

Application Note No. 115

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra Low Noise BFR740L3 SiGe:C

RF & Protection Devices



Never stop thinking

Edition 2007-08-30

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Application Note No. 115

Revision History: 2007-08-30, Rev. 1.2

Previous Version: 2005-08-29, Rev. 1.1

Page	Subjects (major changes since last revision)
All	Layout changes

1 Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra Low Noise BFR740L3 SiGe:C

Applications

- 2.4 + 5 GHz ISM Bands, including 802.11 a/b/g WLAN, 2.4 + 5 GHz Cordless Phones, UWB, etc.

Overview

- The Ultra Low Noise BFR740L3 Silicon-Germanium: Carbon Heterojunction Bipolar Transistor (HBT) is shown in a simple, low-cost general-purpose wideband LNA application. Resistive feedback is used to achieve broadband matching. "0201" case size passive components are used to reduce occupied PCB area. Total component count = 10 pieces, including BFR740L3 transistor.
- The BFR740L3 TSLP-3-4 package is only 1 x 0.6 x 0.4 mm, and is suitable for use in modules. The complete amplifier only uses 16mm² of PCB area.

Design Goals

- The primary goals of this LNA are
 - 1) consume ≤ 10 mA current and
 - 2) achieve 10 dB minimum gain at 6 GHz. (A previous example consumed 13mA)

Summary of Results

($T = 25^\circ\text{C}$, Network Analyzer Source Power $\cong -30$ dBm, $V_{CC} = 3.0$ V, $I = 10.0$ mA)

Table 1 Summary of Results

Frequency MHz	dB[s11] ²	dB[s21] ²	dB[s12] ²	dB[s22] ²	NF^* dB	IIP_3 dBm	OIP_3 dBm	IP_{1dB} dBm	OP_{1dB} dBm
2400	10.2	15.7	20.3	9.3	1.1	-0.2	+15.5	-10.9	+3.8
2483	10.6	15.5	20.2	9.4	1.1	---	---	---	---
4900	17.3	11.0	15.6	8.8	1.3	+6.5	+17.5	-5.0	+5.0
6000	24.0	9.9	13.8	10.7	1.3	---	---	---	---

* PCB loss is not extracted for these results. If PCB losses were extracted, Noise Figure (NF) would be approximately 0.2 dB lower at 2.4 GHz, and approximately 0.3 dB lower at 4.9 GHz.

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Comments

- Achieved 9.9 dB gain at 6 GHz, only 0.1 dB short of goal. Gain could be increased slightly with use of higher Q components e.g. "0201" coil used on collector has Q value of <10.
- Output matching needs slight improvement. Feedback resistance was increased to 1 k Ω from original 560 Ω in order to get back some gain lost by decreasing collector current from 13 mA to 10 mA. This trade-off increased gain but degraded output matching slightly.
- Amplifier shows good Stability margin e.g. "K" factor > 1 from approximately 200 MHz to 8 GHz. K value dips below 1.0 at low frequencies (< 200 MHz) but this could be improved by increasing value of feedback capacitor C2 (see schematic on next page) to extend effect of negative resistive feedback (R2) to lower frequencies

PC Board Cross Section Diagram

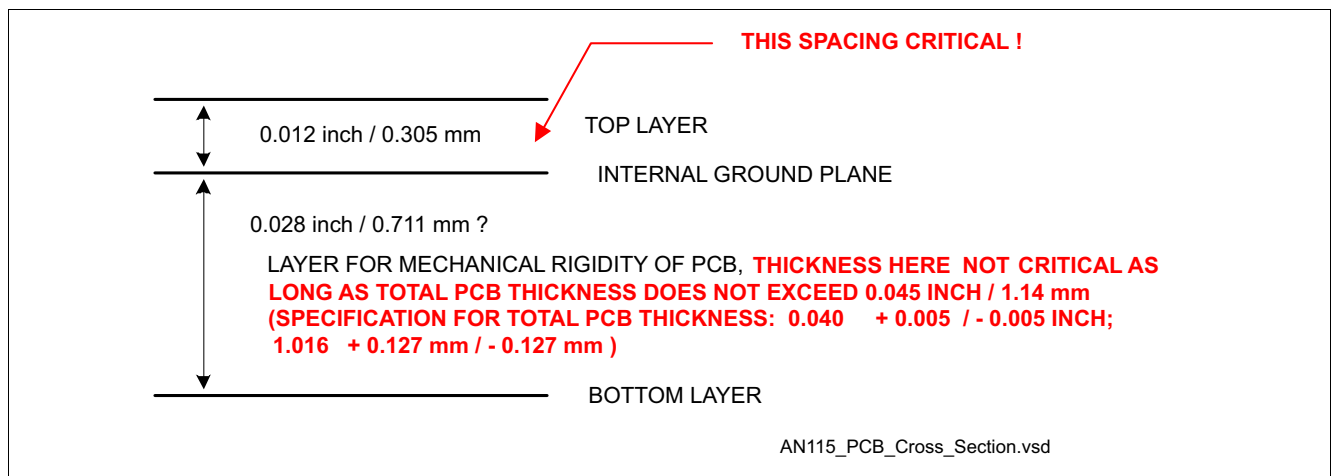


Figure 1 PCB Cross Section

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Schematic Diagram

Total Parts Count = 10, including BFR740L3 Ultra Low Noise SiGe Transistor.

Note: simple, forgiving, low-cost configuration. $V_{CE} = 2.7\text{ V}$ with 3.0 V power supply voltage. Only 1 chip coil is required

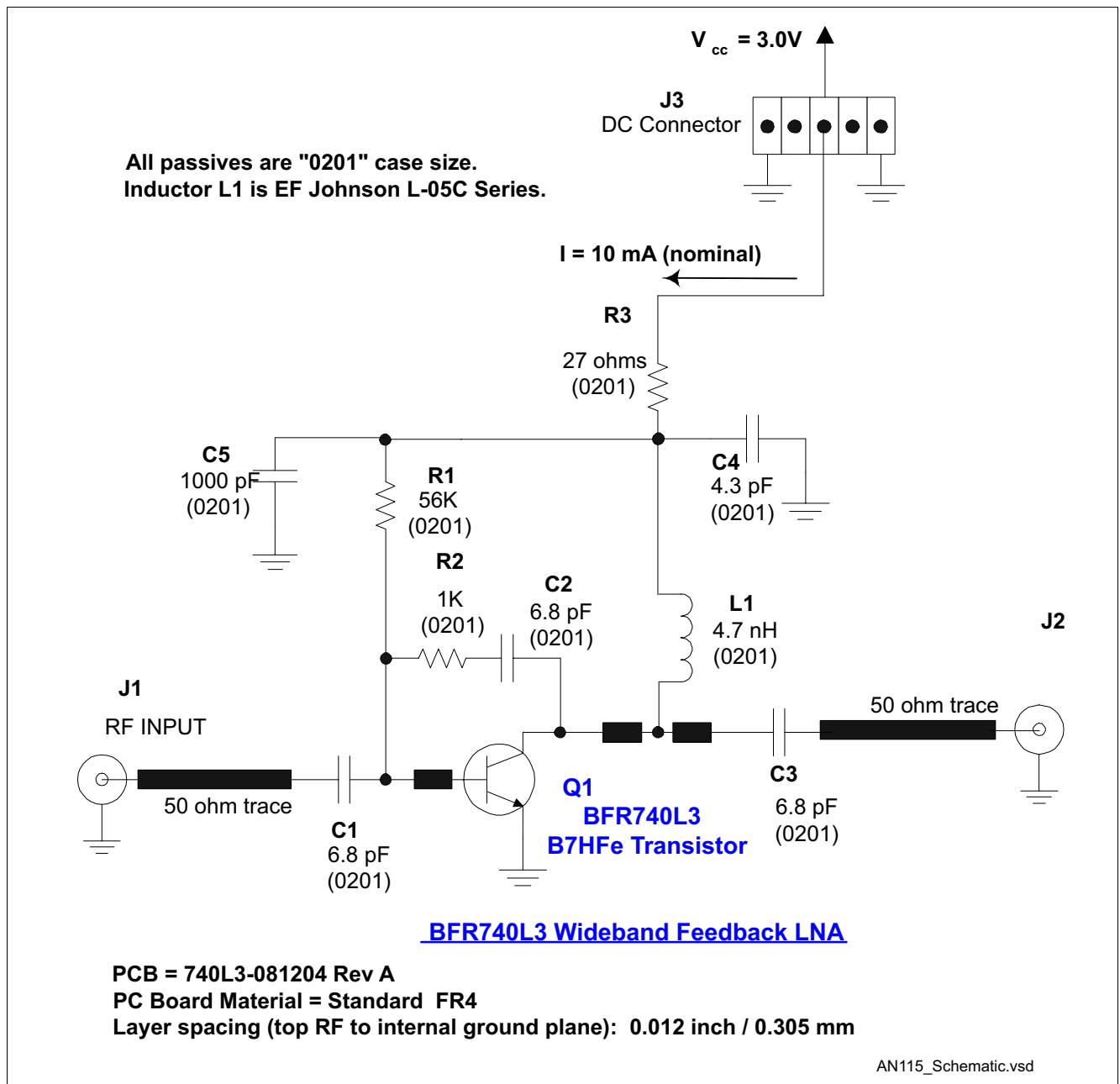


Figure 2 Schematic Diagram

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Noise Figure, Plot, 2 to 4 GHz. Center of Plot (x-axis) is 3000 MHz.

