BFP640F

AN179
High Gain, High IP3 GPS LNA using BFP640F SiGe:C Transistor

Application Note

Revision: Rev 1.2,
2011.09.29

RF and Protection Devices

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Application Note No. 179

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2009-01-16, Rev 1.1
2011-09-29, Rev 1.2

Previous Version:	
Page	**Subjects (major changes since last revision)**
4	**Correction of errors (V1.0 =>V1.1)**
4	**Correction of errors in 'Summary Of Performance Data' (V1.1 => V1.2)**

Trademarks

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Additional Information:

More details about Infineon RF Transistors may be found at **www.infineon.com/RF**

Direct link to RF Transistor Datasheets / Specifications: **www.infineon.com/rf.specs**

For S-Parameters, Noise Parameters, SPICE models: **www.infineon.com/rf.models**

For Application Notes: **www.infineon.com/rf.appnotes**

1 High Gain, High Third-Order Intercept Low Noise Amplifier for 1575 MHz GPS Applications using the BFP640F SiGe:C Low Noise RF Transistor

Overview

- Infineon Technologies' **BFP640F** is a high gain, low noise Silicon-Germanium-Carbon (SiGe:C) Heterojunction Bipolar Transistor (HBT) suitable for a broad range of Low Noise Amplifier (LNA) applications.

- This circuit is targeted for 1575 MHz 'L1' frequency GPS applications. The LNA has high linearity / high Third Order Intercept (IP_3) performance, useful in reducing the magnitude of potential spurious signals generated in the LNA by strong out-of-band signals. Additional charge storage (capacitance) is used to achieve a reduction in Third-Order distortion, with the penalty of increased turn-on / turn-off times. Reference [1] describes in detail how additional charge storage reduces Third Order product levels. Both In-Band and Out-Of-Band IP_3 tests are performed, with the Out-Of-Band test being done in such a way as to enable prediction of levels of a potential spurious signal falling at the desired 1575.42 MHz GPS frequency if the amplifier is injected with signals that could be present in or around a multi-band mobile phone. **Amplifier is Unconditionally Stable (μ_1 > 1.0) from 10 MHz – 12 GHz.**

- External parts count (not including BFP640F transistor) = 10; 5 capacitors, 3 resistors, & 2 chip inductors. All passives are '0402' case size.

2 Summary Of Performance Data

(T=25 °C, network analyzer source power ≈ -25 dBm, V_{CC} = 2.8 V, V_{CE} = 2.4 V, I_C=8.6 mA, Z_S=Z_L=50 Ω)

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
900	- 3.4	17.9	-32.5	-4.8	---	---	---	---	---
1575	**-11.8**	**18.4**	**-24.9**	**-11.7**	**0.7**	**+5.8**	**+24.2**	**-14.1**	**+3.3**
1800	-18.0	13.9	-20.0	-16.0	0.7	---	---	---	---
2400	-15.6	14.8	- 22.3	- 5.5	0.8	---	---	---	---

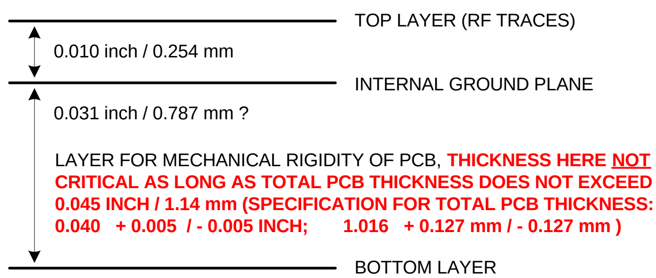
*** does not extract PCB loss. If PCB loss (at input) were extracted, noise figure would be ~ 0.1 dB lower.**
**** In-band IIP_3 result.**

Turn-on time: ~ 1.5 milliseconds; Turn-Off Time ~ 30 microseconds. Please see pages 24 – 26.

3 Details of PC Board Construction

PC board is fabricated from standard, low-cost "FR4" glass-epoxy material. A cross-section diagram of the PC board is given below.

