darlington Amplifier, ADA-4643 is a low current silicon gain block RFIC amplifier housed in a 4-lead SC-70 (SOT-343) surface mount plastic package. Providing a nominal 17 dB gain at up to +13.6 dBm output P1dB at 900 MHz, this device is ideal for small-signal gain stages or IF amplification. The Darlington feedback structure provides inherent broad bandwidth performance. The 25 GHz f_T fabrication process results in a device with low current draw and useful operation below 2.5 GHz. Distinguished features of the ADA-4643 are its inherent broad bandwidth, linearity and easy-to-use that are useful in Cellular, PCS, WLL base stations, Wireless Data, Fiber Optic systems and ISM applications.

Application Guidelines

The ADA-4643 is very easy to use. For most applications, all that is required to operate the ADA-4643 is to apply 20 mA to 60 mA to the RF Output pin.

RF Input and Output

The RF Input and Output ports of the ADA-4643 are closely matched to 50Ω.

DC Bias

The ADA-4643 is a current-biased device that operates from a 20 mA to 60 mA current source. Curves of typical performance as a function of bias current are shown in the data sheet. Figure 1 shows a typical implementation of the ADA-4643. The supply current for the ADA-4643 must be applied to the RF Output pin. The power supply connection to the RF Output pin is achieved by means of a RF choke (inductor). The value of the RF choke must be large relative to 50Ω in order to prevent loading of the RF Output. The supply voltage end of R_c is bypassed to ground with a capacitor. Blocking capacitors are normally placed in series with the RF Input and the RF Output to isolate the DC voltages on these pins from circuits adjacent to the amplifier. The values for the blocking and bypass capacitors are selected to provide a reactance at the lowest frequency of operation that is small relative to 50Ω.

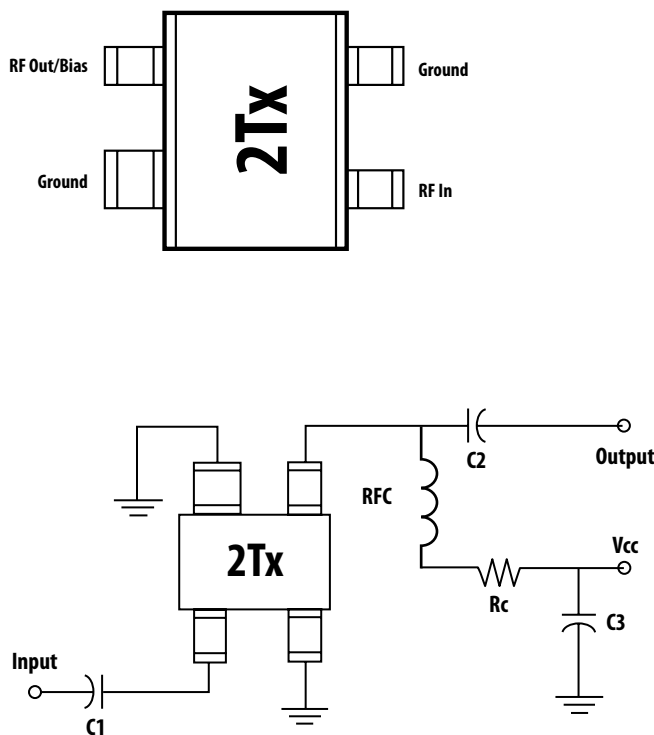


Figure 1. Schematic Diagram with Bias Connections.

PCB Layout

A recommended PCB pad layout for the miniature SOT-343 (SC-70) package that is used by the ADA-4643 is shown in Figure 2.