Rohde & Schwarz FSEK3

29 Aug 2005

Noise Figure

2 – 4 GHz

EUT Name: BFR740L3 Noise Figure, 2 - 4 GHz range, Dual Band Feedback LNA
 Manufacturer: Infineon Technologies
 Operating Conditions: V = 3.0 V, I = 10 mA, T = 25 C
 Operator Name: Gerard Wevers
 Test Specification: 2.4 and 5 GHz Dual Band LNA
 Comment: LWR SD00088 LNA P PCB = 740L3-081204 Rev A
 29 August 2005

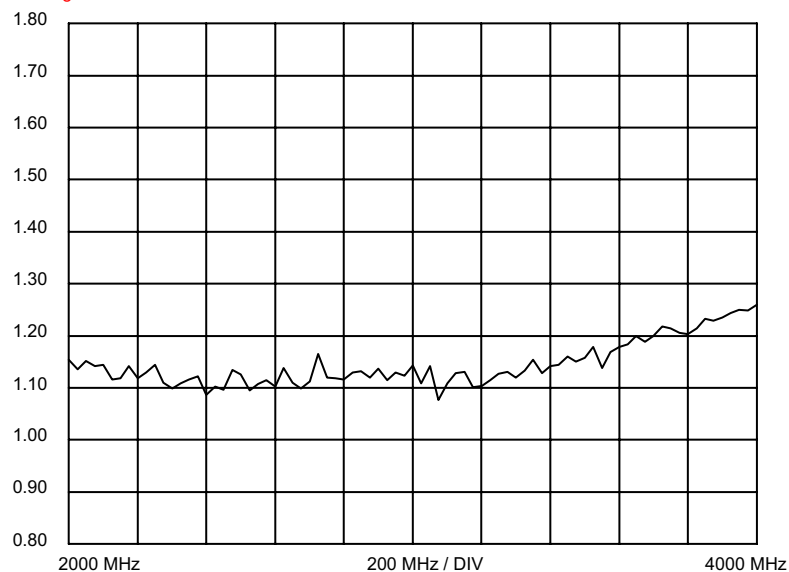
Analyzer

RF Att: 0.00 dB RBW : 1 MHz Range: 40.00 dB
 Ref Lvl: -40.00 dBm VBW : 100 Hz Ref Lvl auto: ON

Measurement

2nd stage corr: ON Mode: Direct ENR: HP346A.ENR

Noise Figure /dB



AN115_plot_Noise_Figure_2-4G.vsd

Figure 3 Plot of Noise Figure (2 - 4 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Noise Figure, Tabular Data

2 GHz - 4 GHz

From Rhode & Schwarz FSEK3+ FSEM30

System Preamplifier = MITEQ SMC-02

Table 2 Noise Figure

Frequency	Noise Figure	Temp
2000 MHz	1.15 dB	88.3 K
2025 MHz	1.14 dB	86.7 K
2050 MHz	1.15 dB	88.1 K
2075 MHz	1.14 dB	87.2 K
2100 MHz	1.14 dB	87.4 K
2125 MHz	1.12 dB	85.0 K
2150 MHz	1.12 dB	85.1 K
2175 MHz	1.14 dB	87.2 K
2200 MHz	1.12 dB	85.2 K
2225 MHz	1.13 dB	86.2 K
2250 MHz	1.14 dB	87.4 K
2275 MHz	1.11 dB	84.5 K
2300 MHz	1.10 dB	83.4 K
2325 MHz	1.11 dB	84.3 K
2350 MHz	1.12 dB	85.0 K
2375 MHz	1.12 dB	85.5 K
2400 MHz	1.09 dB	82.4 K
2425 MHz	1.10 dB	83.8 K
2450 MHz	1.10 dB	83.2 K
2475 MHz	1.13 dB	86.5 K
2500 MHz	1.13 dB	85.8 K
2525 MHz	1.09 dB	83.1 K
2550 MHz	1.11 dB	84.3 K
2575 MHz	1.12 dB	84.9 K
2600 MHz	1.10 dB	83.7 K
2625 MHz	1.14 dB	86.9 K
2650 MHz	1.11 dB	84.4 K
2675 MHz	1.10 dB	83.5 K
2700 MHz	1.11 dB	84.6 K
2725 MHz	1.16 dB	89.2 K
2750 MHz	1.12 dB	85.3 K
2775 MHz	1.12 dB	85.2 K
2800 MHz	1.12 dB	84.9 K
2825 MHz	1.13 dB	86.1 K
2850 MHz	1.13 dB	86.4 K
2875 MHz	1.12 dB	85.3 K

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Table 2 Noise Figure (cont'd)

Frequency	Noise Figure	Temp
2900 MHz	1.14 dB	86.8 K
2925 MHz	1.11 dB	84.8 K
2950 MHz	1.13 dB	86.1 K
2975 MHz	1.12 dB	85.6 K
3000 MHz	1.14 dB	87.3 K
3025 MHz	1.11 dB	84.3 K
3050 MHz	1.14 dB	87.2 K
3075 MHz	1.08 dB	81.6 K
3100 MHz	1.11 dB	84.4 K
3125 MHz	1.13 dB	86.0 K
3150 MHz	1.13 dB	86.2 K
3175 MHz	1.10 dB	83.7 K
3200 MHz	1.10 dB	83.9 K
3225 MHz	1.11 dB	84.9 K
3250 MHz	1.13 dB	85.9 K
3275 MHz	1.13 dB	86.2 K
3300 MHz	1.12 dB	85.3 K
3325 MHz	1.13 dB	86.5 K
3350 MHz	1.15 dB	88.2 K
3375 MHz	1.13 dB	86.1 K
3400 MHz	1.14 dB	87.2 K
3425 MHz	1.14 dB	87.4 K
3450 MHz	1.16 dB	88.8 K
3475 MHz	1.15 dB	87.9 K
3500 MHz	1.16 dB	88.6 K
3525 MHz	1.18 dB	90.4 K
3550 MHz	1.14 dB	86.9 K
3575 MHz	1.17 dB	89.5 K
3600 MHz	1.18 dB	90.4 K
3625 MHz	1.18 dB	90.8 K
3650 MHz	1.20 dB	92.2 K
3675 MHz	1.19 dB	91.2 K
3700 MHz	1.20 dB	92.2 K
3725 MHz	1.22 dB	93.8 K
3750 MHz	1.21 dB	93.5 K
3775 MHz	1.20 dB	92.7 K
3800 MHz	1.20 dB	92.6 K
3825 MHz	1.21 dB	93.6 K
3850 MHz	1.23 dB	95.2 K
3875 MHz	1.23 dB	94.9 K
3900 MHz	1.24 dB	95.4 K

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra**Table 2 Noise Figure (cont'd)**

Frequency	Noise Figure	Temp
3925 MHz	1.24 dB	96.2 K
3950 MHz	1.25 dB	96.7 K
3975 MHz	1.25 dB	96.6 K
4000 MHz	1.25 dB	97.5 K

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Noise Figure, Plot, 4 GHz - 7 GHz. Center of Plot (x-axis) is 5500 Mz.

