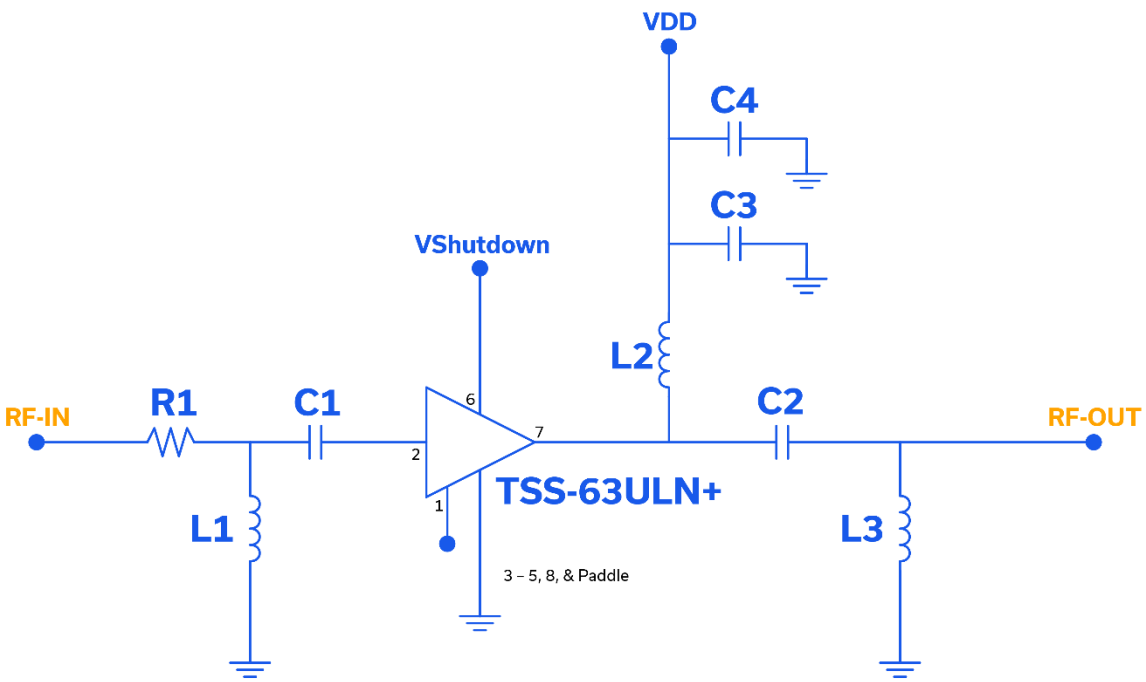
Mini-Circuits®

# Application Note

# Utilizing the TSS-63ULN+ MMIC LNA from 3.7 to 4.2 GHz






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# Introduction

Low-noise amplifiers (LNAs) are critical components for any receiver chain. Their purpose is to amplify an extremely weak signal captured by the receiver's antenna while adding minimal noise power to the signal. Today, Mini-Circuits offers a vast assortment of LNAs that customers can choose from, including both MMIC LNAs and connectorized versions.

One noteworthy model from Mini-Circuits is the TSS-63ULN+ ultra-low-noise MMIC LNA (Fig. 1). Based on pseudomorphic-high-electron-mobility-transistor (pHEMT) technology, the TSS-63ULN+ is specified for an operating frequency range of 1.0 to 6.0 GHz and is equipped with a voltage-controlled shutdown feature. The device operates from a single +5 V DC supply, with typical current consumption of 56 mA. One significant aspect of the TSS-63ULN+ MMIC LNA is its size, as it comes in a small 2 × 2 mm, 8-lead QFN-style package. Finally, the TSS-63ULN+ is intended for a wide range of applications, including cellular infrastructure, satellite communications (satcom), radar, and others.

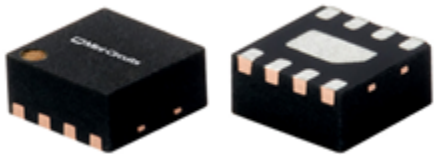


*Figure 1. TSS-63ULN+ MMIC LNA.*

In this application note, we show how the TSS-63ULN+ can be used to design an LNA with an operating frequency range of 3.7 to 4.2 GHz. An application circuit is demonstrated that provides a clear understanding of how to use the device. Measured data is provided that illustrates the level of performance that can be achieved.