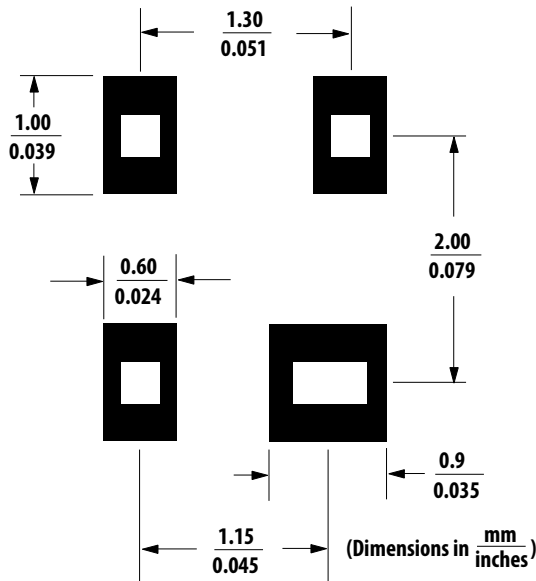


Figure 2. PCB Pad Layout for ADA-4643. Package dimensions in mm/inches.

This layout provides ample allowance for package placement by automated assembly equipment without adding parasitics that could impair the high frequency RF performance of the ADA-4643. The layout is shown with a footprint of a SOT-343 package superimposed on the PCB pads for reference. Starting with the package pad layout in Figure 2, an RF layout similar to the one shown in Figure 3 is a good starting point for microstrip-line designs using the ADA-4643 amplifier.

PCB Materials

FR-4 or G-10 type materials are good choices for most low cost wireless applications using single or multi-layer printed circuit boards. Typical single-layer board thickness is 0.020 to 0.031 inches. Circuit boards thicker than 0.031 inches are not recommended due to excessive inductance in the ground vias. This is discussed in more detail in the section on RF grounding.

Applications Example

The printed circuit layout in Figure 3 is a multi-purpose layout that will accommodate components for using the ADA-4643 for RF inputs from DC through 2.5 GHz. This layout is a micro-stripline design (solid ground plane on the backside of the circuit board) with 50Ω interfaces for the RF input and output. The circuit is fabricated on 0.031-inch thick FR-4 dielectric material. Plated through holes (vias) are used to bring the ground to the topside of the circuit where needed. Multiple vias are used to reduce the inductance of the paths to ground.

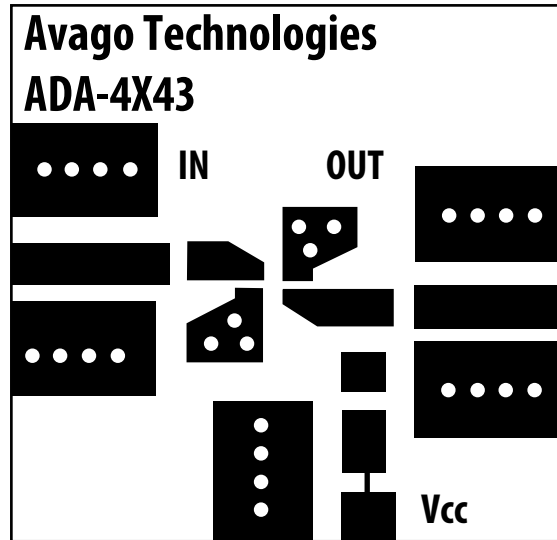


Figure 3. Multi-purpose Evaluation Board.

The amplifier and related components are assembled onto the printed circuit board as shown in Figure 6. The ADA-4X43 circuit board is designed to use edge-mounting SMA connectors such as Johnson Components, Inc., Model 142-0701-881. These connectors are designed to slip over the edge of 0.031-inch thick circuit boards and obviate the need to mount PCBs on a metal base plate for testing. The center conductors of the connectors are soldered to the input and output microstrip lines. The ground pins are soldered to the ground plane on the back of the board and to the top ground pads.

DC blocking capacitors are required at the input and output of the IC. The values of the blocking capacitors are determined by the lowest frequency of operation for a particular application. The capacitor's reactance is chosen to be 10% or less of the amplifier's input or output impedance at the lowest operating frequency. For example, an amplifier to be used in an application covering the 900 MHz band would require an input blocking capacitor of at least 39 pF, which is 4.5Ω of reactance at 900 MHz. The Vcc connection to the amplifier must be RF bypassed by placing a capacitor to ground at the bias pad of the board. Like the DC blocking capacitors, the value of the Vcc bypass capacitor is determined by the lowest operating frequency for the amplifier. A larger value of bypass capacitor may improve the IP3 performance of the circuitry by suppressing the different frequency between the two input tones. RF design software such as Avago Technologies' AppCad is very handy to determine the values of the blocking capacitors with their losses

and RF choke for any operating frequency. This software is downloadable at <http://www.avago.com/view/App-CadSpace> is available on the circuit board to add a bias choke, by-pass capacitors, and collector resistors.