Rohde & Schwarz FSEK3

29 Aug 2005

Noise Figure

4 GHz – 7 GHz

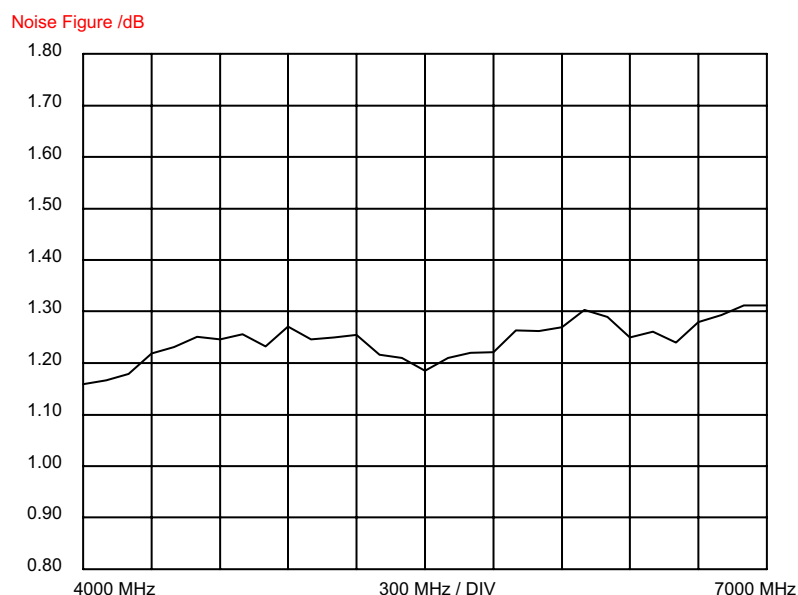
EUT Name: BFR740L3 Noise Figure, 2 - 4 GHz range, Dual Band Feedback LNA
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 29 August 2005

Analyzer

RF Att: 0.00 dB RBW : 1 MHz Range: 40.00 dB
 Ref Lvl: -33.00 dBm VBW : 100 Hz Ref Lvl auto: ON

Measurement

2nd stage corr: ON Mode: Direct ENR: HP346A.ENR



AN115_plot_Noise_Figure_4-7G.vsd

Figure 4 Noise Figure (4 GHz - 7 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Noise Figure, Tabular Data

4 GHz - 7 GHz

From Rhode & Schwarz FSEK3+ FSEM30

System Preamplifier = MITEQ AFS-040000800-10-ULN

Table 3 Noise Figure

Frequency	Noise Figure	Temp
400 MHz	1.16 dB	88.7
4100 MHz	1.17 dB	89.3
4200 MHz	1.18 dB	90.5
4300 MHz	1.22 dB	94.0
4400 MHz	1.23 dB	95.1
4500 MHz	1.25 dB	96.8
4600 MHz	1.25 dB	96.4
4700 MHz	1.26 dB	97.2
4800 MHz	1.23 dB	95.2
4900 MHz	1.27 dB	98.5
5000 MHz	1.25 dB	96.3
5100 MHz	1.25 dB	96.7
5200 MHz	1.26 dB	97.2
5300 MHz	1.22 dB	93.7
5400 MHz	1.21 dB	93.1
5500 MHz	1.19 dB	91.0
5600 MHz	1.21 dB	93.2
5700 MHz	1.22 dB	94.0
5800 MHz	1.22 dB	94.2
5900 MHz	1.26 dB	98.0
6000 MHz	1.26 dB	97.8
6100 MHz	1.27 dB	98.4
6200 MHz	1.30 dB	101.5
6300 MHz	1.29 dB	100.2
6400 MHz	1.25 dB	96.7
6500 MHz	1.26 dB	97.8
6600 MHz	1.24 dB	95.8
6700 MHz	1.28 dB	99.4
6800 MHz	1.29 dB	100.6
6900 MHz	1.31 dB	102.3
7000 MHz	1.31 dB	102.3

