MGA-31189

70 to 500 MHz Amplifier for IF Applications using the Avago Technologies MGA-31189 Amplifier

Application Note 5482

Introduction

The MGA-31189 is a highly linear, Enhancement mode pHEMT (Pseudomorphic High Electron Mobility Transistor) amplifier with a frequency range extending from 50 MHz to 2 GHz. This range makes the MGA-31189 ideal for IF band applications (which typically are below 1 GHz). With high IP3, wide bandwidth and low noise figure, the MGA-31189 may be used as an IF amplifier in transmitter/receiver base station and point-to-point radio applications, as shown in Figure 1. The MGA-31189 operates with a +5 V power supply and draws a nominal current of 111 mA at room temperature. This application note will describe designs and guidelines for four IF bands, 70 MHz, 170 MHz, 240 MHz and 500 MHz. This will be a complement to the datasheet design data which is available for 450 MHz, 900 MHz and 1500 MHz. The 0.25 W MMIC is contained in an industry standard SOT-89 package that also offers good thermal dissipation and RF characteristics. The excellent performance is achieved, in great part, through Avago Technologies' proprietary 0.25-micron GaAs E-pHEMT process. The enhancement mode technology provides superior, high linearity performance that allows direct DC grounding at the source pin and a single polarity supply that is easily designed and built [1].

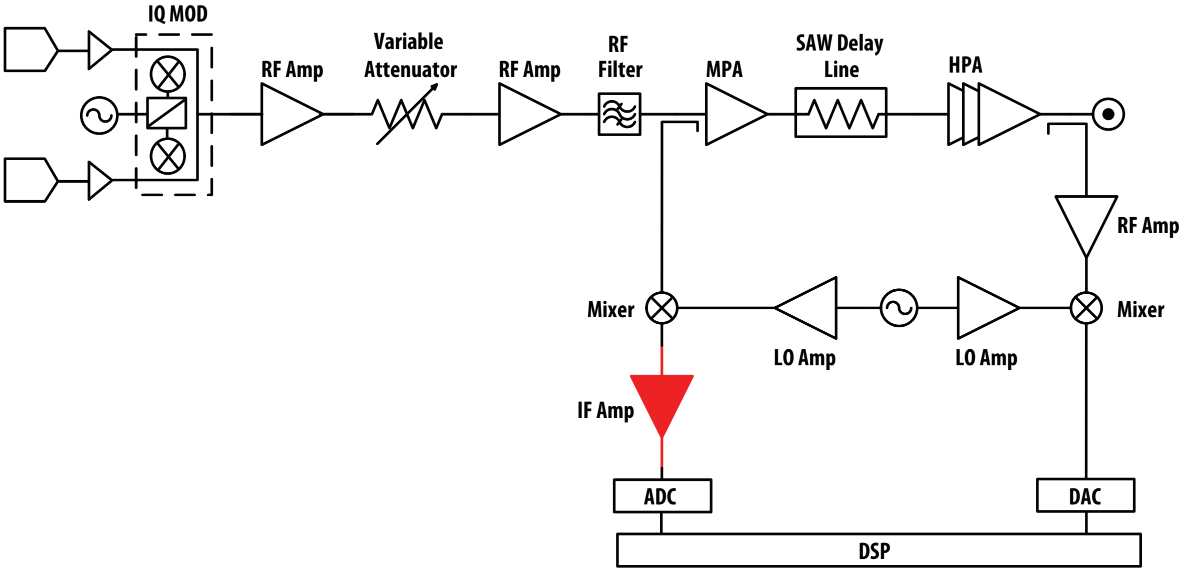


Figure 1. IF amplifier in a typical transmitter base station

PCB Material and Layer Stack Design

Figures 2 and 3 show the top and bottom views of the MGA-31189 demonstration circuit printed circuit board (PCB) with the component placement. The demonstration board is a three-layer board with a Coplanar Waveguide with Ground (CPWG) on the topside as RF traces and a solid metal ground plane on the backside with all RF traces having a characteristic impedance (Z_o) of 50 Ω. For each layer, the copper thickness is 0.5 oz. or 0.7 mils. Every copper layer is separated with a dielectric material, and the board cross sectional diagram is shown in Figure 4.

The first dielectric material is 10-mils Rogers RO4350 with a dielectric constant (ε_r) of 3.48. The second dielectric material is for mechanical strength and stability and uses FR4 with a εr of 4.3. Alternatively, FR-4 or G-10 type material is a good choice for low cost wireless applications. For applications where noise figure is critical or for higher frequency applications, the additional cost of PTFE/glass dielectric material may be necessary to minimize transmission line loss at the amplifier input.