PCB CROSS SECTION

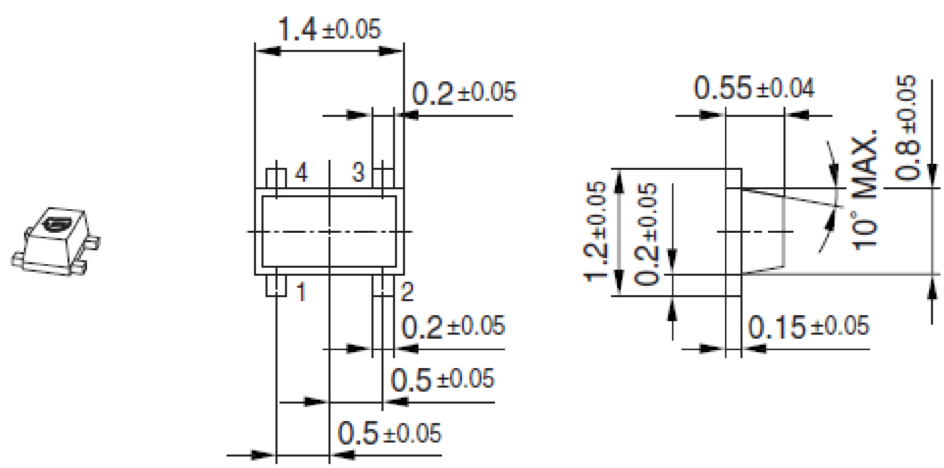


4 TSFP-4 Package Outline & Footprint. Dimensions in millimeters (mm).

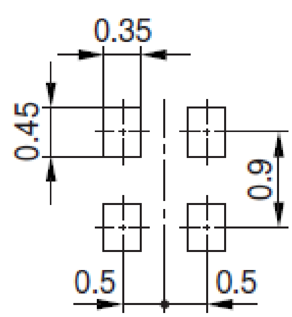
Refer to BFP640F Datasheet [2] for emitter – base – collector pin assignments.

TSFP-4 (–)