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Scanned Image of PC Board

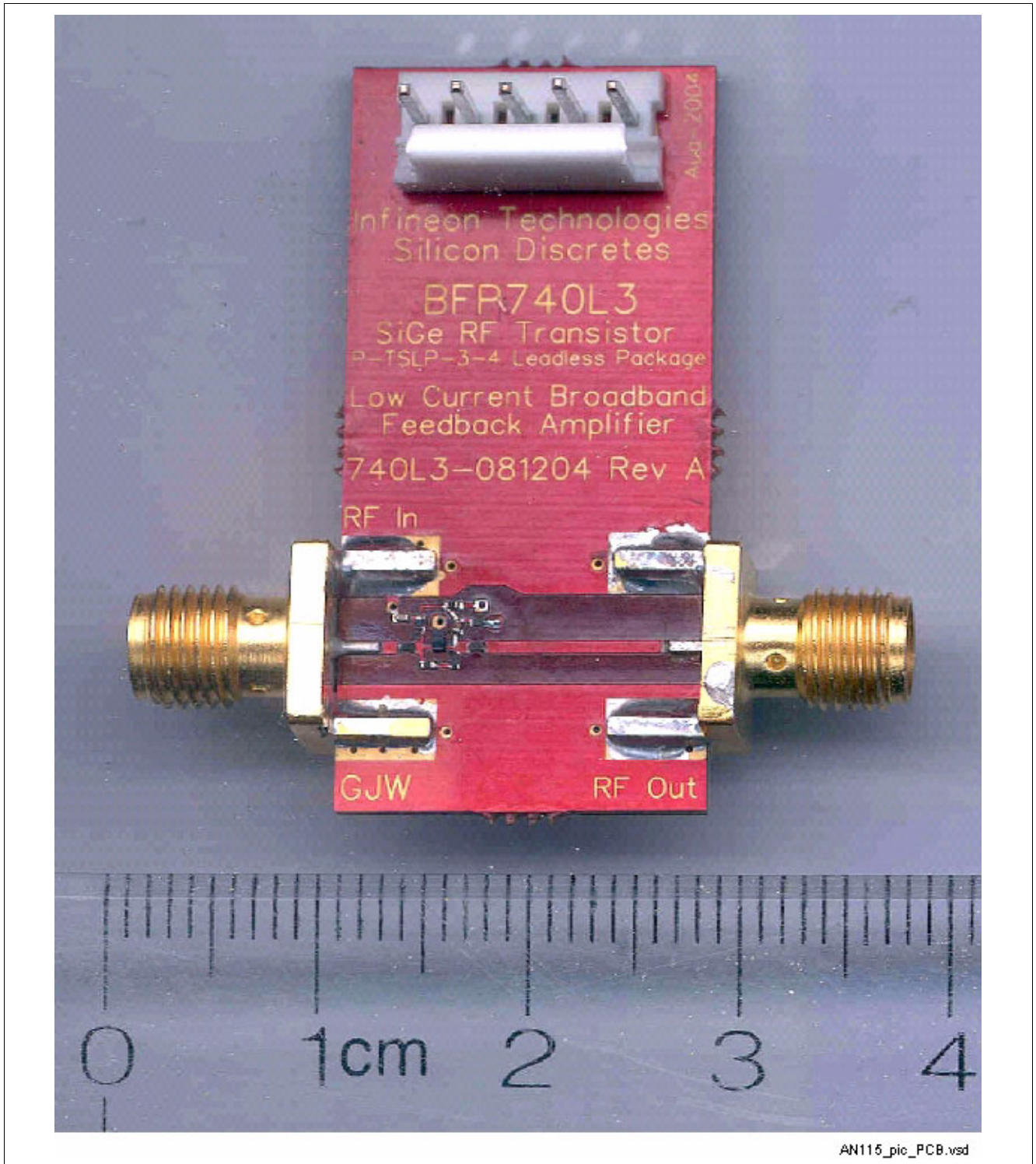


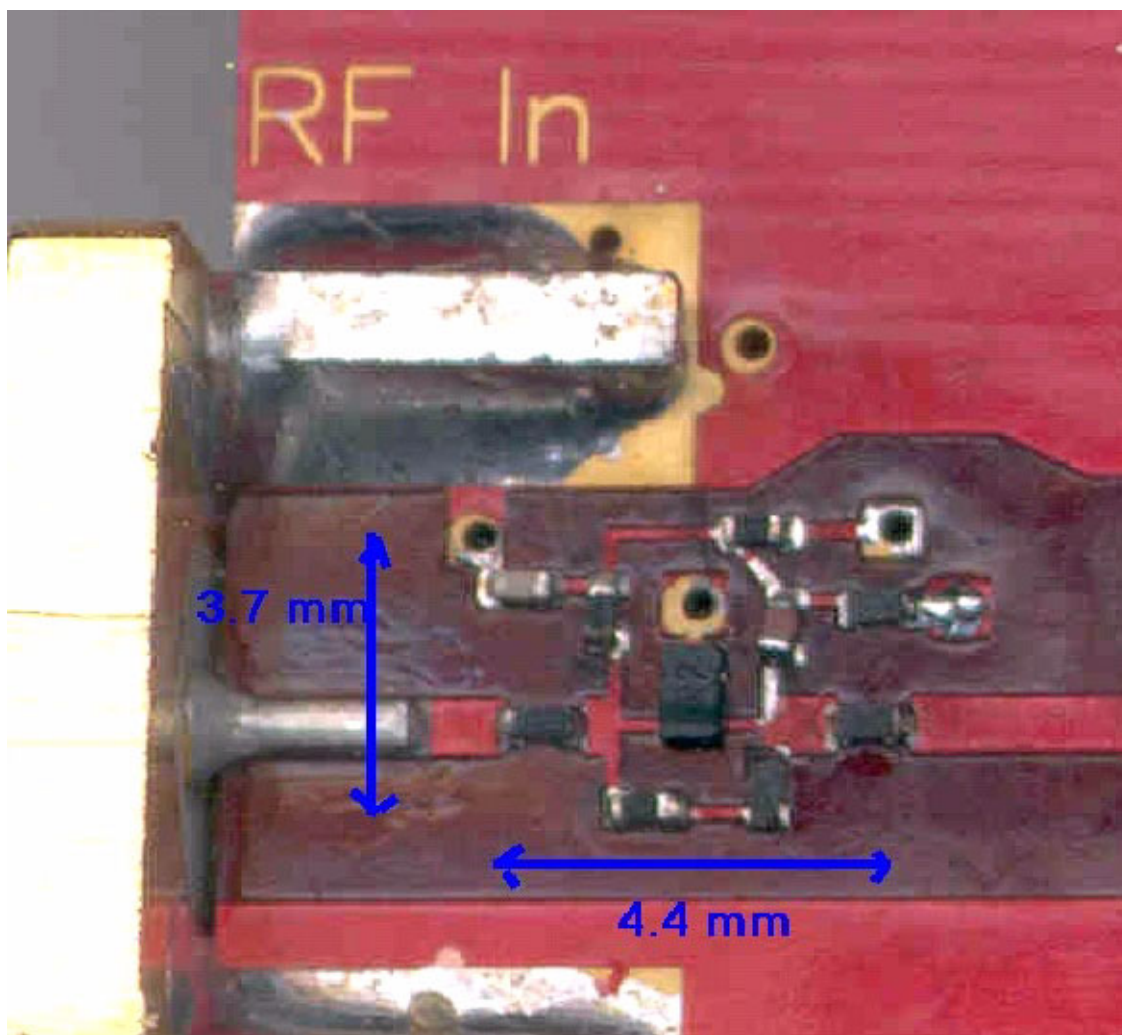
Figure 5 Image of PC Board

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Scanned Image of PC Board, Close-In Shot

Note: Use of "0201" case size components.

Total PCB area used $\cong 16.3 \text{ mm}^2$



AN115_pic_PCB_Close_In.vsd

Figure 6 Image of PC Board, Close-In Shot

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Amplifier Stability

Plots of Stability Factor "K" from 5 MHz to 8 GHz, taken directly from Rohde and Schwarz ZVC network analyzer, as network analyzer measures demo board.

Note: $K > 1$ except below 100 MHz --- this may be "artifact" due to small S12. K value is 1.02 at 6 GHz. Stability margin < 200 MHz may also be improved by increasing the value of capacitor C2, which would extend the effects of negative resistive feedback to lower frequencies

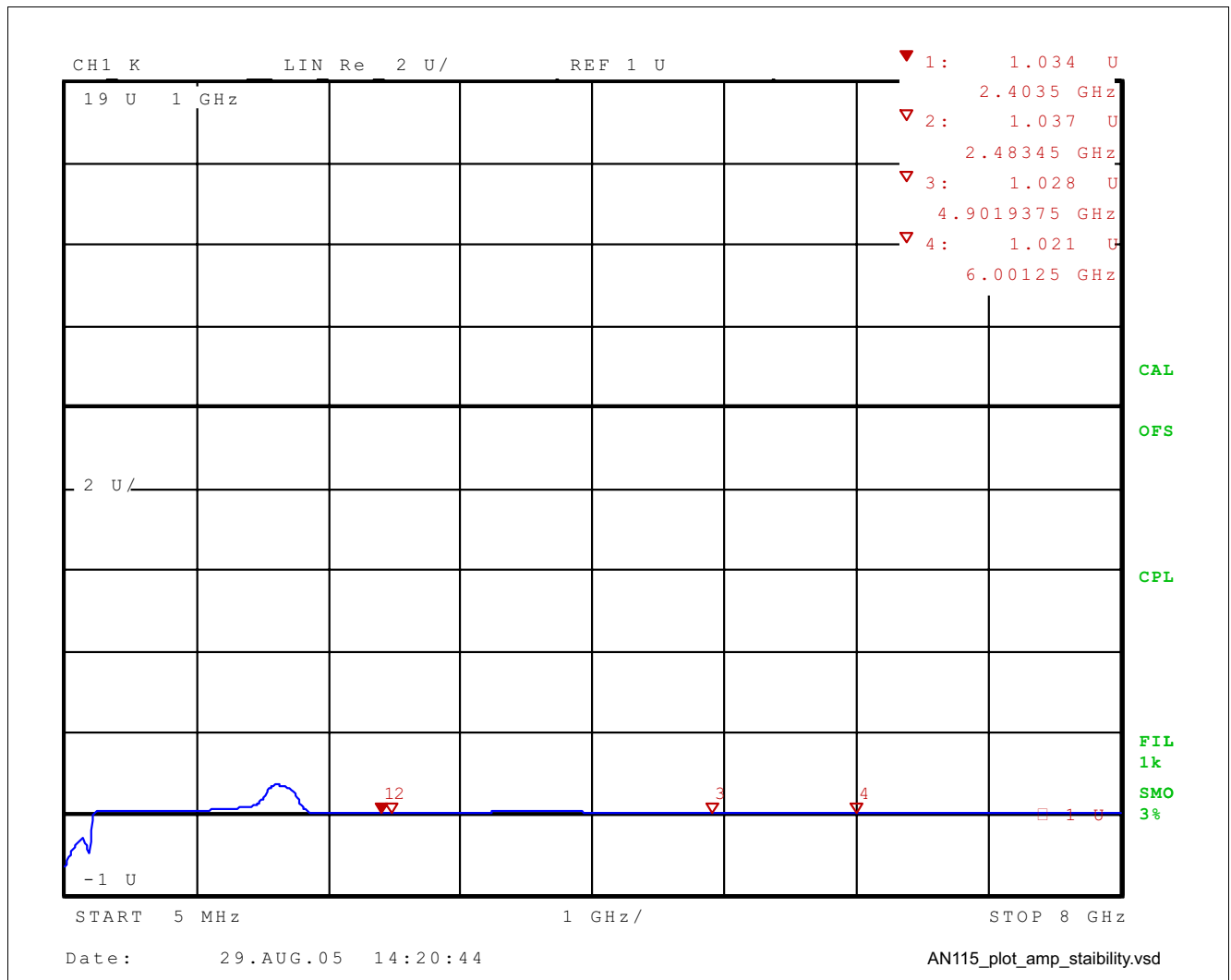


Figure 7 Amplifier Stability K(f)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Gain Compression at 2400 MHz and 4900 MHz

Amplifier is checked for output 1 dB compression point at $V_{CC} = 3\text{ V}$, $I = 10.0\text{ mA}$ (with $V_{CE} = 2.7\text{ V}$). An Agilent power meter was used to ensure accurate power levels are measured

- 2400 MHz
Output $P_{1dB} \cong +3.8\text{ dBm}$; Input $P_{1dB} = +3.8\text{ dBm} - (\text{Gain} - 1\text{ dB}) = +3.8\text{ dBm} - 14.7\text{ dB} = -10.9\text{ dBm}$
- 4900 MHz
Output $P_{1dB} \cong +5.0\text{ dBm}$; Input $P_{1dB} = +5.0\text{ dBm} - (\text{Gain} - 1\text{ dB}) = +5.0\text{ dBm} - 10.0\text{ dB} = -5.0\text{ dBm}$

Table 4 Tabular Data

P_{OUT} , dBm	2400 MHz Gain, dB	4900 MHz Gain, dB
-10.0	19.9	18.5
-9.0	19.9	18.5
-8.0	19.9	18.5
-7.0	19.8	18.5
-6.0	19.8	18.4
-5.0	19.8	18.4
-4.0	19.7	18.4
-3.0	19.7	18.4
-2.0	16.6	18.3
-1.0	19.5	18.3
0.0	19.4	18.2
+1.0	19.1	18.1
+2.0	18.6	17.9
+3.0	17.7	17.5
+4.0	16.3	16.7
+5.0		