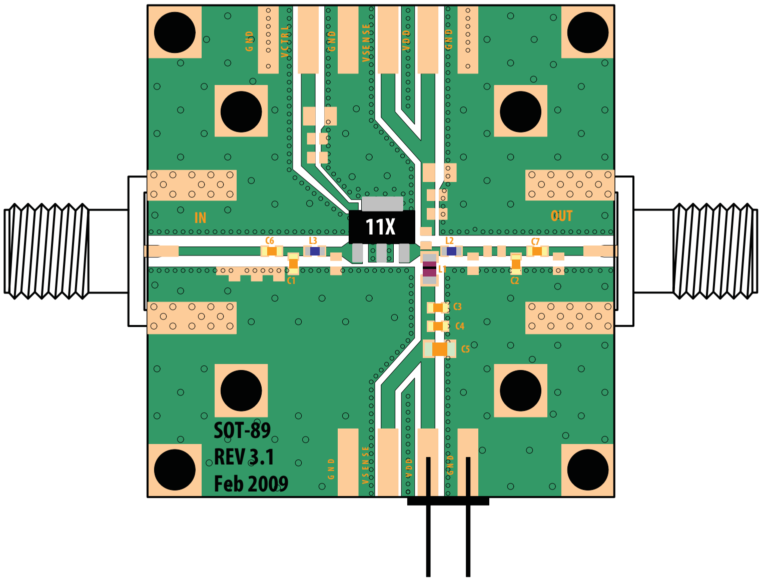


Figure 2. Demonstration board – top view

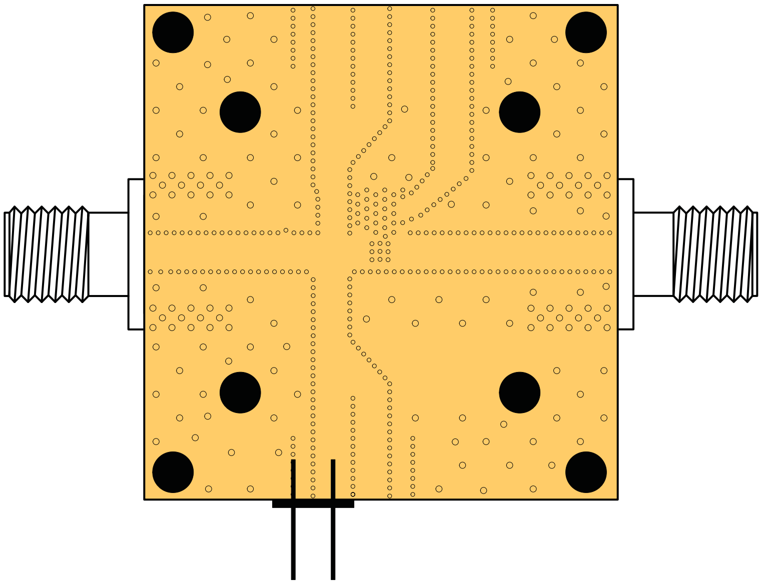


Figure 3. Demonstration board – bottom view

CPWG Design

The dimensions of the CPWG lines can easily be determined using AppCAD, a free and easy-to-use RF simulation software package available from Avago. As shown in Figure 4, the overall thickness of the board is about 62 mils, which allows SMA connectors from EF Johnson (142-0701-851) to be slipped on at both board edges. With a 20-mils diameter center pin, this requires the demonstration board transmission line width to be slightly wider to accommodate the SMA center pin. In this demonstration board, 22 mils was chosen, and the Z_O at 170 MHz is 50.1 Ω. There is some degree of freedom for the designer to determine the transmission line width as long the resultant Z_O is close to 50 Ω and able to fit a design with limited space.

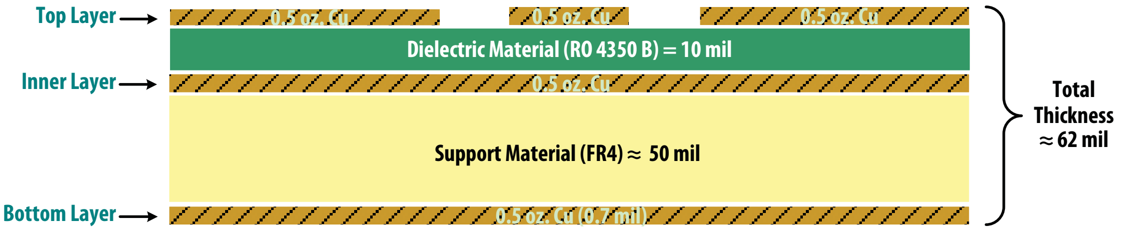
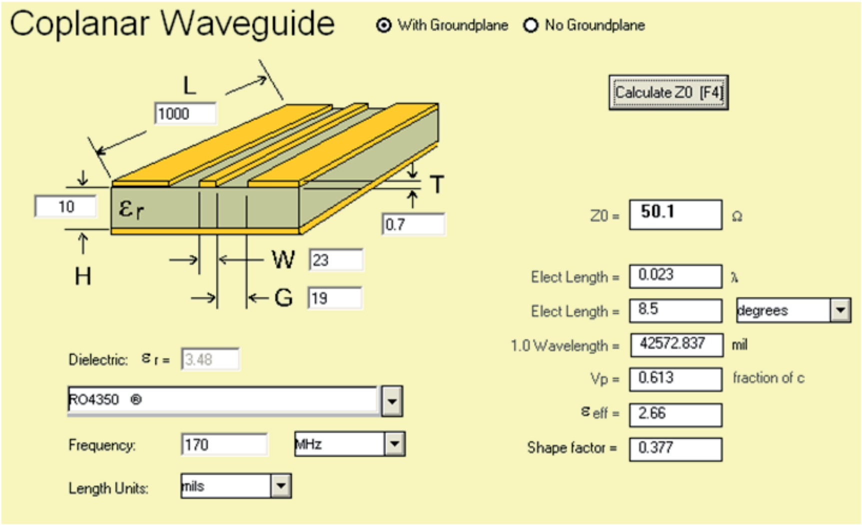


Figure 4. Demonstration board cross sectional view



● With Groundplane ○ No Groundplane

L: 1000

H: 10

T: 0.7

W: 23

G: 19

Z0 = 50.1 Ω

Elect Length = 0.023 λ

Elect Length = 8.5 degrees

1.0 Wavelength = 42572.837 mil

Vp = 0.613 fraction of c

ε eff = 2.66

Shape factor = 0.377

Dielectric: ε r = 3.48

RO4350 ®

Frequency: 170 MHz

Length Units: mils

Figure 5. CPWG design using AppCAD

Application Example

In order to demonstrate the suitability of the MGA-31189 as an IF band amplifier, the device is tuned and optimized to four IF bands, 70 MHz, 170 MHz, 240 MHz and 500 MHz. Table 1 shows the IF frequency bands with their end application.

Table 1. Typical IF band and their applications

Frequency (MHz)	Application
70	CDMA BTS
153.6	3G BTS
170	GSM
204	TD/SCDMA
240	Wireless Data
465	GPS
500	Broadband Access

For most applications, all that is required to operate the MGA-31189 is to apply a DC bias of +5 V and match the RF input and output. The following discussion describes a typical application for the MGA-31189 for four different IF bands. Design steps discussed include matching the input and output as well as providing a DC bias while maintaining acceptable linearity, gain and noise figure performance. The four IF amplifier designs were based on the typical requirements shown in Table 2.

Table 2. Typical IF amplifier requirements

	Parameter	Performance	Unit
1	Input Return Loss (IRL)	≥ 10	dB
2	Small Signal Gain (SSGain)	≥ 20	dB
3	Reverse Isolation (ISO)	≥ 27	dB
4	Output Return Loss (ORL)	≥ 10	dB
5	Output Third-Order Intercept Point (OIP3)	≥ 40	dBm

Impedance Matching

The most important criteria when designing with the MGA-31189 is choosing the input and output-matching network. The MGA-31189 MMIC is designed to give an excellent 40 dBm of OIP3 across the band, but in order to achieve this performance the input and output matching networks must present specific impedances (Γ_S and Γ_L) to the MGA-31189. Matching to the input and the output of the MGA-31189 can be modified to make tradeoffs between IP3, NF and return loss performance.

Table 3. Required matching for NF, IP3, IRL, ORL and Gain

Matching Purpose	Input Tuning	Output Tuning
IP3	Γ_S	Γ_L
NF	Γ_{opt}	none
IRL	S11*	none
ORL	none	S22*
SSGain	S11*	S22*

In general, matching for minimum noise figure does not necessarily guarantee good IP3 performance nor does it guarantee good gain. This is because the impedance parameters for the MGA-31189 are not guaranteed to lie near each other on a Smith chart. If all input matching parameters are near each other, or at the same point, and all output parameters also lie near each other, or at the same point, the amplifier would have minimum noise figure, maximum IP3 and maximum gain, all with a single match. Practically, this is not the case, and some parameter must be sacrificed to improve another. Table 3 lists the input and output parameters required for each type of match, and Figure 6 depicts how each is defined.