# Functional Aspects of the TSS-63ULN+ MMIC LNA

Figure 2 shows the functional diagram for the TSS-63ULN+. Pin 2 is used to connect the RF input signal to the device, while Pin 7 is used to connect both the RF output signal and the DC supply voltage ($V_{DD}$). While the typical value of $V_{DD}$ is specified as +5 V, $V_{DD}$ can range from +2.7 to +5.25 V. Furthermore, Pin 6 is the shutdown voltage ($V_{SHUTDOWN}$) pin. Applying 0 V to this pin sets the TSS-63ULN+ to the ON state. The ON state is still in effect when the voltage applied is as high as +0.9 V. To set the TSS-63ULN+ to the OFF state, a minimum voltage of +1.0 V must be applied to the $V_{SHUTDOWN}$ pin. For the OFF state, the datasheet specifies a typical condition as $V_{SHUTDOWN} = V_{DD}$ (i.e., $V_{SHUTDOWN}$ = +5 V when $V_{DD}$ = +5 V, $V_{SHUTDOWN}$ = +3 V when $V_{DD}$ = +3 V, etc.).



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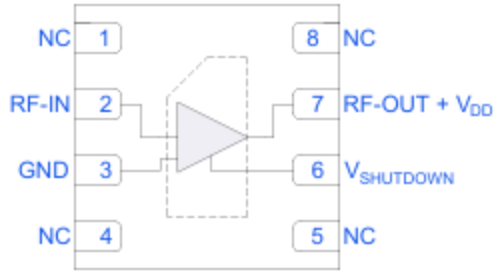



*Figure 2. Functional diagram of the TSS-63ULN+ MMIC LNA.*

Pins 1, 4, 5, and 8 are not used internally. They can either be connected to ground or left floating. Pin 3 must be connected to ground. Finally, as is the case for a QFN-style package, the TSS-63ULN+ has an exposed pad (i.e., paddle) that must also be connected to ground.

# LNA Application Circuit

To fully demonstrate the LNA application circuit featuring the TSS-63ULN+ MMIC LNA, we narrow down its specified operating frequency range of 1.0 to 6.0 GHz to the targeted frequency range of 3.7 to 4.2 GHz. While the TSS-63ULN+ can be considered a wideband device, the goal of this circuit design is to optimize the performance over the specific frequency band of 3.7 to 4.2 GHz. Potential use cases for an LNA that covers this frequency range include 5G and satcom.

Figure 3 shows the schematic of the application circuit that includes the TSS-63ULN+ device. Here, $V_{DD}$ will be set to +5 V, while $V_{SHUTDOWN}$ will be set to 0 V. Included in the schematic are the appropriate capacitors and inductors for matching and DC biasing. L1 and C1 represent the input matching network. Note that R1 is simply a 0 Ω jumper resistor. L2 serves as an RF choke, while C2 serves as a DC blocking capacitor. These two components also combine with L3 to form the output matching network. Finally, C3 and C4 serve as RF bypass capacitors.