The ADA series of ICs requires a bias resistor to ensure thermal stability. The bias resistor value is calculated from the operating current value, device voltage and the supply voltage; see equation below. When applying bias to the board, start at a low voltage level and slowly increase the voltage until the recommended current is reached. Both power and gain can be adjusted by varying I_d .

$$R_c = \frac{V_{cc} - V_d}{I_d} \Omega$$

Where:

V_{cc} = The power supply voltage applied to R_c (volts)

V_d = The device voltage (volts)

I_d = The quiescent bias current drawn by the device

Notes on R_c Selection

The value of R_c is dependant on V_d , any production variation in V_d will have an effect on I_d . As the gain and power performance of the ADA-4643 may be adjusted by varying I_d , this will have to be taken into account. The characterization data in the data sheet shows the relationship between V_d and I_d over temperature. At lower temperatures the value of V_d increases. The increase in V_d at low temperatures and production variations may cause potential problems for the amplifier performance if it is not taken into account. One solution would be to operate the circuit from a higher supply voltage. This will increase the voltage drop across R_c and improve the current stability from part-to-part variation and over temperature. Table 1 shows the effects of R_c on the performance of the ADA-4643 over temperature. Avago Technologies' AppCad can also be used to examine the effect of supply voltage over temperature on any current-biased device.

An alternative solution to ensure good temperature stability without having a large voltage drop across a re-



Figure 4. Active Bias Circuit.

Table 1. Effects of R_c on Performance over Temperature.

Operating voltage is 3.4V nominally.

Supply Voltage, V	Resistor Value, Ω	Temperature, $^{\circ}\text{C}$	Bias Current, mA	Power Gain @ 900 MHz, dB
3.5	0	0	21.5	16.3
		25	35.0	16.7
		85	63.1	16.8
5.1	47	0	32.6	16.9
		25	35.0	16.7
		85	40.2	16.5
7.7	120	0	34.1	16.8
		25	35.0	16.7
		85	37.9	16.3
10.5	200	0	35.4	17.1
		25	35.0	16.7
		85	37.9	16.6

Note: Higher supply voltage means higher value of R_c . If R_c is much larger than 500 Ohm, then the RFC is no longer needed.

sistor would be to use an active bias circuit as shown in Figure 4. The resistors R1 and the PNP transistor connected to form a diode by connecting the base and collector together and R2 form a potential divider circuit to set the base voltage of the bias PNP transistor. The diode connected PNP transistor is used to compensate for the voltage variation with temperature of bias PNP transistor. R3 provides a bleed path for any excess bias; it is a safety feature and can be omitted from the circuit, a typical value for R3 is 1kΩ. Rc is a feedback element that keeps the Id constant. If the device current starts to increase, the voltage drop across Rc also increases, turning off the E-B junction of the PNP transistor, and hence decreasing the bias current applied to the ADA. For best circuit operation, there should be at least 0.5V drop across Rc. The values of Rc, R1 and R2 are approximated using the equations below. The value of Rc is approximated by assuming a 0.5V drop across it.

$$R_c = \frac{0.5V}{I_d} \Omega$$

$$R_2 = \frac{0.5V}{10 \cdot I_d} \cdot \beta_{pnp}$$

$$R_1 = \frac{(V_{cc} - 0.5V) - V_{BEpnp}}{11 \cdot I_d} \cdot \beta_{pnp}$$

For 35 mA Id, 5V Vcc bias, the estimated value of Rc is 15Ω, R1 is 1kΩ and R2 is 150Ω. A CAD program such as Avago Technologies' ADS is recommended to determine the values of R1 and R2 at other bias levels. The value of RF choke should be large compared to 50Ω, typical value for 0.9 GHz is 47 nH. The DC blocking capacitors are calculated as described above. A typical value for C3 would be 1.0 μF. To ensure correct bias circuit operation, the PNP transistor should be kept out of saturation even when Vd is at its highest. The absolute minimum voltage drop need across the emitter to collector junction of this transistor will therefore be equal to its VCEsat, for example 0.5V. In this case the active bias solution will only require about 1V difference between Vcc and Vd for good bias stability over temperature and normal part-top part variation. For more details on the active bias circuit please refer to application note AN-003, "Biasing MODAMP MMICs."