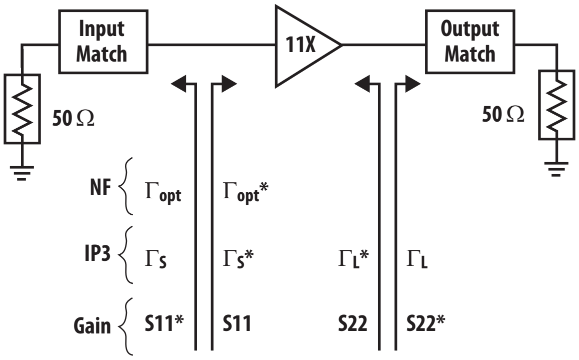


Figure 6. Typical impedance matching requirement for microwave FET and MMIC amplifiers

OIP3 depends on the input and output match, but in practice, OIP3 largely depends on the output match. Of course, these points are valid at one particular frequency point, and other frequencies will follow the same design rules but will have different locations. Also, the location of these points is largely due to the manufacturing process and partly due to IC layout, but in either case, further discussion is beyond the scope of this application note

Using EM Simulator to Determine the Optimum Load Reflection Coefficient (Γ_L)

Without OIP3 load-pull data, it is difficult to match the MGA-31189 for optimum IP3. However, based on the existing 450 MHz, 900 MHz and 1500 MHz circuit data available in the datasheet and with the aid of an electromagnetic (EM) simulator (i.e. Momentum ADS from Agilent Technologies), the Γ_L location can easily be determined.

Momentum ADS is a full-wave simulator, which is based on the Method-of-Moments (MoM) numerical method. Unlike the schematic simulator that used equations to obtain S-parameters and other electrical properties of the components under test, a full-wave simulation actually solves Maxwell's equation for the design. As a result, a full-wave simulation is more accurate and should always be performed for devices that have bends or close gaps or when the user wishes to model the device as accurately as possible [4].

Figures 7 to 9 show a comparison between the measured Γ_L obtained using the load-pull method and the simulated Γ_L using Momentum ADS. Momentum ADS is able to accurately replicate the measured Γ_L. Due to this fact, Γ_L for the IF frequencies can be determined using the same simulation method, and Figure 10 illustrates the Γ_L locations for the 70 MHz, 170 MHz, 240 MHz and 500 MHz circuits that are discusses in subsequent sections.