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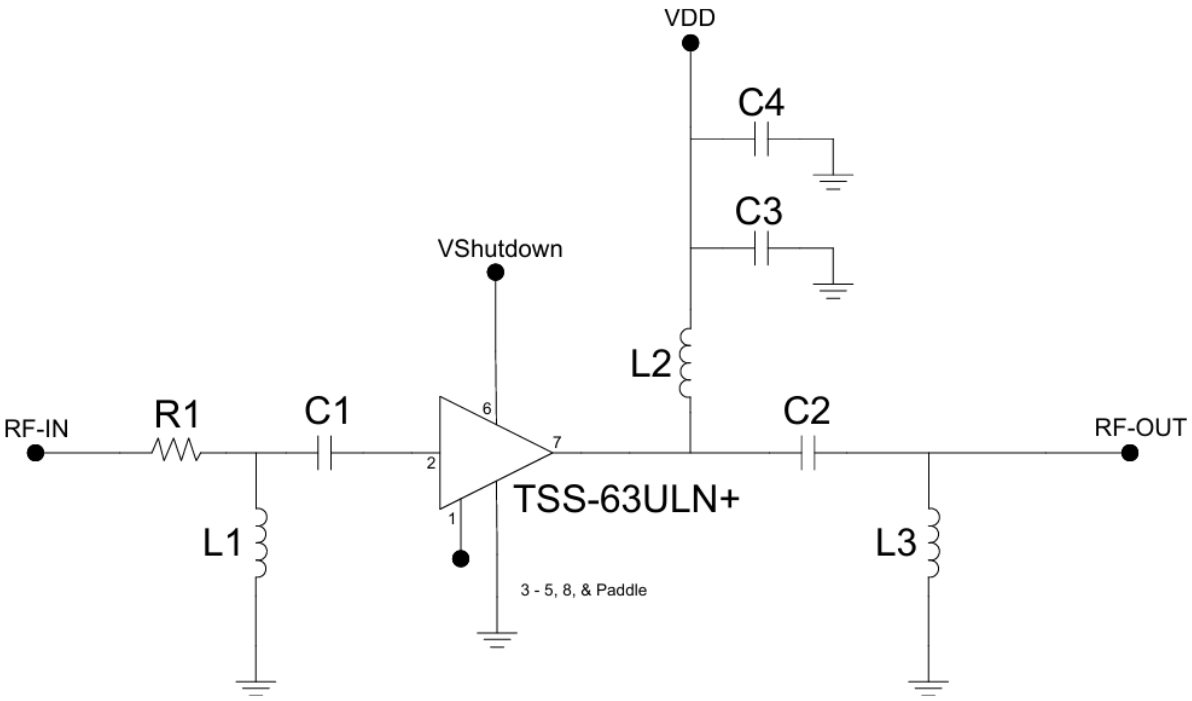



*Figure 3. Schematic of the 3.7 – 4.2 GHz application circuit that includes the TSS-63ULN+ device.*

Figure 4 shows an assembled test board. Note that the substrate is 10 mil Rogers 4350B. In this case, pins 3, 4, 5, 8, and the paddle are connected to ground, while pin 1 is left floating. Finally, Table 1 lists all the parts used for this circuit.