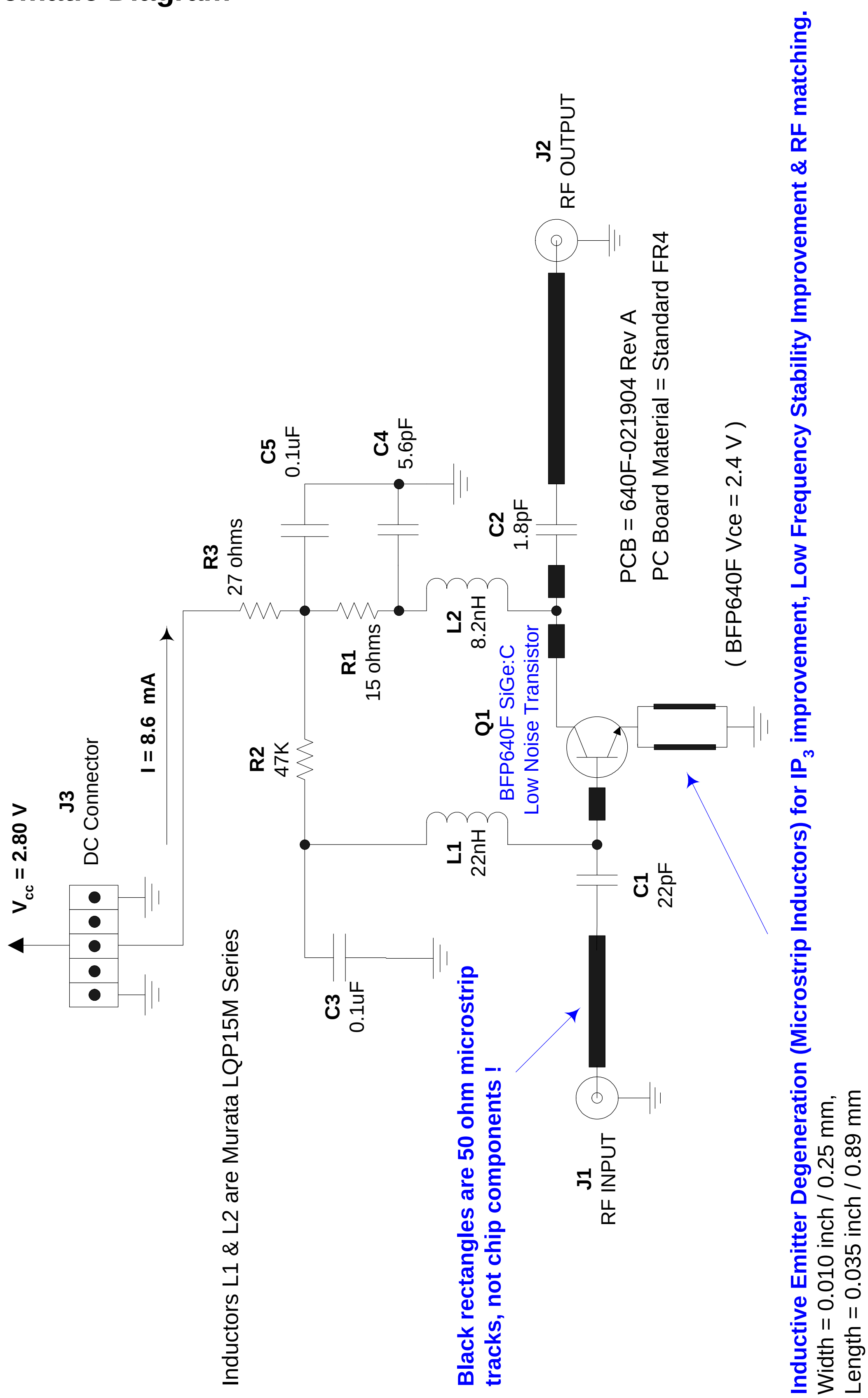
Package Outline



Foot Print



5 Schematic Diagram

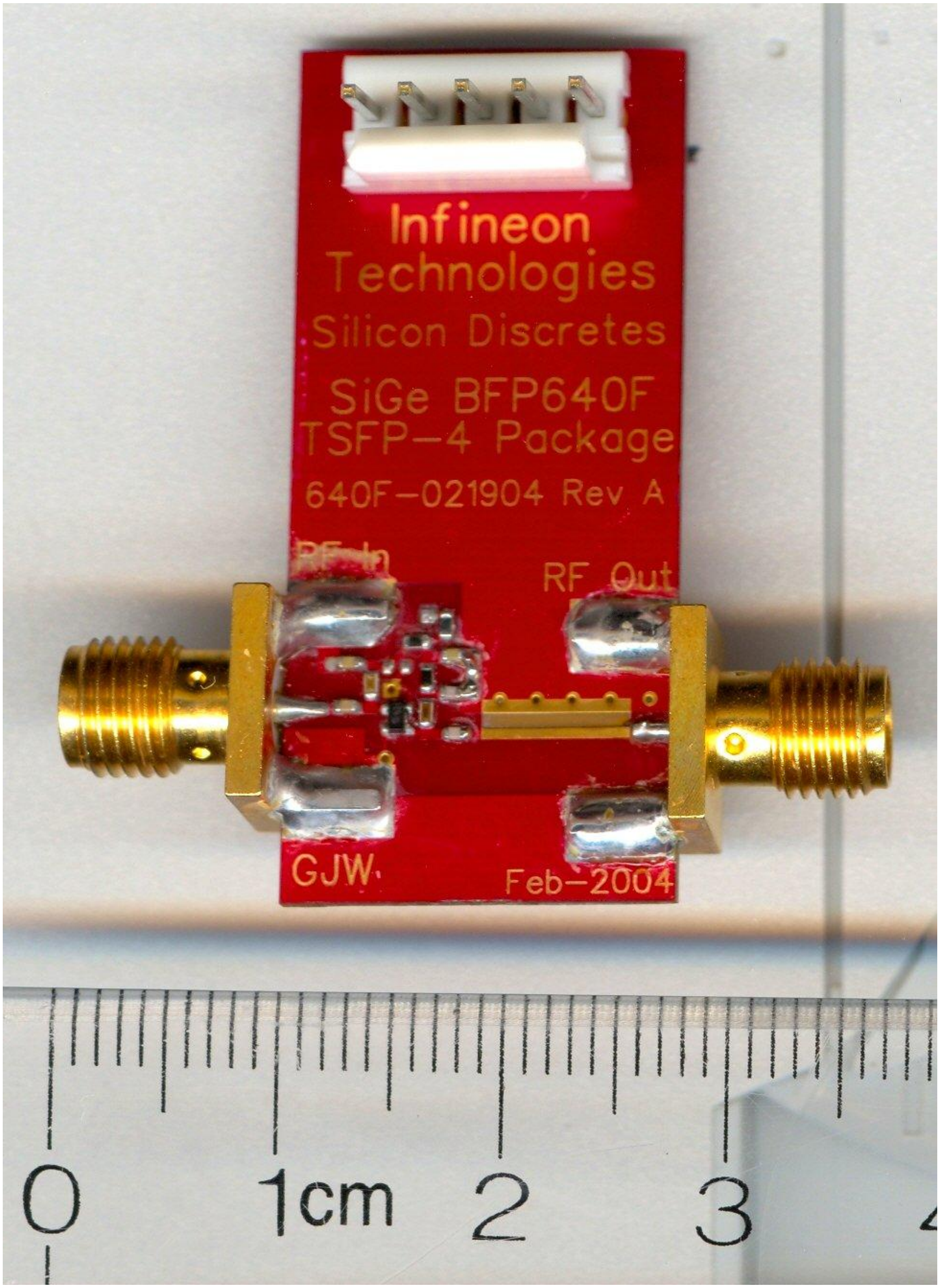


6 Bill Of Material (BOM)

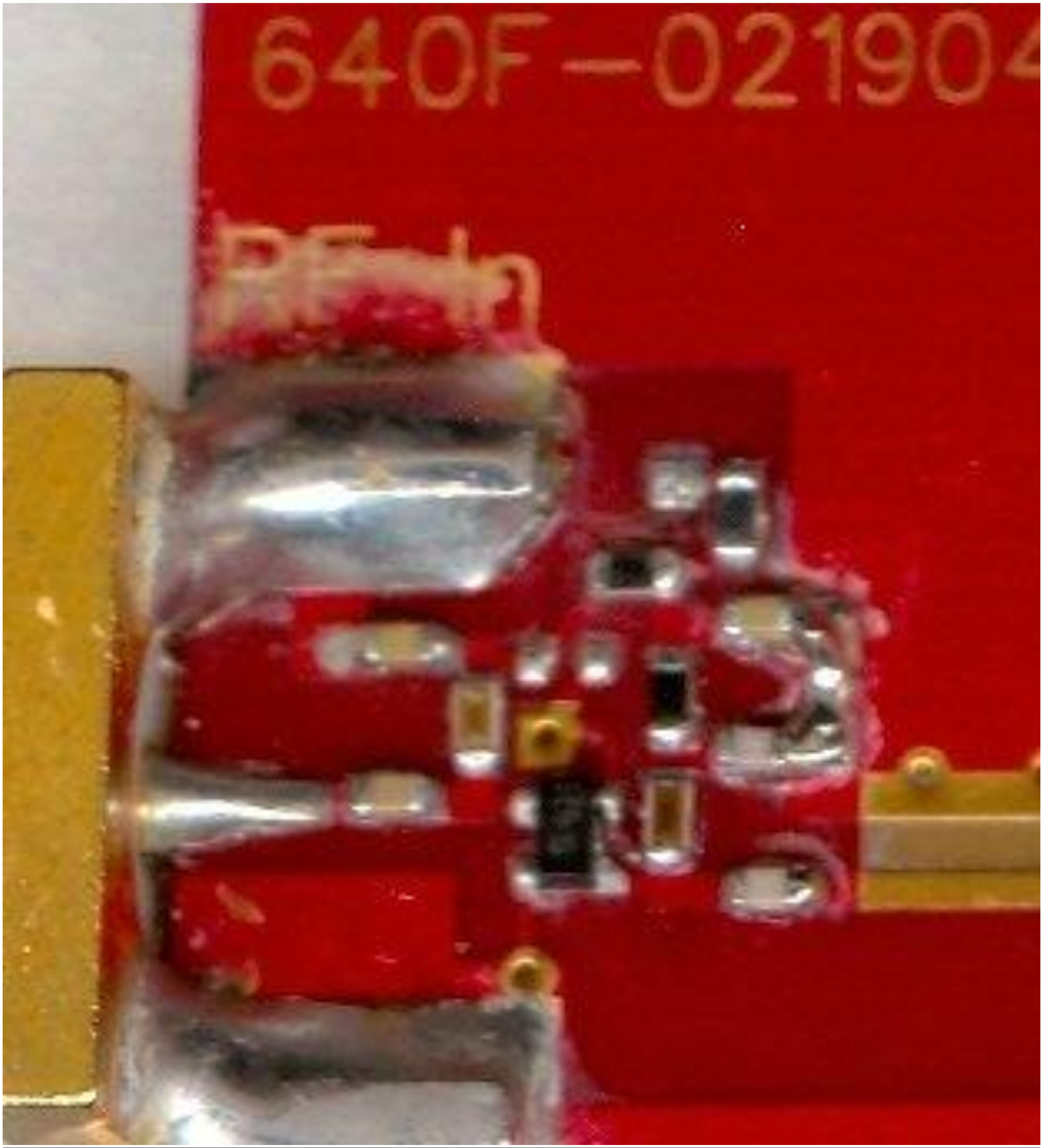
Reference Designator	Value	Description / Part #	Manufacturer	Function
C1	22pF	‘0402’ chip capacitor	Various	Input DC block
C2	1.8pF	‘0402’ chip capacitor	Various	Output DC block, output match
C3	0.1uF	‘0402’ chip capacitor	Various	Low frequency decoupling / blocking cap; improves third-order intercept (TOI). Please refer to Reference [1], pages
C4	5.6pF	‘0402’ chip capacitor	Various	RF decoupling / blocking cap; also has some influence on stability and output match