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

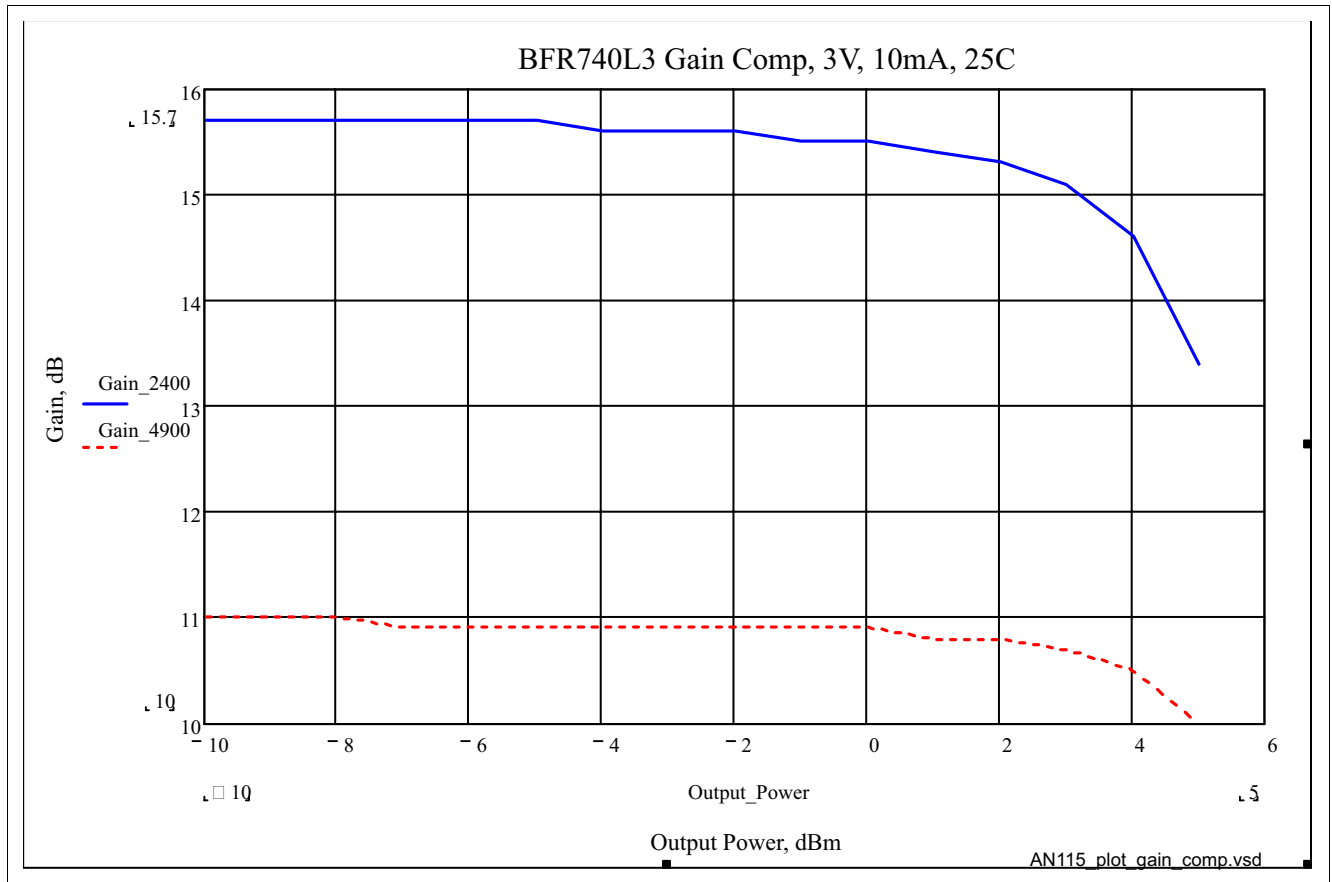


Figure 8 Plot of Gain Compression (2.4 GHz & 4.9 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Input Return Loss, Log Mag

5 MHz to 8 GHz

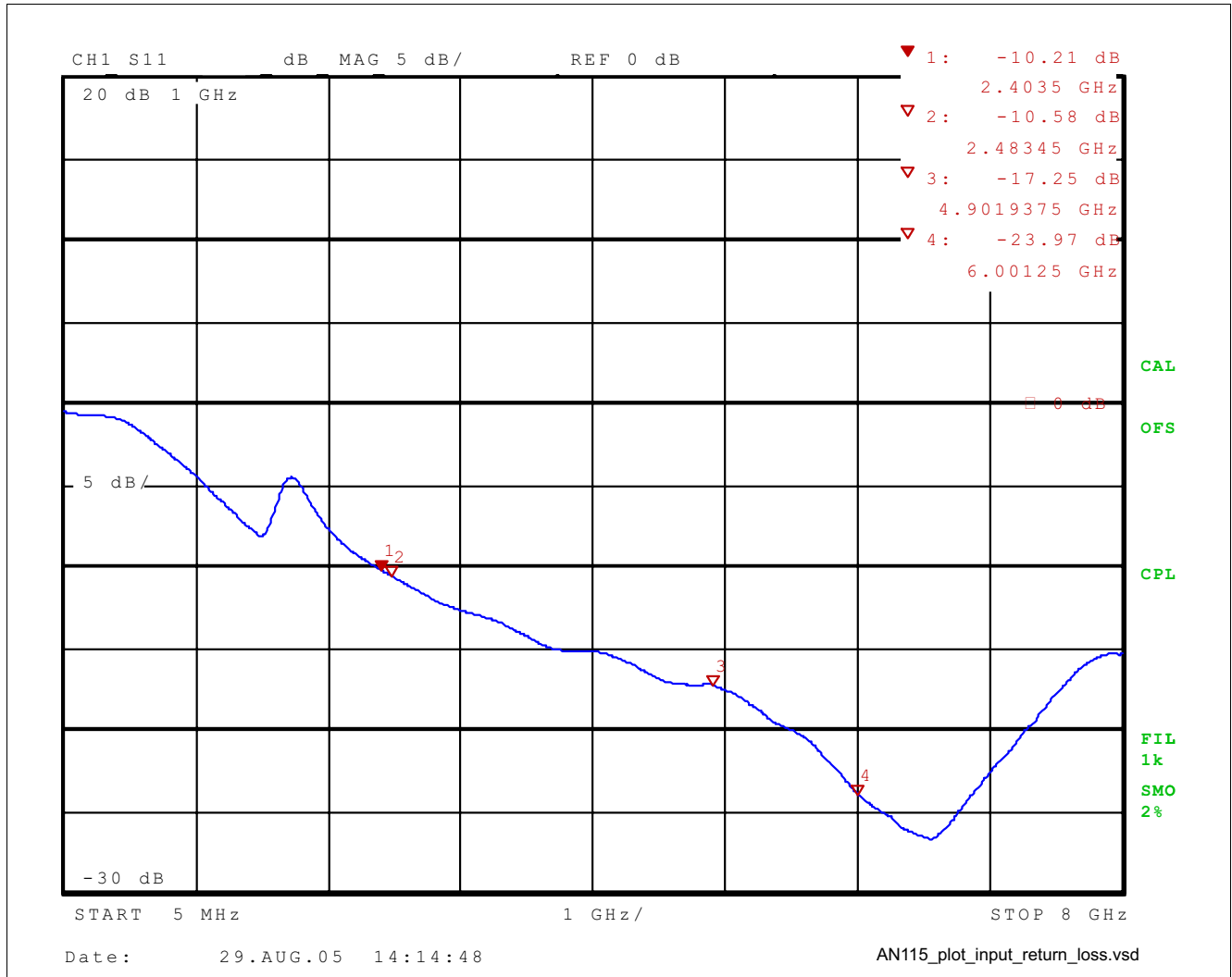


Figure 9 Plot of Input Return Loss (5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Input Return Loss, Smith Chart