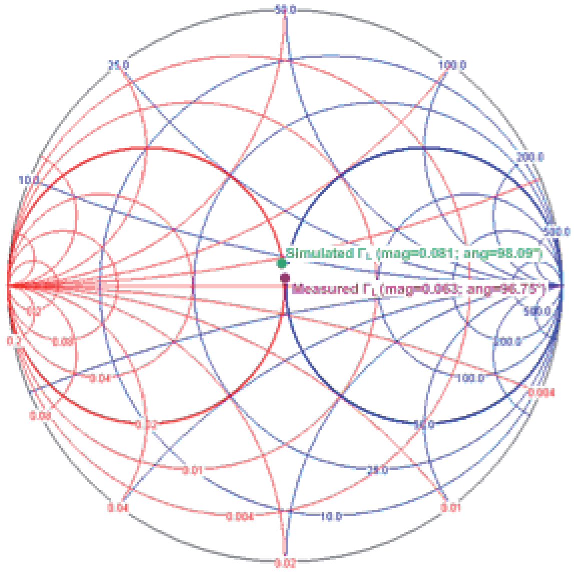


Figure 7. Comparison of simulated and measured Γ_L at 450 MHz

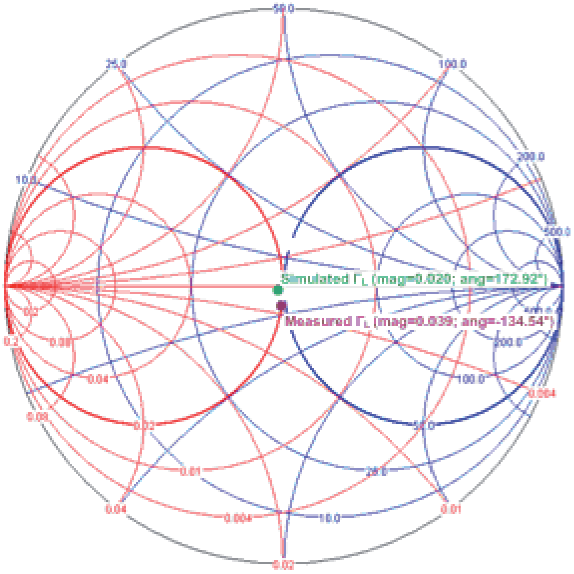


Figure 8. Comparison of simulated and measured Γ_L at 900 MHz

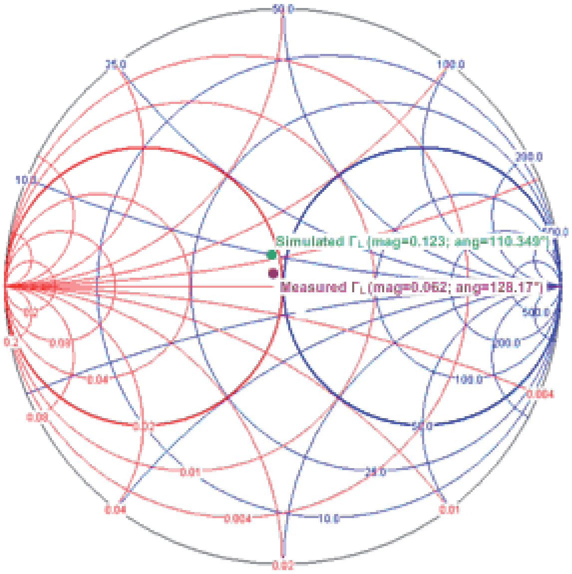


Figure 9. Comparison of simulated and measured Γ_L at 1500 MHz

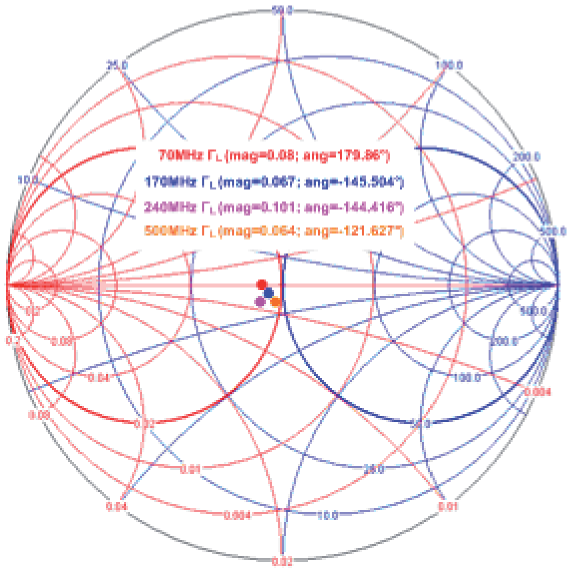


Figure 10. Simulated Γ_L for 70 MHz, 170 MHz, 240 MHz and 500 MHz

70 MHz IF Amplifier Design

When designing a DC biasing scheme, a good rule of thumb to follow is to limit series reactance to less than 5 Ω and keep shunt reactance above 500 Ω [3]. In order to achieve this reactance value, a minimum inductance of 1.1 μH is needed, and typically a "μH" range inductor will come either with a large footprint, i.e. 1206 and 1210, or very low Q. The large size of the inductor and lower Q is not practical for a miniature and high linearity wireless application, so a 2012 size, 820 nH wirewound inductor (L1), with a reasonable reactance of 361 Ω at 70 MHz, was chosen. On the other hand, the high Q could be a disadvantage in a narrowband application because of sensitivity to part variation. Even though the reactance is lower than the suggested value, it is sufficient to isolate the DC supply from in-band signals. In addition, the high Q (minimum of 23) offered by the TOKO wirewound inductor will minimize the loss and improve OIP3 performance.

The 0.1 μF (C4) and 2.2 μF (C5) DC bypass capacitors short any unwanted low frequency signalsto ground, especially signals from the voltage supply rail. If any high frequency signal is created or enters the DC supply, a 10 nF (C3) capacitor shorts it to ground. The 10 nF capacitors are also chosen as RF coupling and DC blocks at the input and output, as the 10 nF capacitors (Murata GRM155 Series) have a self-resonant frequency (SRF) at 75 MHz. A coupling capacitor is selected so that its impedance is as low as possible at the frequency of interest. The completed 70 MHz amplifier schematic is shown in Figure 11, and the component part list is shown in Table 4.

In order to fulfill the narrowband performance at 70 MHz, an L-C low-pass impedance matching configuration was chosen at the input and output of the MGA-31189. A 33 pF capacitor (C1) and 56 nH (L3) inductor are used for the input match. This combination will ensure good return loss performance at 70 MHz. A 22 pF capacitor (C2) and 33 nH inductor (L2) is used for the output match in order to steer the MGA-31189 impedance towards the new Γ_L position to ensure good OIP3 performance.

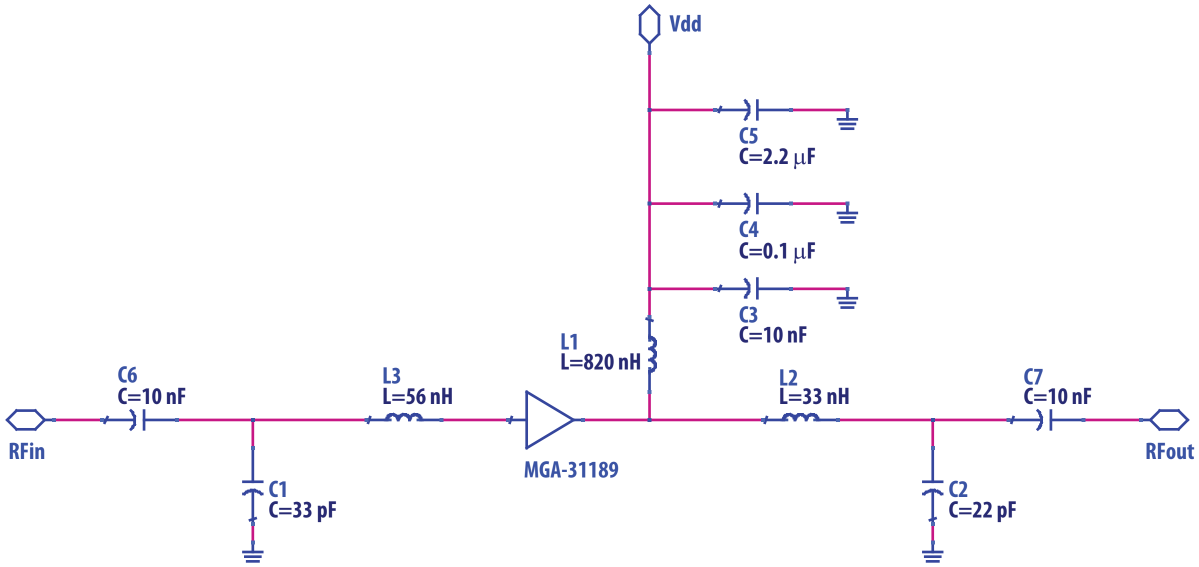


Figure 11. Schematic diagram for 70 MHz design

Table 4. Component part list for the 70 MHz design

Reference Designator	Value	Size	Part Number	Description
C1	33 pF	0402	MURATA, GRM1555C1H330JZ01	Input Matching
C2	22 pF	0402	MURATA, GRM1555C1H220JZ01	Output Matching
C3, C6, C7	10 nF	0402	MURATA, GRM155R71C103KA01	RF Bypass
C4	0.1 μF	0402	MURATA, GRM155R71C104KA88D	DC Bypass
C5	2.2 μF	0805	MURATA, GRM21BR61E225KA12L	DC Bypass
L1	820 nH	0805	TOKO, LLQ2012-FR82	RF Choke
L2	33 nH	0402	TOKO, LL1005-FHL33NJ	Output Matching
L3	56 nH	0402	TOKO, LL1005-FHL56NJ	Input Matching

Performance of the MGA-31189 at 70 MHz

With a device voltage of +5 V, the MGA-31189 demonstration board delivers a small signal gain of 21 dB, as shown in Figure 13. Figure 12 shows the return loss curves for the MGA-31189 when tuned for 70 MHz. The narrowband matching approach allows the MGA-31189 to produce an exceptionally good IRL of -20 dB and ORL of about -10.6 dB at 70 MHz. Figure 14 shows that the MGA-31189's reverse isolation is about -27.8 dB at 70 MHz. The NF for the device was measured to be about 2.2 dB at 70 MHz. As for linearity performance, the MGA-31189 produces 40.5 dBm of OIP3 and OP1dB at 70 MHz is about 23 dBm. Table 5 lists the MGA-31189's performance at 70 MHz.