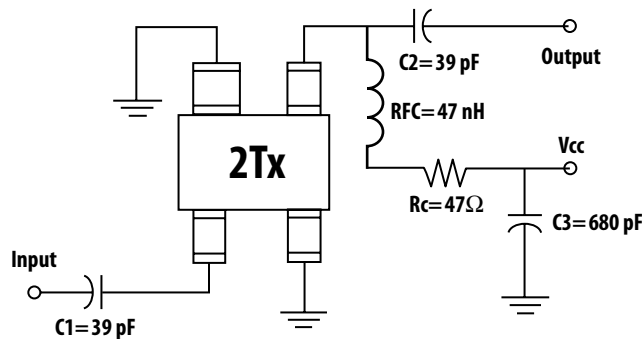


Figure 5. Schematic of 900 MHz Circuit.

900 MHz Design

To illustrate the simplicity of using the ADA-4643, a 900 MHz amplifier is presented. The amplifier uses a 5V, 35 mA supply. The input and output of the ADA-4643 is already matched to 50Ω and no additional matching is needed. A schematic diagram of the complete 900 MHz with DC biasing is shown in Figure 5. DC bias is applied to the ADA-4643 through the RFC at the RF output pin. The power supply connection is bypassed to ground with capacitor C3. Provision is made for an additional bypass capacitor, C4, to be added to the bias line near the 5V connection. C4 will not normally be needed unless several stages are cascaded using a common power supply.

The input terminal of the ADA-4643 is not at ground potential; an input DC blocking capacitor is needed. The values of the DC blocking and RF bypass capacitors should be chosen to provide a small reactance (typically < 5Ω) at the lowest operating frequency. For this 900 MHz design example, 39 pF capacitors with a reactance of 4.5Ω are adequate. The reactance of the RF choke (RFC) should be high (i.e., several hundred ohms) at the lowest frequency of operation. A 47 nH inductor with a reactance of 266Ω at 900 MHz is sufficiently high to minimize the loss from circuit loading.

Table 2. Component Parts List for the ADA-4543 Amplifier at 900 MHz.

R1	47 OHm Garret MCR03J220
RFC	47 nH Coilcraft 0805CS-470X-BC
C1, C2	39 pF Garret 0603CG390J9B20
C3	680 pF Murata GRM40C0G681
SMA Connector	Johnson Components, Inc., Model 142-0701-881

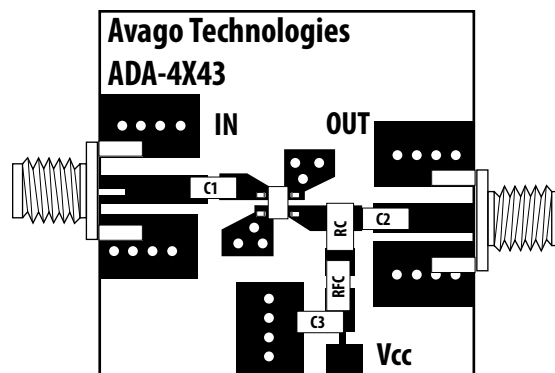


Figure 6. Complete of 900 MHz Amplifier.

Performance of ADA-4643 900 MHz Amplifier

The amplifier is biased at a V_{cc} of 5.1V, I_d of 35 mA. The measured gain, noise figure, input and output return loss of the completed amplifier is shown in Figure 7. Noise figure is a nominal 3.8 to 3.9 dB from 800 through 1000 MHz. Gain is a minimum of 16.9 dB from 800 MHz through 1000 MHz. The input return loss at 900 MHz is 14.2 dB with a corresponding output return loss of 15.1 dB. The amplifier output intercept point (OIP3) was measured at a nominal +28.3 dBm. P1dB measured +13.6 dBm.