C5	0.1uF	‘0402’ chip capacitor	Various	Low frequency decoupling / blocking cap; improves third-order intercept (TOI). Please refer to Reference [1], pages
L1	22nH	‘0402’ case size chip inductor Murata LQP15M Series or equivalent	Murata	RF Choke at LNA input (for DC bias to base).
L2	8.2nH	‘0402’ case size chip inductor Murata LQP15M series or equivalent	Murata	RF ‘Choke’ at LNA output, for DC bias to collector. Also influences matching and stability.
R1	15Ω	‘0402’ chip resistor	Various	For RF stability improvement. Not a DC bias component.
R2	47kΩ	‘0402’ chip resistor	Various	DC biasing (base current).
R3	27Ω	‘0402’ chip resistor	Various	DC biasing (provides DC negative feedback to stabilize DC operating point over temperature variation, transistor h_{FE} variation, etc.)
Q1	**---**	**BFP640F SiGe:C Low Noise RF Transistor, TSFP-4 package**	**Infineon Technologies**	**LNA active device.**
J1, J2		RF Edge Mount SMA Female Connector, 142-0701-841	Emerson / Johnson	Input, Output RF connector
J3		MTA-100 Series 5 pin connector 640456-5	Tyco (AMP)	5 Pin DC connector header
---		PC Board, Part # 640F-021904 Rev A	Infineon Technologies	Printed Circuit Board