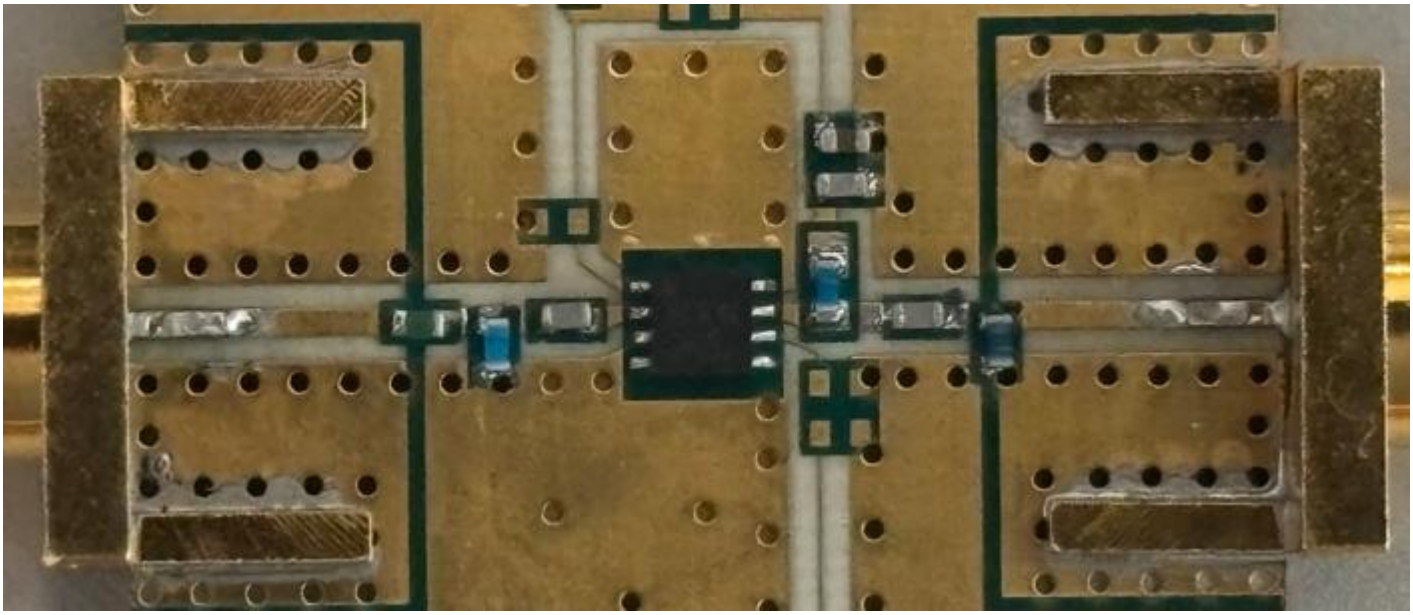


*Figure 4. Fully assembled 3.7 – 4.2 GHz test board.*



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*Table 1: Parts list of the LNA circuit.*

| Component | Value | Manufacturer | Part Number |
|---|---|---|---|
| C1 | 0.9 pF | Passive Plus | 0402N0R9BW201 |
| C2 | 2.2 pF | Passive Plus | 0402N2R2BW201 |
| C3 | 100 pF | KEMET | CBR04C101JAGAC |
| C4 | 0.1 µF | KEMET | C0402C104M4PACTU |
| L1 | 1.2 nH | Coilcraft | 0402DC-1N2XJRW |
| L2 | 0.8 nH | Coilcraft | 0402DC-N80XJRW |
| L3 | 4.7 nH | Coilcraft | 0402DC-4N7XGRW |
| R1 | 0 ohms | KOA Speer | RK73Z1ETTP |
| Amp | | Mini-Circuits | TSS-63ULN+ |

# Optimized Performance: Gain, Isolation, Return Loss, and Noise Figure

We can now see how well the circuit performance has been optimized by looking at measured data of the test board. Gain, isolation, and input/output return loss were measured using a vector network analyzer (VNA). Noise figure was measured using a noise figure analyzer together with a noise source. Finally, to demonstrate the nonlinear performance, a VNA was also used to measure output power at 1-dB compression (P1dB), output third-order intercept point (OIP3), and output second-order intercept point (OIP2). Note that all measurements correspond to the complete test board with the RF connectors (i.e., no elements are de-embedded from the measured data).

Figure 5 shows the measured gain, isolation, input return loss, and output return loss over the targeted frequency range of 3.7 to 4.2 GHz. Across the band, the gain ranges from 18.0 to 17.0 dB. The isolation is greater than 24.0 dB across the targeted frequency range of 3.7 to 4.2 GHz. For the input and output return loss, the circuit achieves values greater than 10.5 and 11 dB, respectively, over the intended frequency range. Figure 6 shows the results of the same measurements when performed over a wide frequency range of 10 MHz to 10 GHz. Moreover, Figure 7 shows the stability factor (K) along with the stability measure (B). The results show that the circuit achieves unconditional stability.