100 MHz Design

The 100 MHz example follows the same design approach that was described in the previous 900 MHz design. A schematic diagram of the complete 100 MHz circuit is shown in Figure 8. And the component part list is shown in Table 3.

Performance of ADA-4643 100 MHz Amplifier

The amplifier is biased at a V_{cc} of 5.1V, I_d of 35 mA. The measured gain, noise figure, input and output return loss of the completed amplifier is shown in Figure 9. Noise figure is a nominal 4.0 to 4.1 dB from 100 through 400 MHz. Gain is a minimum of 17.5 dB from 100 MHz through 400 MHz. The input return loss at 100 MHz is 16.5 dB with a corresponding output return loss of 14 dB. The amplifier output intercept point (OIP3) was measured at a nominal +28.1 dBm. P1dB measured +14.3 dBm.

Designs for Other Frequencies

The same basic design approach described above for 900 MHz can be applied to other frequency bands. Inductor values for matching the input for low noise figure are shown in Table 4. RF design software such as Avago Technologies' AppCad is very handy to determine the values of the blocking capacitors and RF choke for any operating frequency. This software is available at <http://www.avago.com/view/AppCad>.

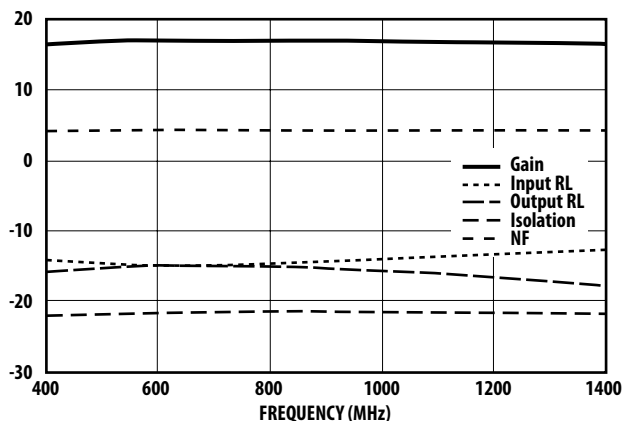


Figure 7. Gain, Noise Figure, Input and Output Return Loss Results.

Actual component values may differ slightly from those shown in Table 4 due to variations in circuit layout, grounding, and component parasitics. A CAD program such as Avago Technologies' ADS® is recommended to fully analyze and account for these circuit variables.

Notes on RF Grounding

The performance of the MSA series is sensitive to ground path inductance. Good grounding is critical when using the ADA-4643. The use of via holes or equivalent minimal path ground returns as close to the package edge as is practical is recommended to assure good RF grounding. Multiple vias are used on the evaluation board to reduce the inductance of the path to ground. The effects of the poor grounding may be observed as a "peaking" in the gain versus frequency response, an increase in input VSWR, or even as return gain at the input of the RFIC.

Table 3. Component Parts List for the ADA-4543 Amplifier at 100 MHz.

R1	47 OHm Garret MCR03J220
RFC	680nH Coilcraft 0805CS-681X_BC
C1, C2	1000 pF Murata GRM40X7R102K50
C3	6.8 pF Murata GRM40X7R682K50
SMA Connector	Johnson Components, Inc., Model 142-0701-881

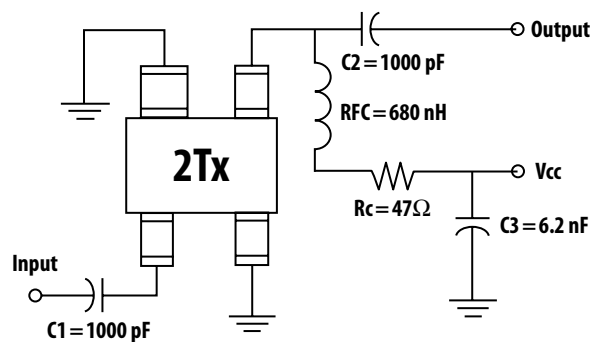


Figure 8. Schematic of 100 MHz Circuit.