Reference Plane = Input SMA Connector on PC Board

5 MHz to 8 GHz

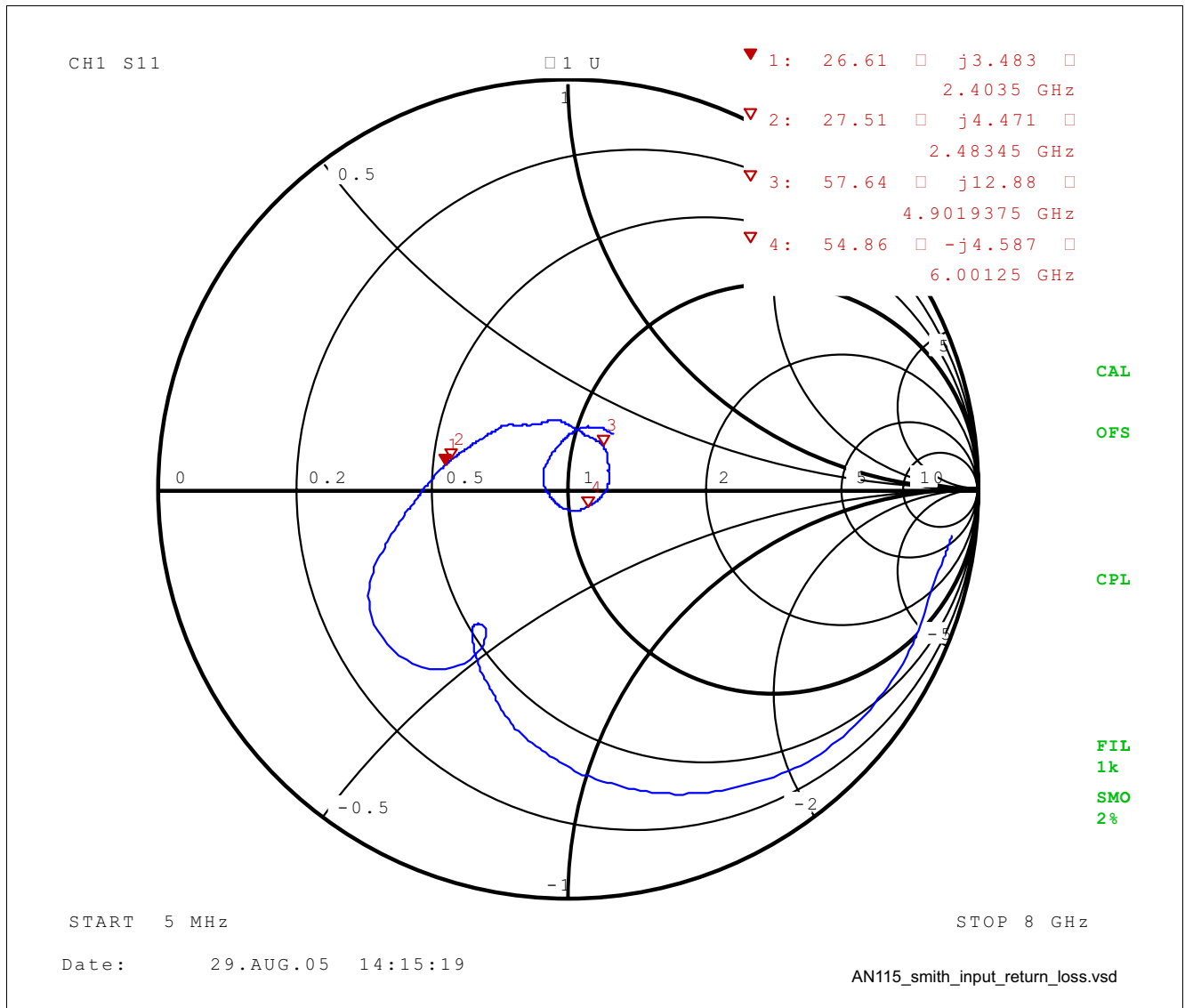


Figure 10 Smith Chart of Input Return Loss (5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Forward Gain, Wide Sweep

5 MHz to 8 GHz

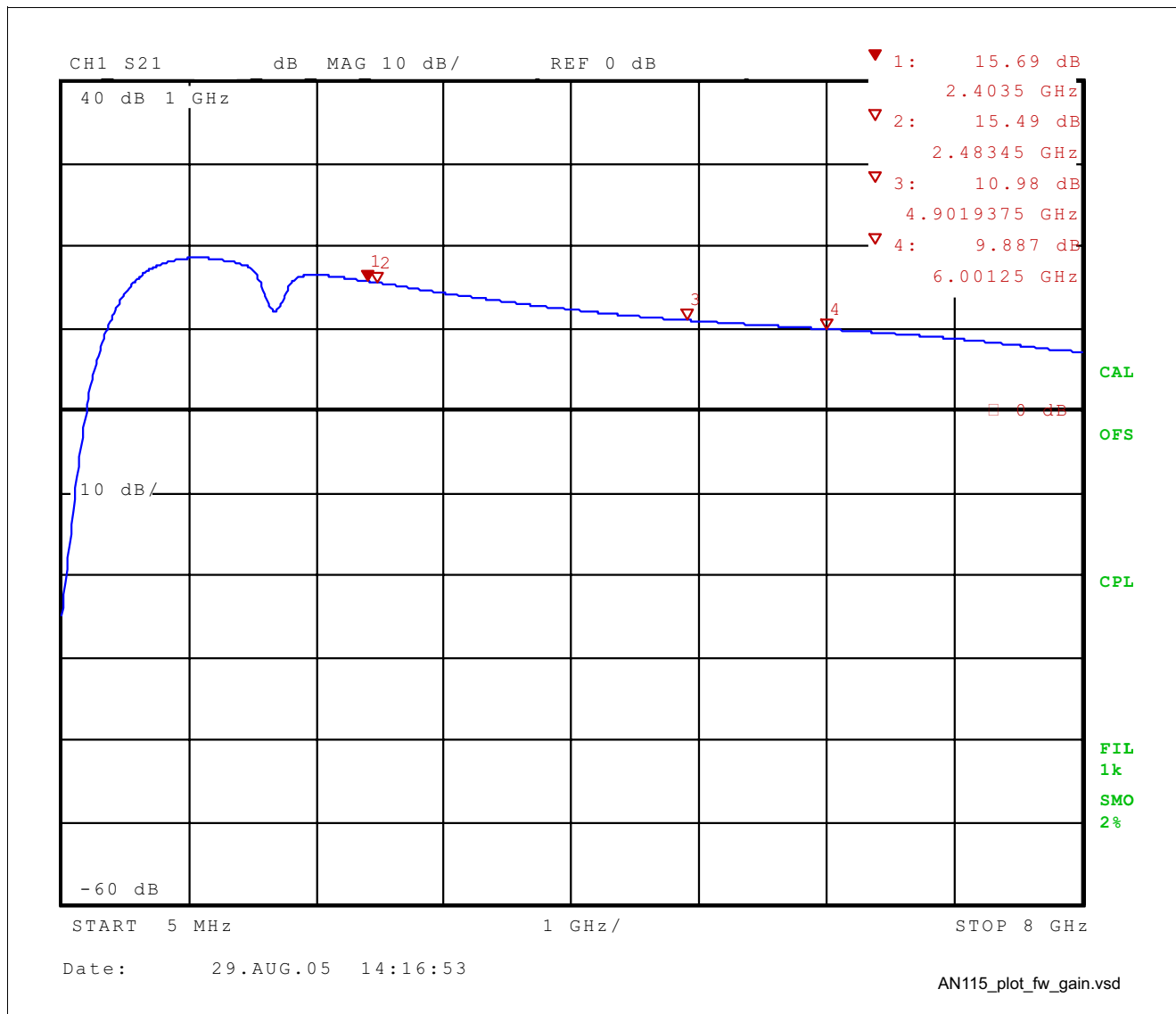


Figure 11 Plot of Forward Gain with Wide Sweep(5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Reverse Isolation

5 MHz to 8 GHz

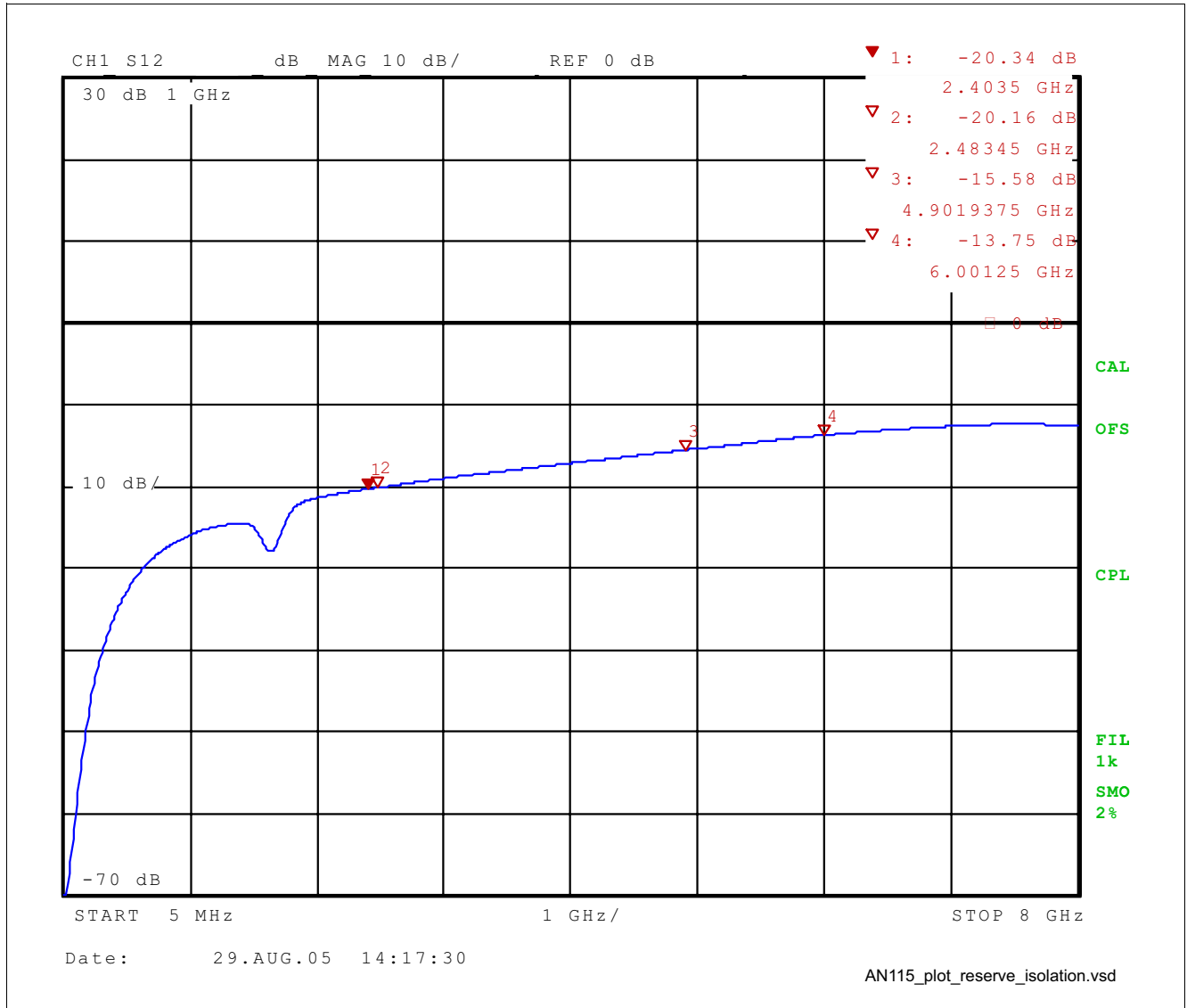


Figure 12 Plot of Reverse Isolation (5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Output Return Loss, Log Mag