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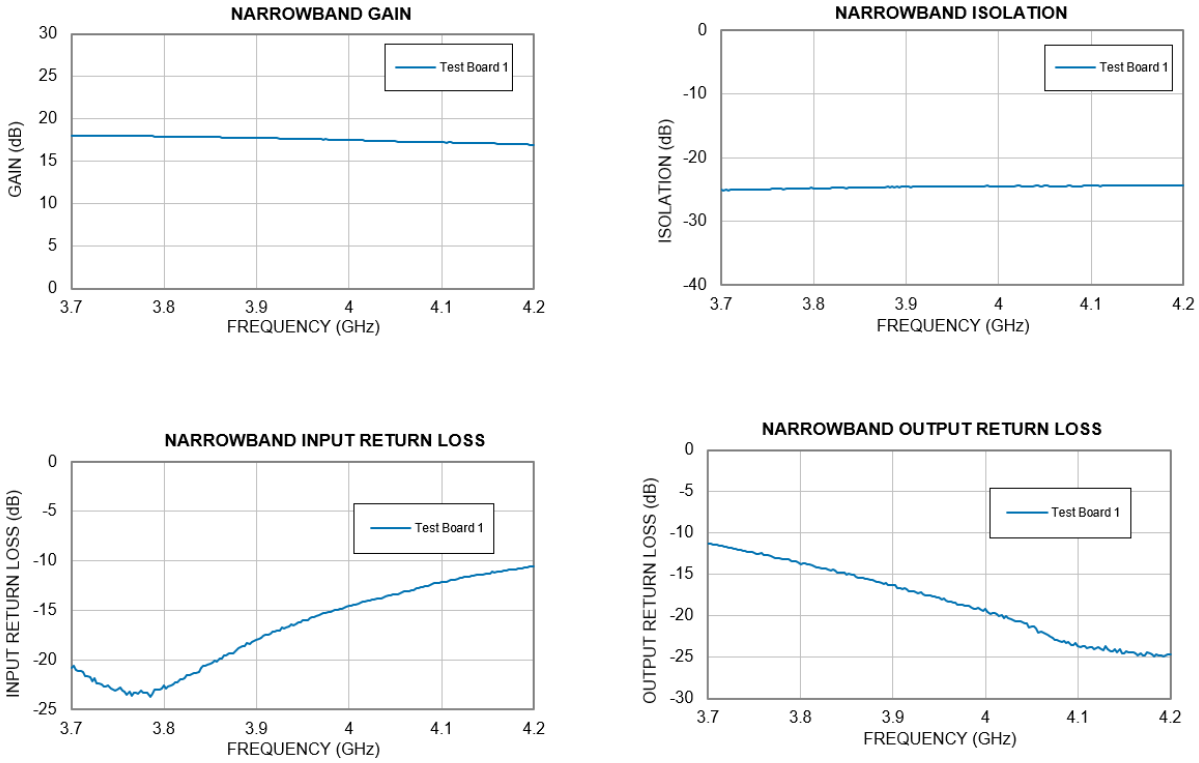



*Figure 5. Measured gain (top left), isolation (top right), input return loss (bottom left), and output return loss (bottom right).*

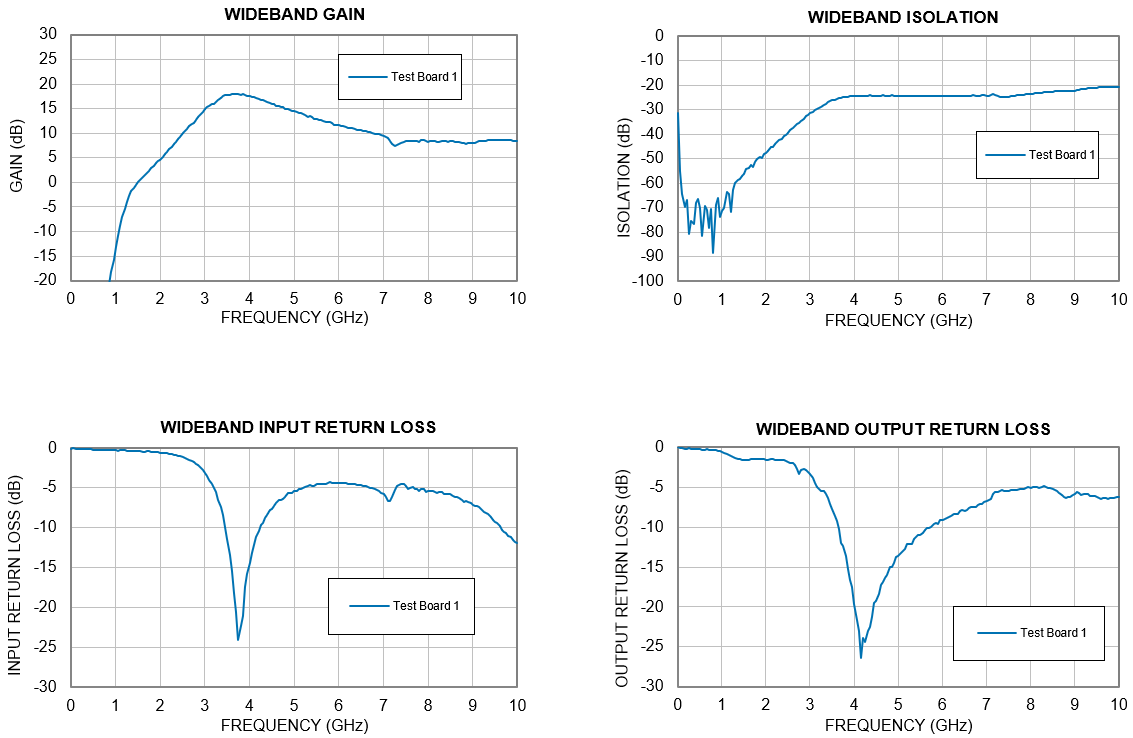



*Figure 6. Wideband measured gain (top left), isolation (top right), input return loss (bottom left), and output return loss (bottom right).*