A Final Note on Performance

Actual performance of the ADA RFIC mounted on the demonstration board may not exactly match data sheet specifications. The board material, passive components, and connectors all introduce losses and parasitics that may degrade device performance, especially at higher frequencies. Some variation in measured results is also to be expected as a result of the normal manufacturing distribution of products.

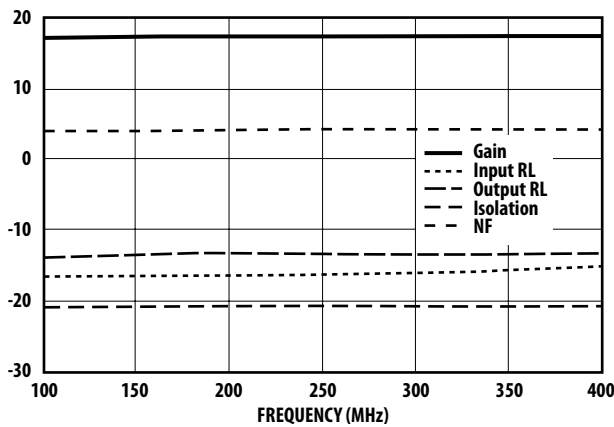


Figure 9. Gain, Noise Figure, Input and Output Return Loss Results.

Phase Reference Planes

The positions of the reference planes used to specify S-parameters for the ADA-4643 are shown in Figure 10. As seen in the illustration, the reference planes are located at the point where the package leads contact the test circuit for the RF input and RF output/bias. As noted under the s-parameter table in section one of the data sheet the ADA-4643 was tested in a fixture that includes plated through holes through a 0.025" thickness printed circuit board. Due to the complexity of de-embedding these grounds, the S-parameters include the effects of the test fixture grounds. Therefore, when simulating the performance of the ADA-4643 the added ground path inductance should be taken into account. For example if you were designing an amplifier on 0.031" thickness printed circuit board material, only the difference in the printed circuit board thickness needs to be included in the simulation, i.e. $0.031" - 0.025" = 0.006"$.

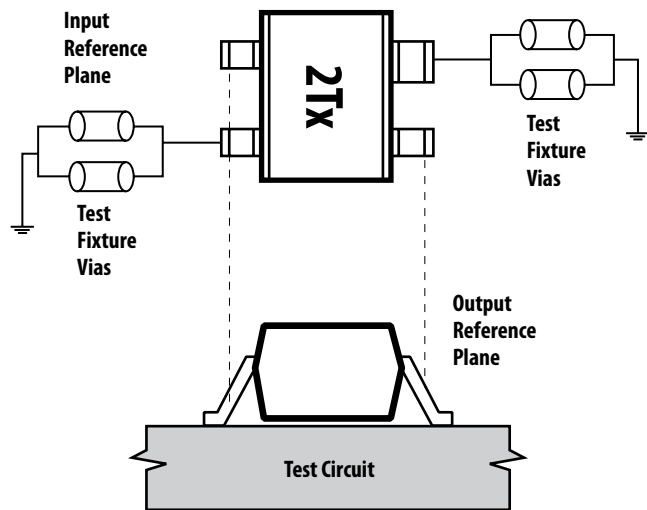


Figure 10. Phase Reference Planes.

Table 4. Input and Output Inductor Values for Various Operating Frequencies.

Frequency	C1 & C2 (pF)	RFC (nH)	C3 (pF)
100 MHz	1000	680	6200
400 MHz	88	100	1500
900 MHz	39	47	680
1500 MHz	22	22	470

Application Notes

AN-S001: Basic MODAMP MMIC Circuit Techniques

AN-S002: MODAMP MMIC Nomenclature

AN-S003: Biasing MODAMP MMICs

AN-S011: Using Silicon MMIC Gain Blocks as Transimpedance Amplifiers

References

<http://www.avago.com/view/rf>

<http://www.avago.com/view/AppCad>

For product information and a complete list of distributors, please go to our web site: www.avagotech.com

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