Table 5. MGA-31189 performance summary at 70 MHz

Parameter	Performance	Unit
Frequency	70	MHz
Input Return Loss (IRL)	-20.0	dB
Small Signal Gain (SSGain)	21.0	dB
Reverse Isolation (ISO)	-27.8	dB
Output Return Loss (ORL)	-10.6	dB
Noise Figure (NF)	2.2	dB
Third-Order Intercept Point (OIP3)	40.5	dBm
1 dB Gain Compression Point (OP1dB)	23.0	dBm

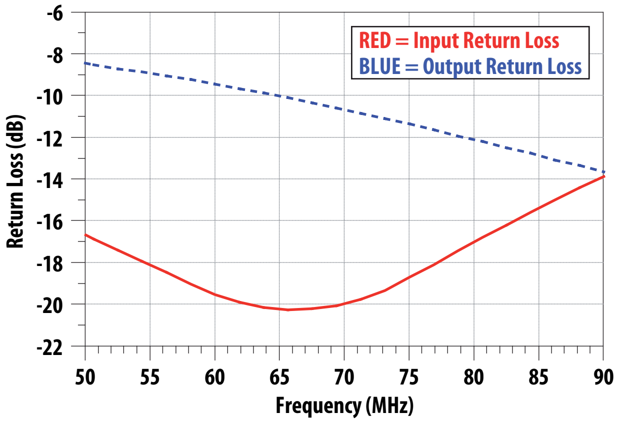


Figure 12. Input and output return loss

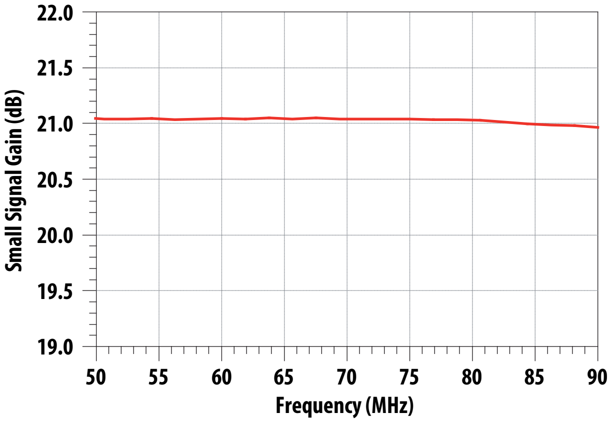


Figure 13. Small Signal Gain

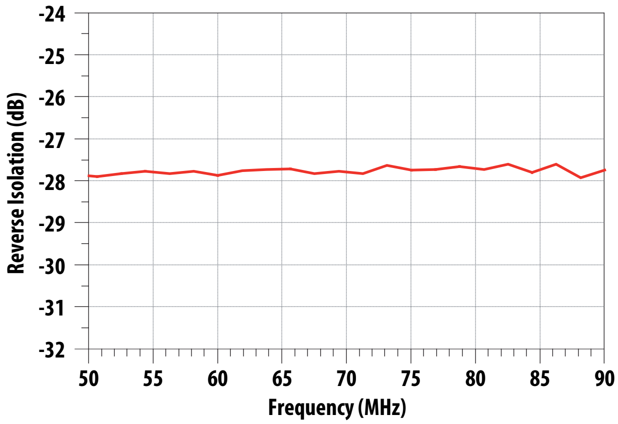


Figure 14. Reverse isolation

170 MHz IF Amplifier Design

Optimizing the MGA-31189 for best IRL and good IP3 at 170 MHz closely follows the 70 MHz design procedure, but the input and output tuning conditions must change for a different Γ_L that determines the optimum OIP3 location. Figure 15 shows the schematic diagram for a complete 170 MHz circuit, and Table 6 shows the component part list.

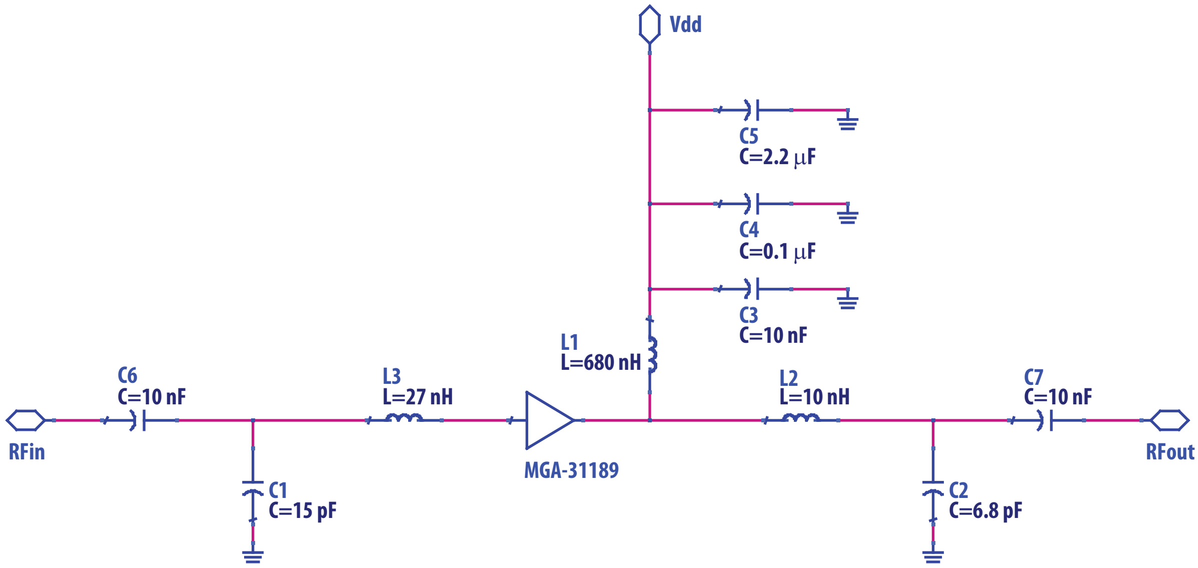


Figure 15. Schematic diagram for the 170 MHz design

Table 6. Component part list for the 170 MHz design

Reference Designator	Value	Size	Part Number	Description
C1	15 pF	0402	MURATA, GRM1555C1H150JZ01	Input Matching
C2	6.8 pF	0402	MURATA, GRM1555C1H6R8DZ01	Output Matching
C3, C6, C7	10 nF	0402	MURATA, GRM155R71C103KA01	RF Bypass
C4	0.1 µF	0402	MURATA, GRM155R71C104KA88D	DC Bypass
C5	2.2 µF	0805	MURATA, GRM21BR61E225KA12L	DC Bypass
L1	680 nH	0805	TOKO, LLQ2012-FR68	RF Choke
L2	10 nH	0402	TOKO, LL1005-FHL10NJ	Output Matching
L3	27 nH	0402	TOKO, LL1005-FHL27NJ	Input Matching

Performance of the MGA-31189 at 170 MHz

At 170 MHz, the MGA-31189 delivers a small signal gain of 21.2 dB, as shown in Figure 17, and an excellent IRL of -17.2 dB, as shown in Figure 16. On the other hand, the ORL is about -10.4 dB at 170 MHz. Figure 18 shows the MGA-31189's reverse isolation is about -27.9 dB at 170 MHz. The MGA-31189 NF was measured to be about 2.5 dB at 170 MHz. As for linearity performance, the MGA-31189 exhibits 41dBm of OIP3 and 23.1 dBm of OP1dB at 170 MHz. Table 7 shows the MGA-31189's performance at 170 MHz.