7 Scanned Images of PC Board

View of Entire PC Board



Close-In View of LNA Section



8 Noise Figure Measurement Data

Noise Figure Plot, from Rohde and Schwarz FSEK3 + FSEM30

Rohde & Schwarz FSEK3 — 14 Jan 2009

Noise Figure Measurement

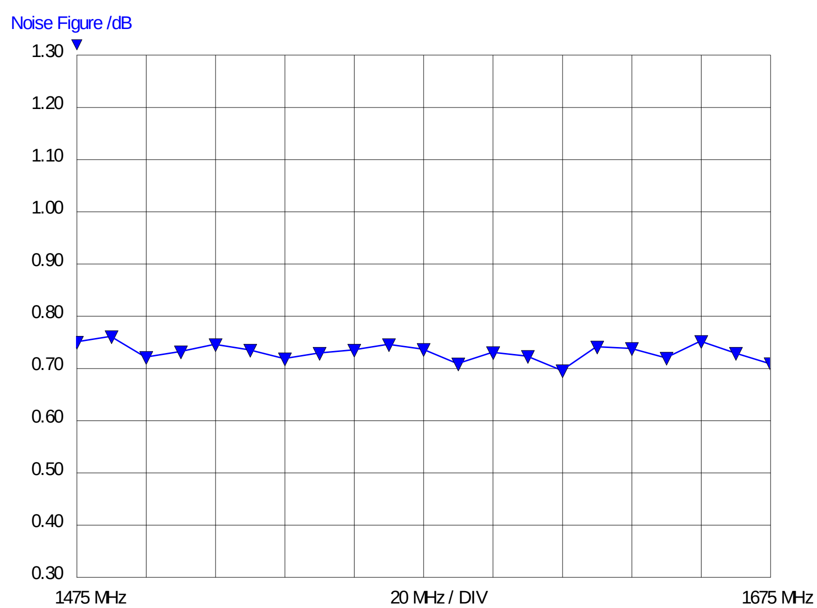
EUT Name:	BFP640F High Linearity GPS LNA - AN179
Manufacturer:	Infineon Technologies
Operating Conditions:	T=25 C, V = 2.8 V, Vce = 2.4 V, I = 8.6 mA
Operator Name:	Gerard Wevers
Test Specification:	GPS
Comment:	PCB = 640F-021904 Rev A; Preamp = MITEQ SMC-02 12 January 2009

Analyzer

RF Att:	0.00 dB	RBW :	1 MHz	Range:	30.00 dB
Ref Lvl:	-50.00 dBm	VBW :	100 Hz	Ref Lvl auto:	ON