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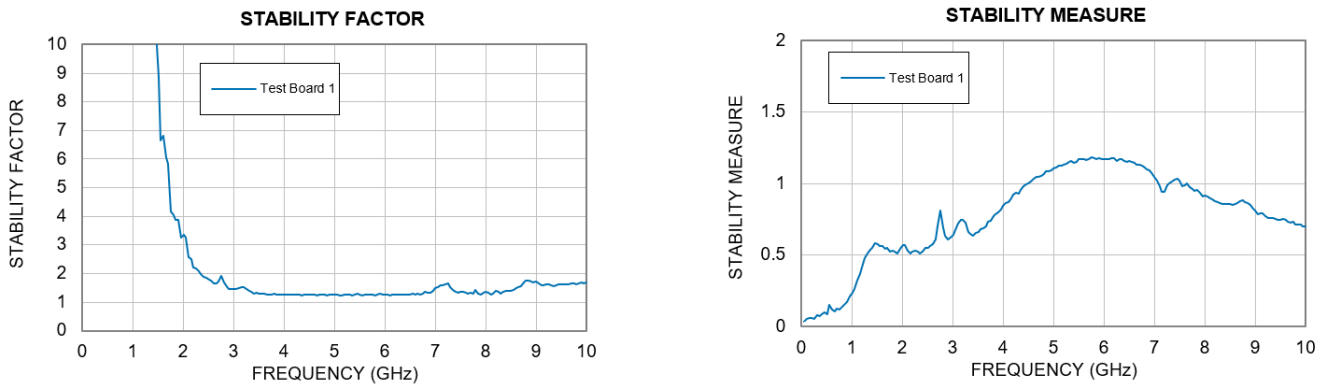



*Figure 7. Measured stability factor (K) and stability measure (B).*

Of course, noise figure is a critical parameter for any LNA. Figure 8 shows the measured noise figure of the complete LNA circuit. We see that the maximum noise figure does not exceed 0.9 dB over the targeted frequency range of 3.7 to 4.2 GHz.