Table 7. MGA-31189 performance summary at 170 MHz

Parameter	Performance	Unit
Frequency	170	MHz
Input Return Loss (IRL)	-17.2	dB
Small Signal Gain (SSGain)	21.2	dB
Reverse Isolation (ISO)	-27.9	dB
Output Return Loss (ORL)	-10.4	dB
Noise Figure (NF)	2.5	dB
Third-Order Intercept Point (OIP3)	41.0	dBm
1 dB Gain Compression Point (OP1dB)	23.1	dBm

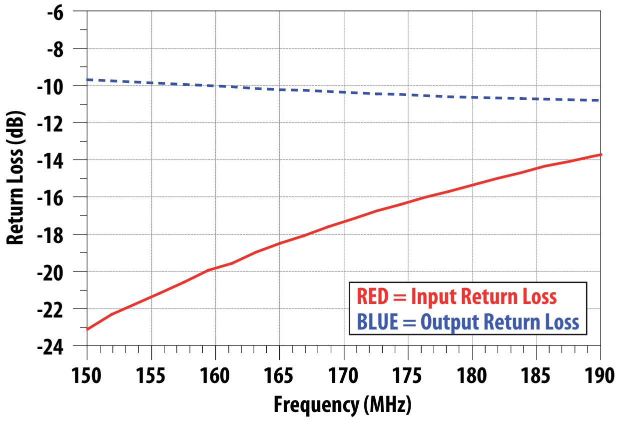


Figure 16. Input and output return loss

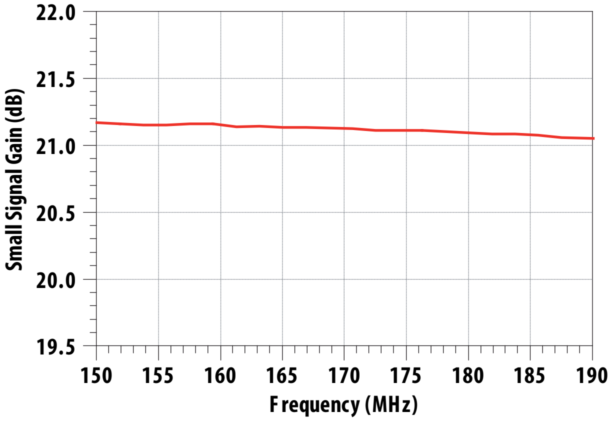


Figure 17. Small signal gain

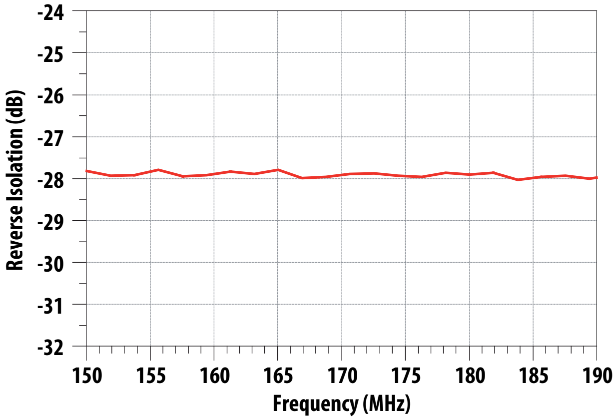


Figure 18. Reverse isolation

240 MHz IF Amplifier Design

The 240 MHz example follows the same design approach that was described in the previous 170 MHz design. A schematic diagram of the complete 240 MHz circuit, with input and output match and DC biasing components, is shown in Figure 19. The 240 MHz component part list is shown in Table 8.

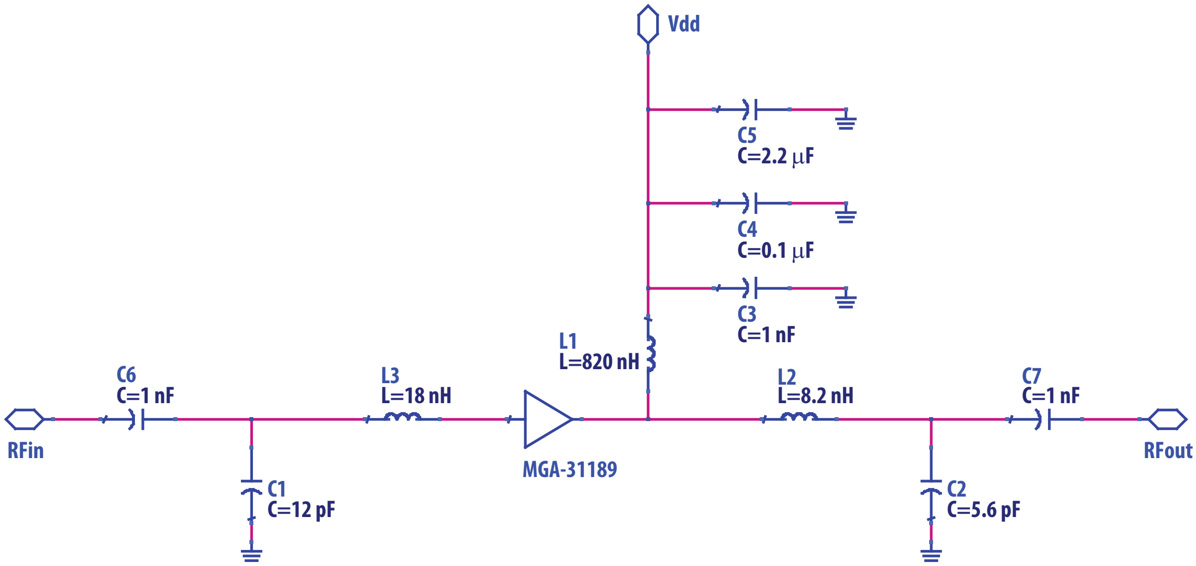


Figure 19. Schematic diagram for 240 MHz design

Table 8. Component part list for 240MHz design

Reference Designator	Value	Size	Part Number	Description
C1	12 pF	0402	MURATA, GRM1555C1H120JZ01	Input Matching
C2	56 pF	0402	MURATA, GRM1555C1H560JZ01	Output Matching
C3, C6, C7	1 nF	0402	MURATA, GRM155R71H102KA01	RF Bypass
C4	0.1 µF	0402	MURATA, GRM155R71C104KA88D	DC Bypass
C5	2.2 µF	0805	MURATA, GRM21BR61E225KA12L	DC Bypass
L1	820 nH	0805	TOKO, LLQ2012-FR82	RF Choke
L2	8.2 nH	0402	TOKO, LL1005-FHL8N2J	Output Matching
L3	18 nH	0402	TOKO, LL1005-FHL18NJ	Input Matching

Performance of the MGA-31189 at 240MHz

With a +5 V supply, the MGA-31189's small signal gain was measured to be 21.1 dB, as shown in Figure 21. IRL was -15.4 dB and ORL was -12.1 dB as shown in Figure 20. The MGA-31189 delivered a noise figure of 2.6 dB at 240 MHz. Figure 22 shows the MGA-31189's reverse isolation to be about -28 dB at 240 MHz. The nominal OIP3 was measured to be 40.8 dBm, and OP1dB was observed to be 23.4 dBm at 240 MHz. Table 9 shows the MGA-31189 performance at 240 MHz.