Measurement

2nd stage corr:	ON	Mode:	Direct	ENR:	346A_1.ENR



Noise Figure, Tabular Data

Taken With Rohde & Schwarz FSEM30 + FSEK3
System Preamplifier = MITEQ SMC-02

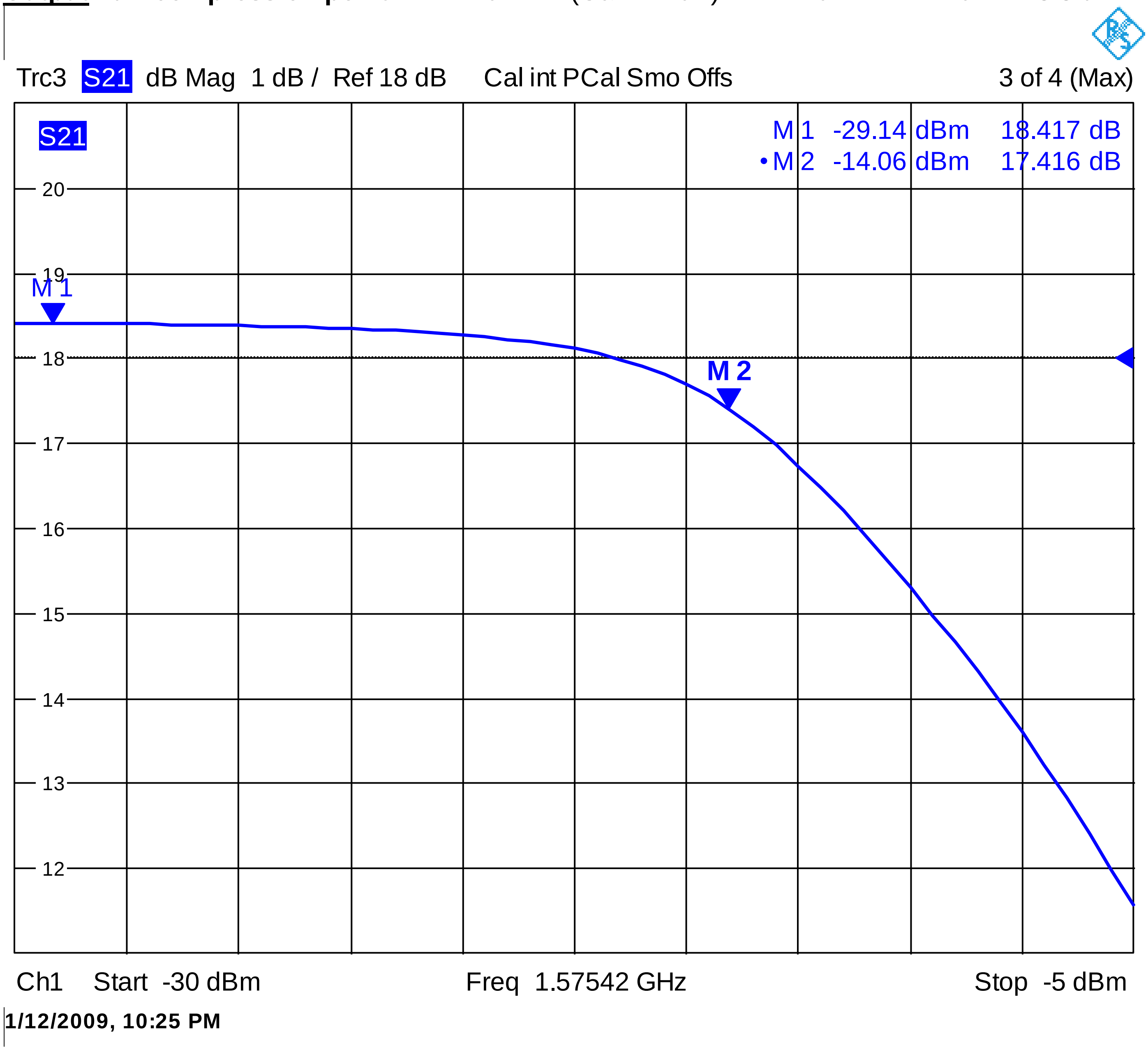
Frequency	Nf	Temp
1475 MHz	0.75 dB	54.6 K
1485 MHz	0.76 dB	55.4 K
1495 MHz	0.72 dB	52.3 K
1505 MHz	0.73 dB	53.2 K
1515 MHz	0.74 dB	54.2 K
1525 MHz	0.73 dB	53.4 K
1535 MHz	0.72 dB	52.1 K
1545 MHz	0.73 dB	52.9 K
1555 MHz	0.73 dB	53.4 K
1565 MHz	0.74 dB	54.2 K
1575 MHz	0.74 dB	53.5 K
1585 MHz	0.71 dB	51.3 K
1595 MHz	0.73 dB	53 K
1605 MHz	0.72 dB	52.4 K
1615 MHz	0.69 dB	50.3 K
1625 MHz	0.74 dB	53.9 K
1635 MHz	0.74 dB	53.6 K
1645 MHz	0.72 dB	52.2 K
1655 MHz	0.75 dB	54.7 K
1665 MHz	0.73 dB	52.9 K
1675 MHz	0.71 dB	51.3 K

9 Amplifier Compression Point Measurement

Gain Compression at 1575.42 MHz, V_{CC} = +2.8 V, I = 8.6mA, V_{CE} = 2.4V, T = 25°C:
Rohde & Schwarz ZVB20 Vector Network Analyzer is set up to sweep input power to LNA in a "Power Sweep" at a fixed frequency of 1575.42 MHz. ZVB20 Port 1, which provides INPUT power to drive the LNA, has its power level calibrated with the NRP-Z21 power sensor to ensure power level accuracy with the reference plane at the RF input connector of the amplifier. X-axis of VNA screen-shot below shows input power to LNA swept from –30 to –5 dBm.