5 MHz to 8 GHz

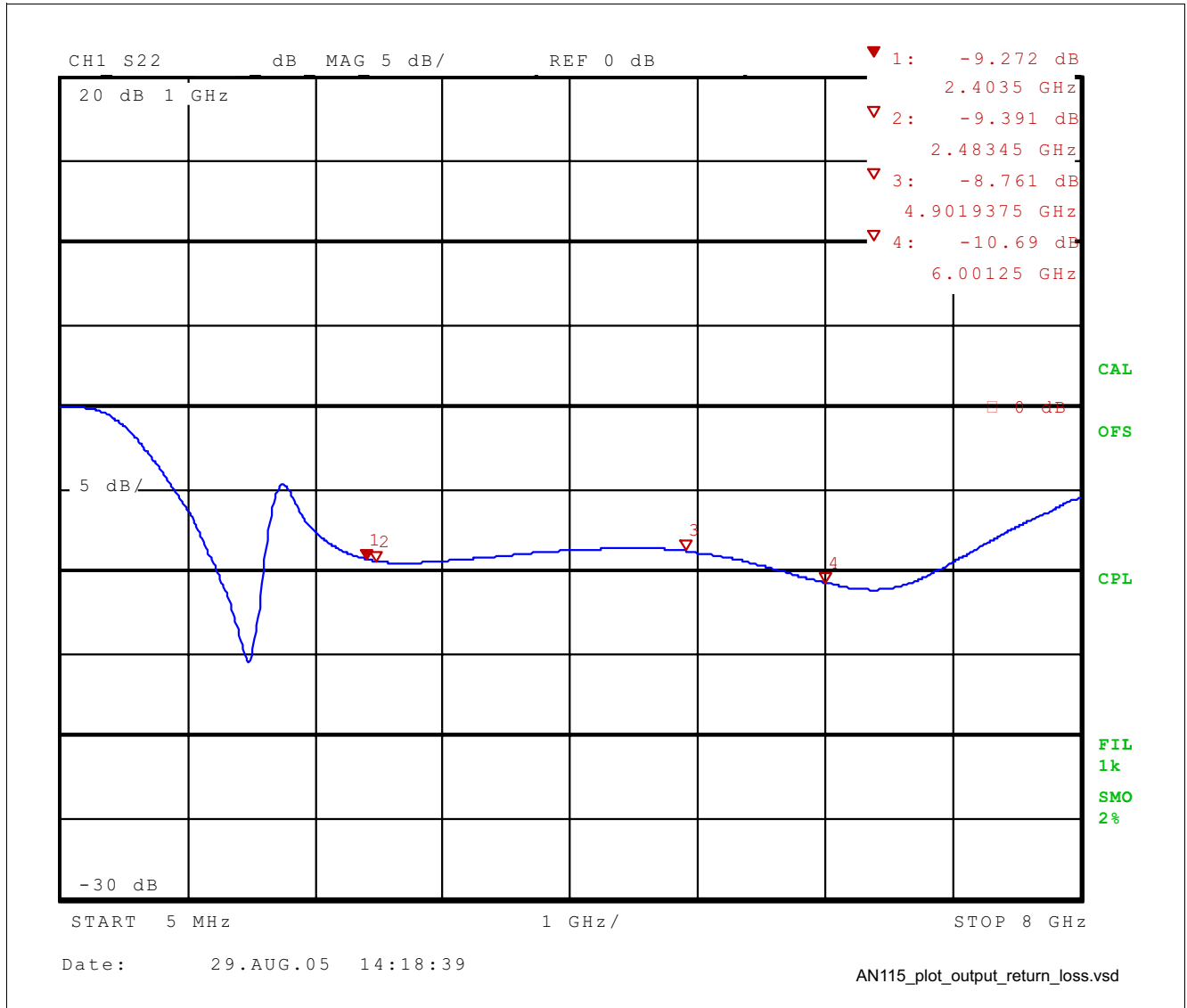


Figure 13 Plot of Output Return Loss (5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

Output Return Loss, Smith Chart

Reference Plane = Output SMA Connector on PC Board
5 MHz to 8 GHz

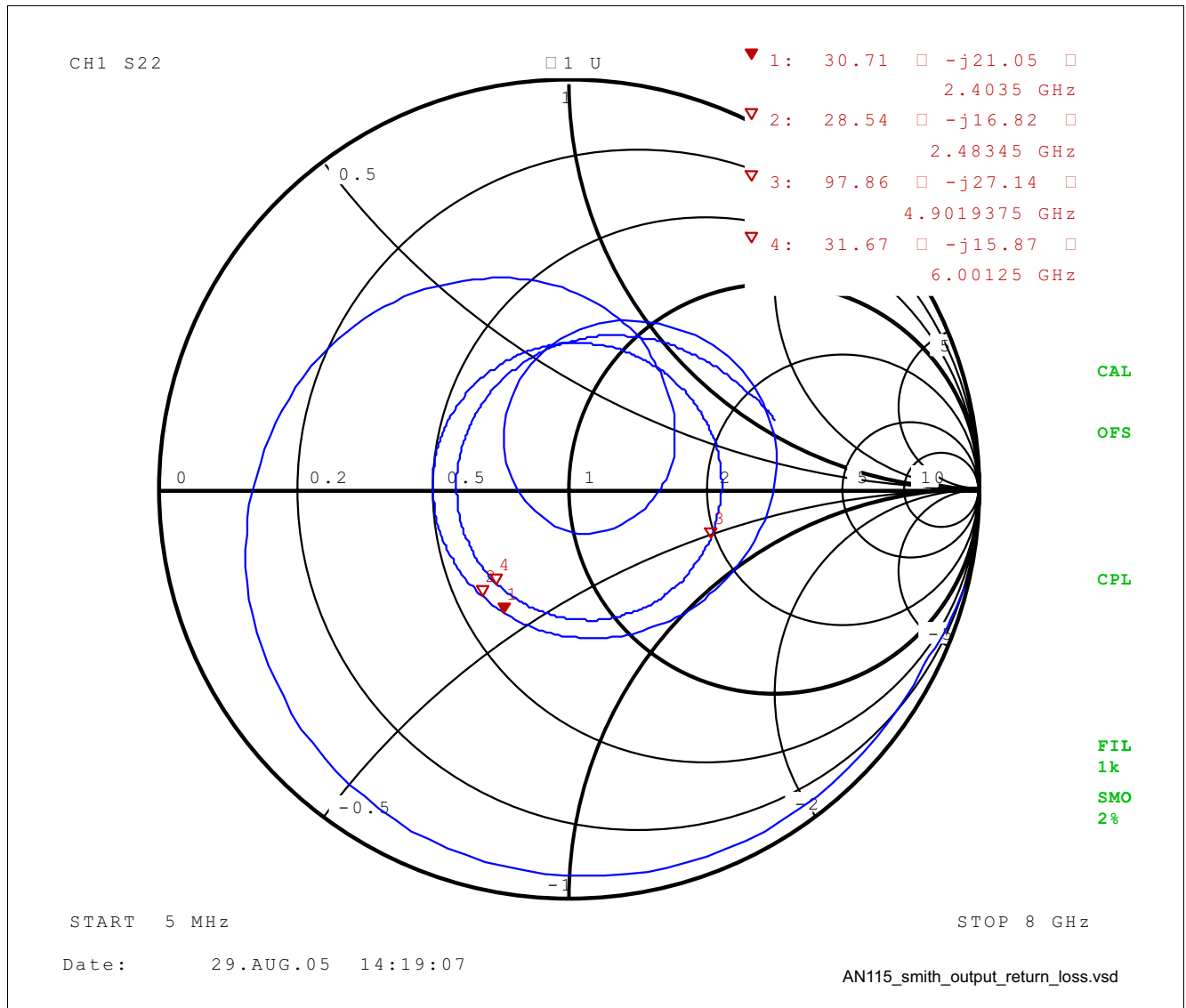


Figure 14 Smith Chart of Output Return Loss (5 MHz - 8 GHz)