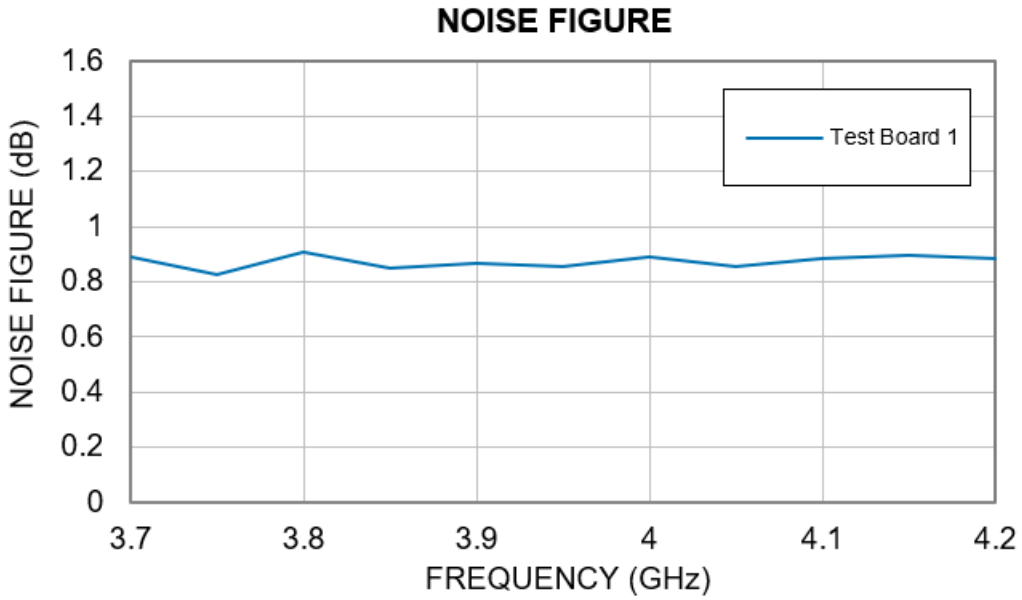



*Figure 8. Measured noise figure.*

# Nonlinear Performance

In addition to achieving high gain and low noise figure as shown previously, the TSS-63ULN+ MMIC LNA achieves high P1dB and OIP3 levels as well. To demonstrate, Figure 9 shows the measured P1dB. The results show that the P1dB is greater than +17.5 dBm across the frequency range of 3.7 to 4.2 GHz.


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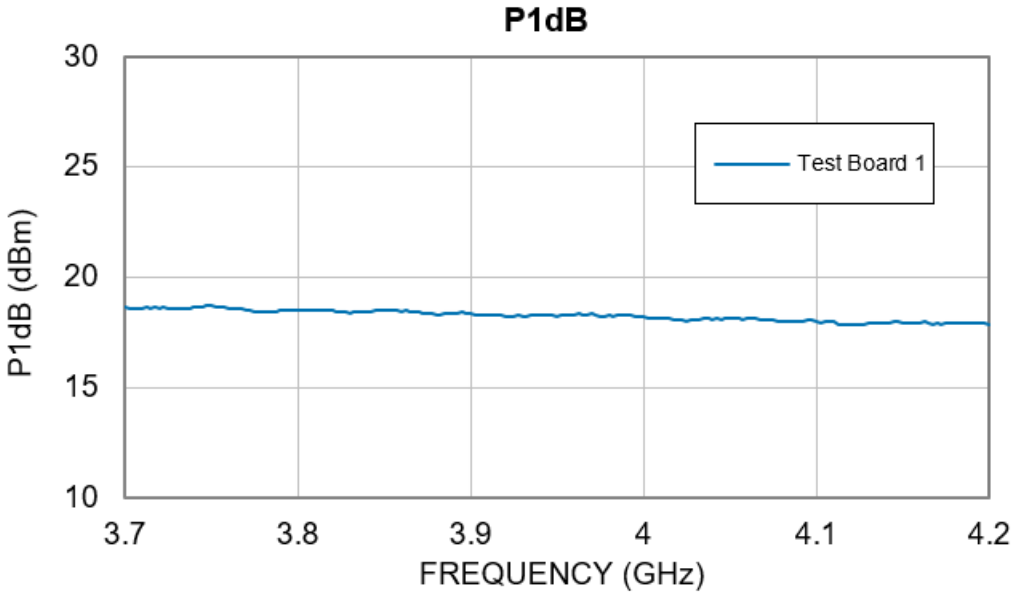



*Figure 9. Measured P1dB.*

Figure 10 shows the measured OIP3 across the targeted frequency range, with the level of each of the output fundamental tones set to a fixed value of +4 dBm for all frequencies. Note that the fundamental tones are spaced 1 MHz apart. The results show the OIP3 is greater than +34.5 dBm over the intended frequency range. Figure 10 also shows the measured OIP3 for output fundamental tone levels ranging from +4 to +14 dBm. The results are shown for three frequencies: 3.7, 3.95, and 4.2 GHz. Again, the fundamental tones are spaced 1 MHz apart.