Table 9. MGA-31189 performance summary at 240 MHz

Parameter	Performance	Unit
Frequency	240	MHz
Input Return Loss (IRL)	-15.4	dB
Small Signal Gain (SSGain)	21.1	dB
Reverse Isolation (ISO)	-28.0	dB
Output Return Loss (ORL)	-12.1	dB
Noise Figure (NF)	2.6	dB
Third-Order Intercept Point (OIP3)	40.8	dBm
1 dB Gain Compression Point (OP1dB)	23.4	dBm

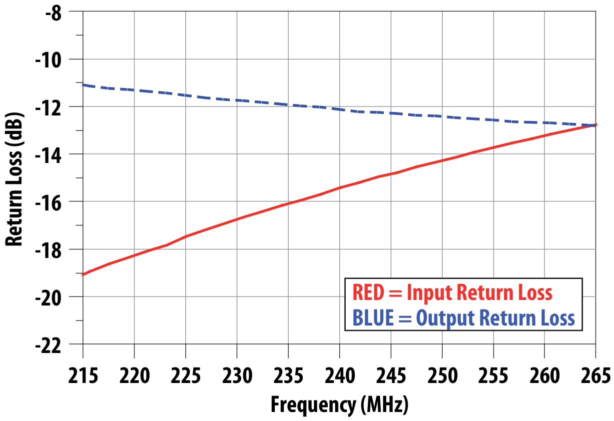


Figure 20. Input and output return loss

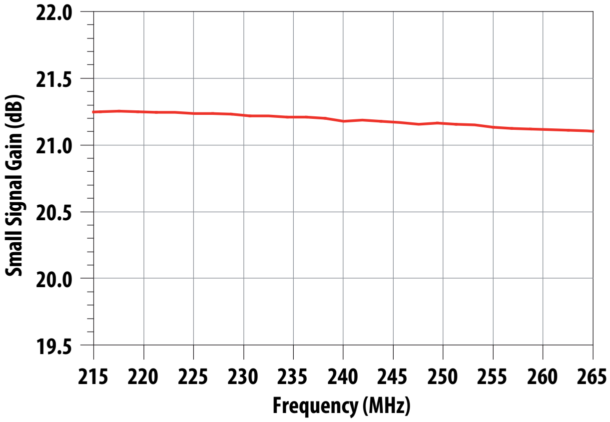


Figure 21. Small signal gain

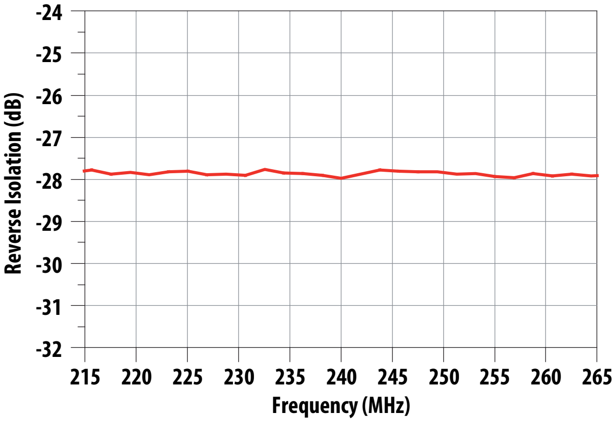


Figure 22. Reverse isolation

500 MHz IF Amplifier Design

The design process and same PCB layout used for previous IF bands was repeated for the 500 MHz amplifier. The schematic diagram and component values for the 500 MHz design are shown in Figure 23 and Table 10 respectively.

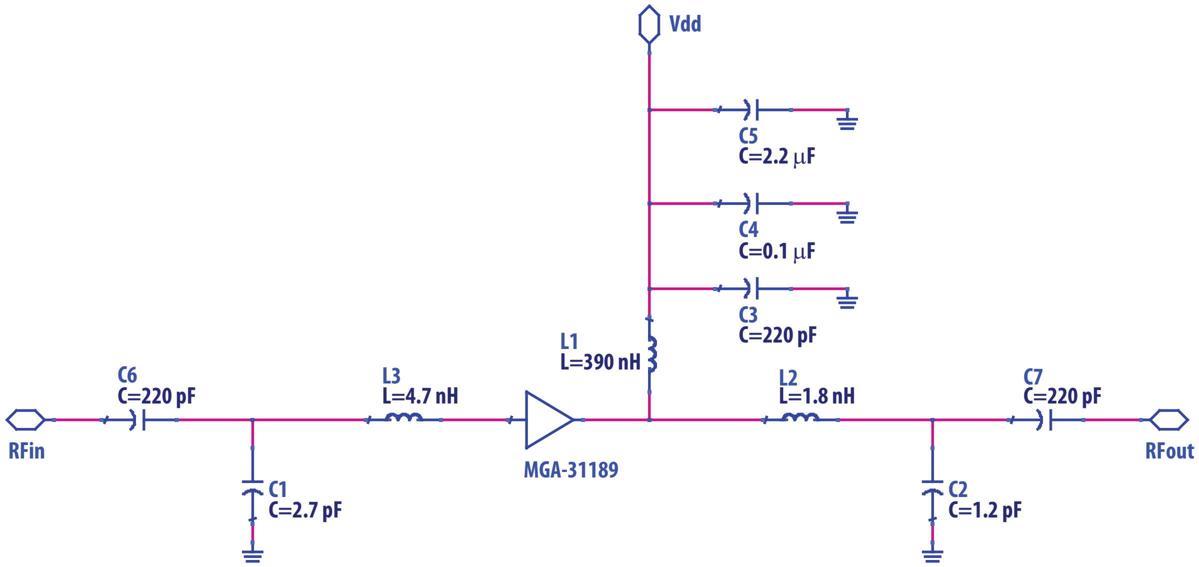


Figure 23. Schematic diagram for the 500 MHz design

Table 10. Component part list for the 500 MHz design

Reference Designator	Value	Size	Part Number	Description
C1	2.7 pF	0402	MURATA, GRM1555C1H2R7CZ01	Input Matching
C2	1.2 pF	0402	MURATA, GRM1555C1H1R2CZ01	Output Matching
C3, C6, C7	220 pF	0402	MURATA, GRM1555C1H221JA01	RF Bypass
C4	0.1 µF	0402	MURATA, GRM155R71C104KA88D	DC Bypass
C5	2.2 µF	0805	MURATA, GRM21BR61E225KA12L	DC Bypass
L1	390 nH	0805	TOKO, LLQ2012-FR39	RF Choke
L2	1.8 nH	0402	TOKO, LL1005-FHL1N8S	Output Matching
L3	4.7 nH	0402	TOKO, LL1005-FHL4N7S	Input Matching