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

LNA Response to Two-Tone Test, 2400 MHz

Input Stimulus: $f_1 = 2400$ MHz, $f_2 = 2401$ MHz, -25 dB per tone

Input $IP_3 = -25 + (49.7 / 2) = -0.2$ dBm

Output $IP_3 = -0.2$ dBm + 15.7 dB gain = +15.5 dBm

*Note: Third Order Interception could be improved by 8 -8 10 dB by using Charge Storage Off of base of transistor.
This approach would require the addition of one more "RF Choke " inductor to the circuit*

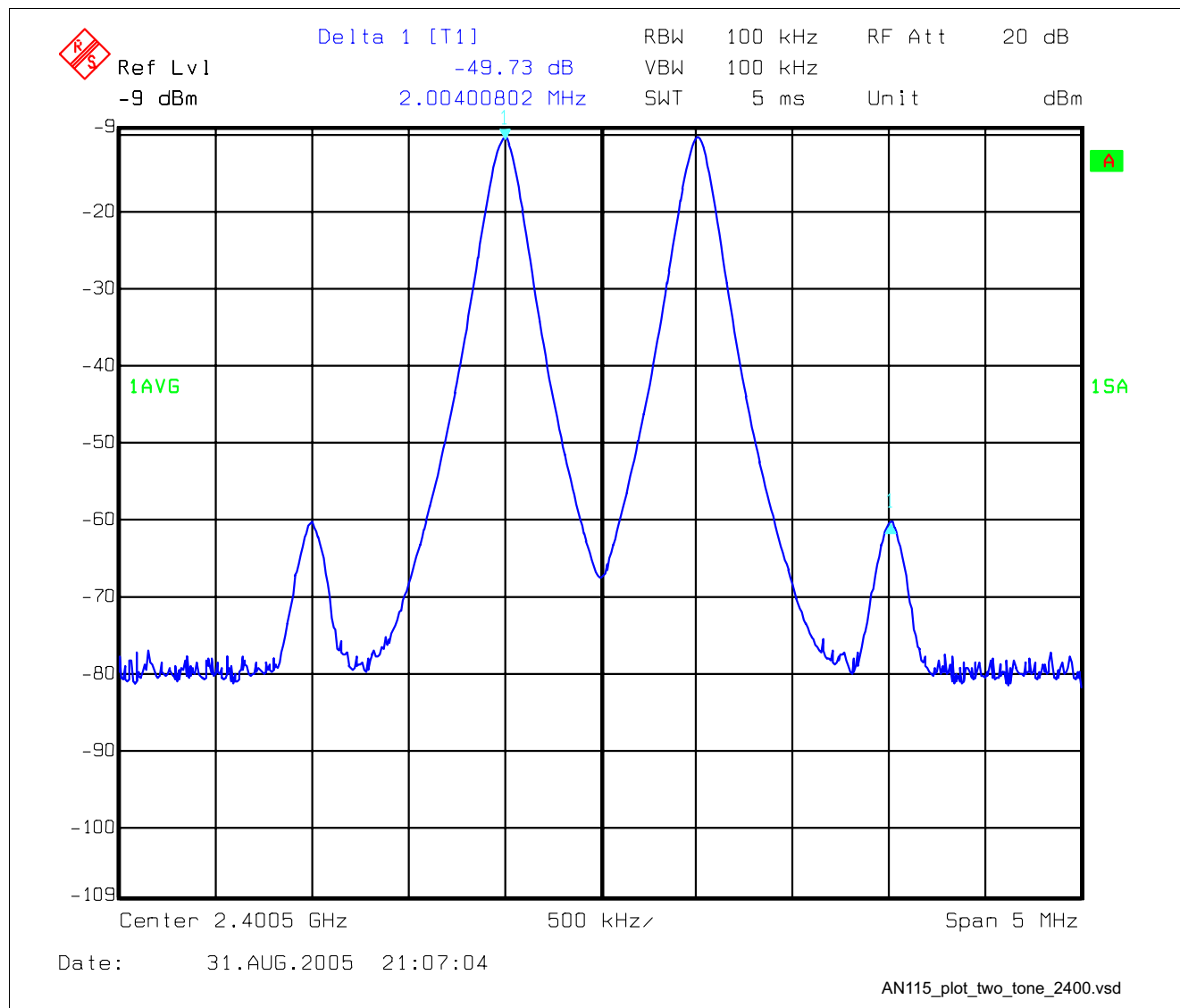


Figure 15 LNA Response to Two-Tone Test @ 2400 MHz

Dual-Band, Low Noise Amplifier for 2.4-2.5 & 4.9-6 GHz Bands using the Ultra

LNA Response to Two-Tone Test, 4900 MHz

Input Stimulus: $f_1 = 4900$ MHz, $f_2 = 4901$ MHz, -25 dB per tone

Input $IP_3 = -25 + (62.9 / 2) = +6.5$ dBm

Output $IP_3 = +6.5$ dBm + 11.0 dB gain = +17.5 dBm

*Note: Third Order Interception could be improved by 8 - 10 dB by using Charge Storage Off of base of transistor.
This approach would require the addition of one more "RF Choke" inductor to the Circuit.*

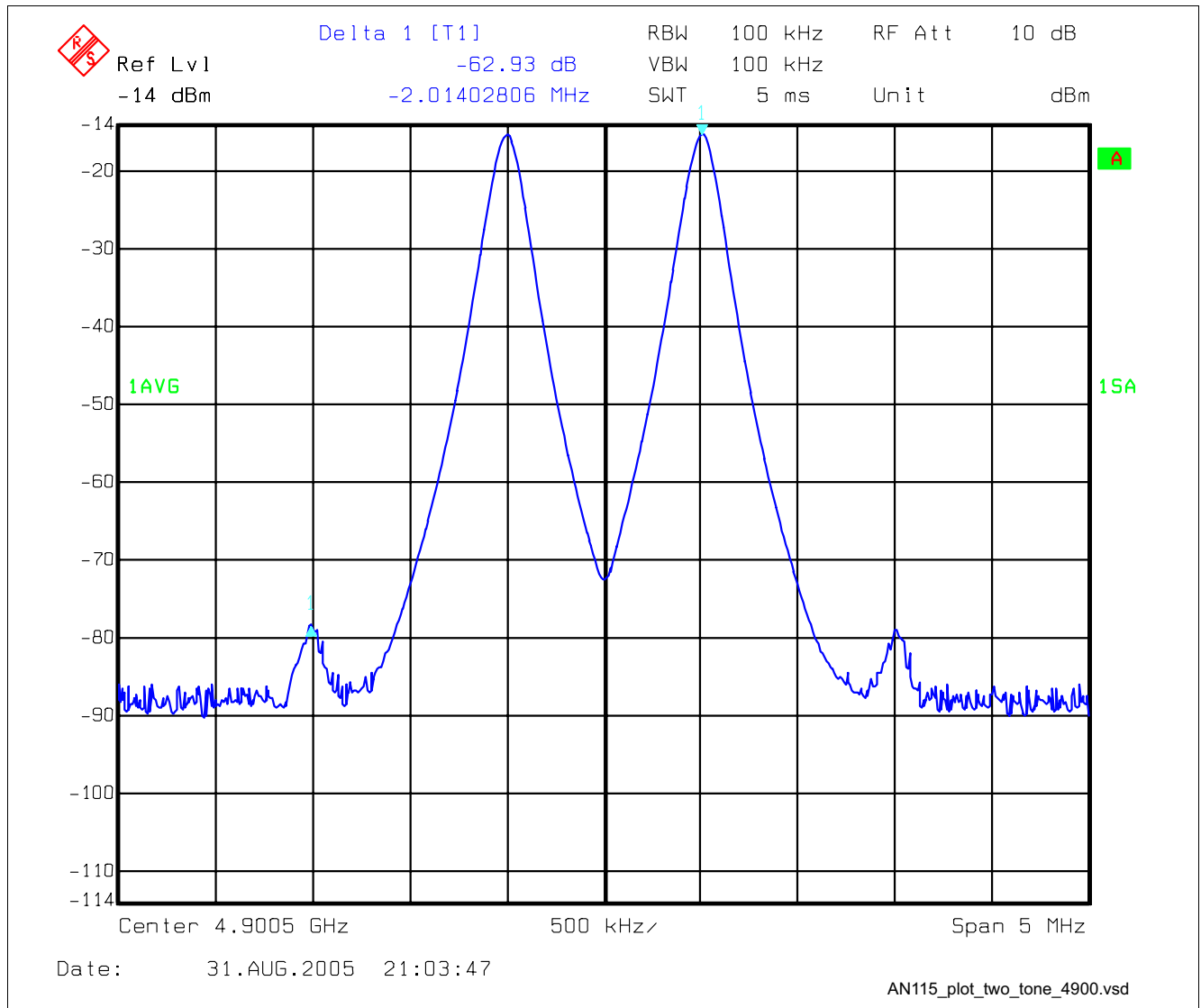


Figure 16 LNA Response to Two-Tone Test @ 4900 MHz