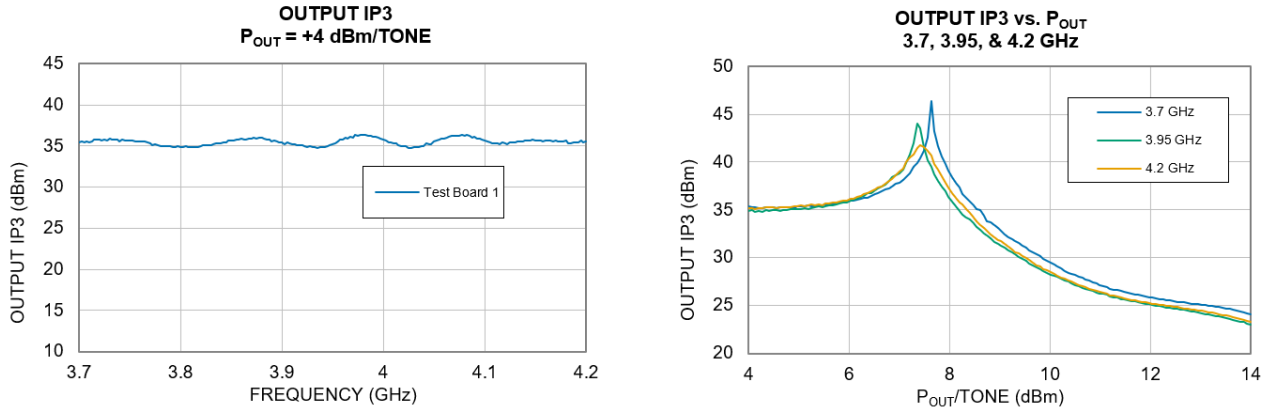



*Figure 10. Shown on the left is the measured OIP3 versus frequency, with the fundamental tone set to a fixed value of +4 dBm. Shown on the right is the measured OIP3 versus fundamental tone levels for three frequencies.*

In certain cases, OIP2 may also be an important parameter. Figure 11 shows the measured OIP2 across the targeted frequency range. Again, the level of each of the output


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fundamental tones is set to a fixed value of +4 dBm. Figure 11 also shows the measured OIP2 for output fundamental tone levels ranging from 0 to +14 dBm. The results are once again shown for 3.7, 3.95, and 4.2 GHz. Note that the fundamental tones are still spaced 1 MHz apart. Also note that the results shown correspond to the second-order sum term ($f_1 + f_2$).

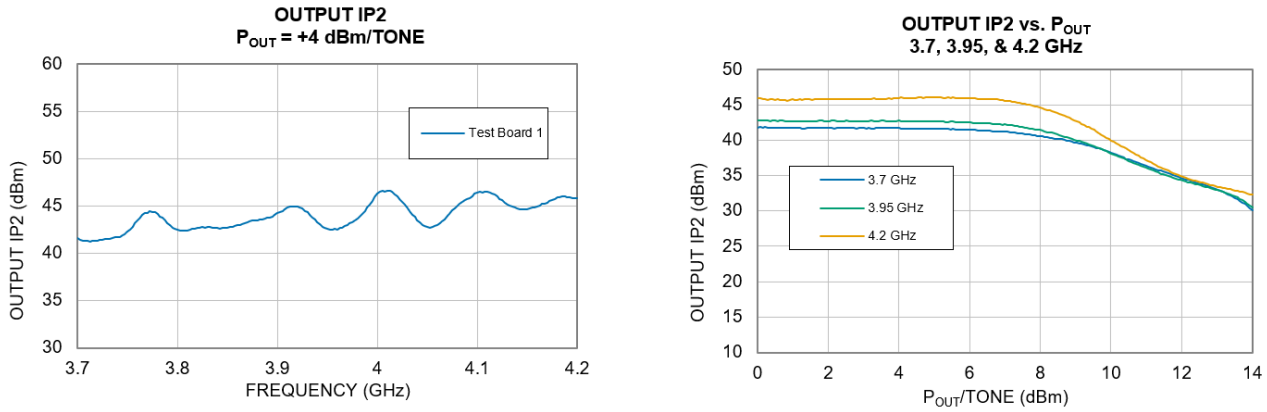



*Figure 11. Shown on the left is the measured OIP2 versus frequency, with the fundamental tone set to a fixed value of +4 dBm. Shown on the right is the measured OIP2 versus fundamental tone levels for three frequencies.*

# Conclusion

In this application note, we demonstrated how the Mini-Circuits TSS-63ULN+ MMIC LNA performs when used to build an LNA circuit that is optimized for use from 3.7 to 4.2 GHz. Over this frequency range, the LNA circuit achieves at least 17.0 dB of gain along with a noise figure within 0.9 dB. In addition, the P1dB and OIP3 are greater than +17.5 and +34.5 dBm, respectively. All this performance is available from a device that operates from a single +5 V DC power supply, consumes only 56 mA, and comes in a small 2 × 2 mm QFN-style package that can be easily integrated into densely packed printed-circuit-board (PCB) layouts. On top of that, a voltage-controlled shutdown feature enables the TSS-63ULN+ to be quickly disabled for power conservation when not in use.

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