Performance of the MGA-31189 at 500 MHz

The MGA-31189 delivers good performance within the 500 MHz IF band. With a Vdd of +5 V and typical Idd of 110 mA, the device is produces 21.1 dB of small signal gain, as shown in Figure 25, and an IRL of -23.9 dB and ORL of -10.8 dB, as shown in Figure 24. The MGA-31189 delivers a noise figure of 2.1 dB at 500 MHz. As for linearity, the MGA-31189's OIP3 is approximately 40 dBm for input tones of -12 dBm amplitude and 10 MHz frequency spacing, and OP1dB is approximately 23.3 dBm. Table 11 shows the MGA-31189 performance at 500 MHz.

Table 11. MGA-31189 performance summary at 500 MHz

Parameters	Performances	Unit
Frequency	500	MHz
Input Return Loss (IRL)	-23.9	dB
Small Signal Gain (SSGain)	21.1	dB
Reverse Isolation (ISO)	-27.9	dB
Output Return Loss (ORL)	-10.8	dB
Noise Figure (NF)	2.1	dB
Third-Order Intercept Point (OIP3)	40.0	dBm
1 dB Gain Compression Point (OP1dB)	23.3	dBm

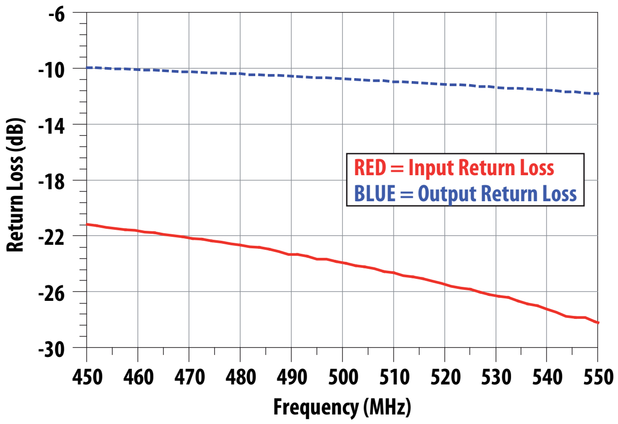


Figure 24. Input and output return loss

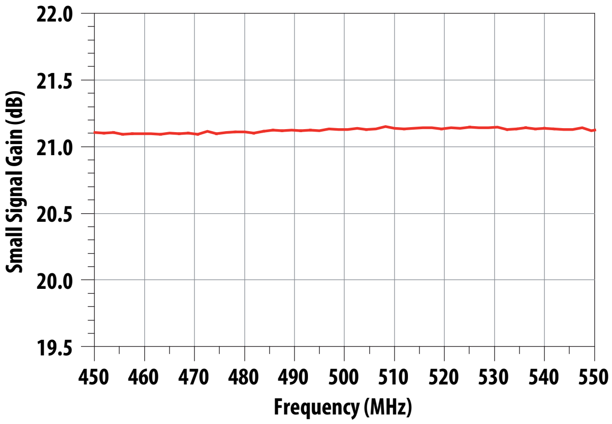


Figure 25. Small signal gain

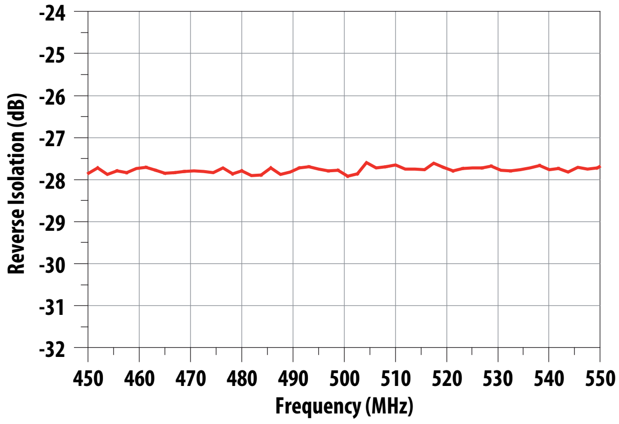


Figure 26. Reverse isolation

Phase Reference Plane

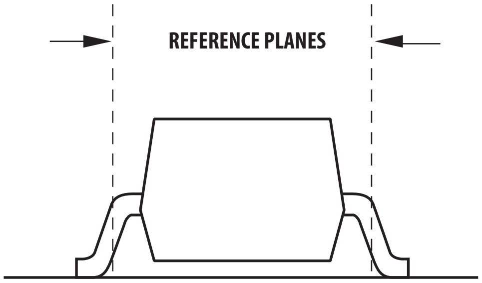


Figure 27. MGA-31189 phase reference plane

The positions of the reference planes used to specify the S-parameters and noise parameters for the MGA-31189 are shown in Figure 27. As seen in the illustration, the reference planes are located at the point where the package leads contact the TRL board (10-mils Rogers RO4350).

PCB Design and Layout Guidelines

Details about the recommended PCB land pattern, stencil design and reflow profile for Avago's SOT-89 devices can be found in Application Note 5051 [2] .

Conclusion

This application note clearly shows that the MGA-31189 is well suit for narrowband IF applications, as demonstrated by example designs that exhibited good performance when tuned to IF frequencies. Proper input and output matching will guarantee good return loss and linearity, as well as good noise figure performance at IF frequencies.

Although this work covers only four IF frequencies (70 MHz, 170 MHz, 240 MHz and 500 MHz), the MGA-31189 can be tuned for other frequencies and applications within the 50 MHz to 2 GHz frequency range with the techniques discussed.

References

[1] "Characteristics of E-pHEMT vs. HBTs for PA Applications, White Paper, Avago Technologies, March 2010.

[2] "SOT89 Package", Application Note 5051, Avago Technologies

[3] "MGA-53543", Datasheet, Avago Technologies.

[4] "What's All This Planar EM simulation Stuff Anyhow?" Murthy Upmaka, Agilent ADS Momentum Seminar, 2003.

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