Input 1 dB compression point = **-14.1 dBm**

Output 1dB compression point = -14.1 dBm + (Gain – 1dB) = -14.1 dBm + 17.4 dB = **+3.3 dBm**

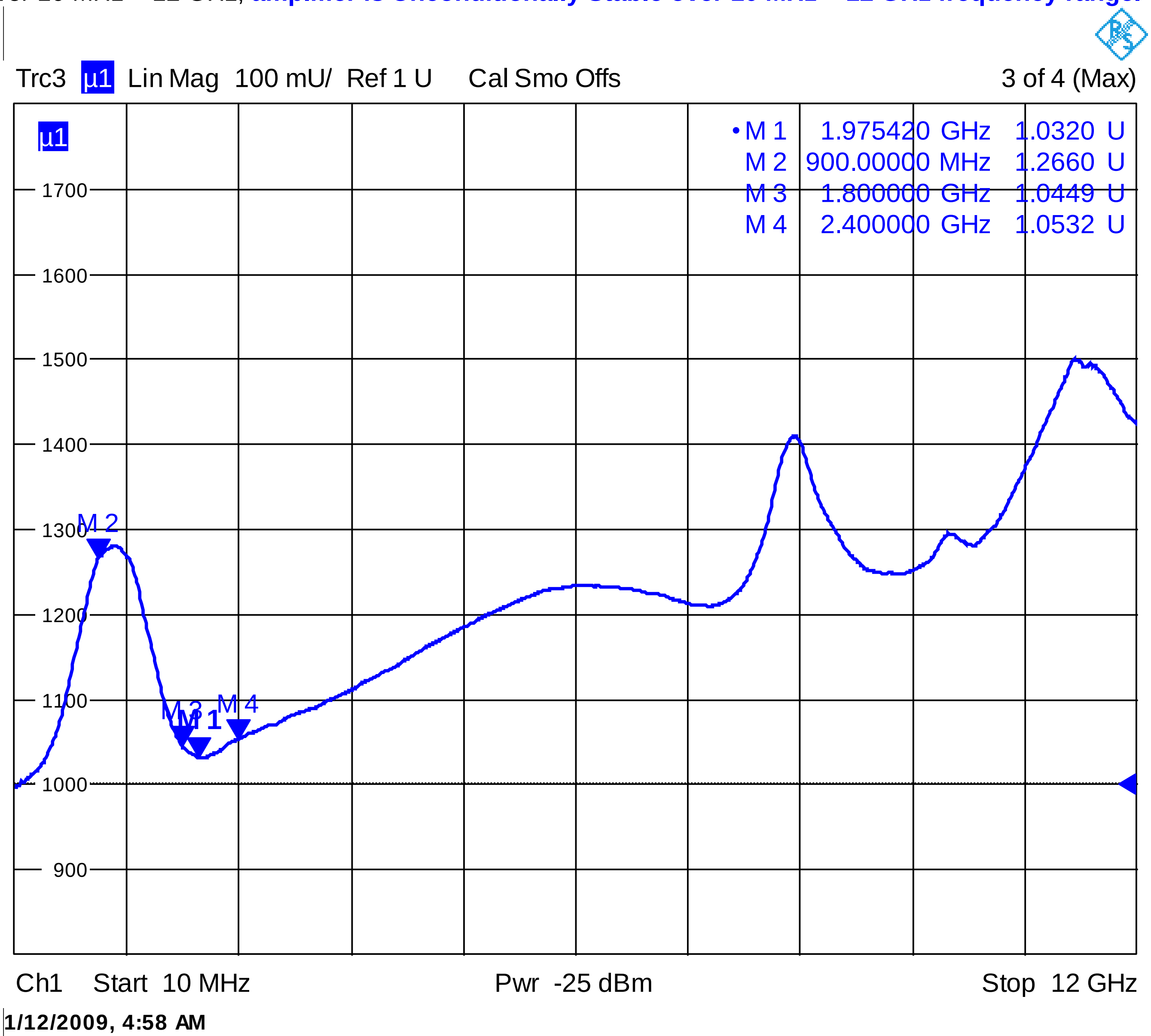


10 Amplifier Stability, Gain, Return Loss and Reverse Isolation Plots

Rohde and Schwarz ZVB Network Analyzer Calculates and plots stability factor **"μ_1"** of the BFP640F amplifier in real time. Stability Factor μ_1 is defined as follows [1]:

$$\mu_1 = \frac{1 - |S_{11}|^2}{| S_{22} - S_{11}^* \det(\mathbf{S}) | + |S_{21}S_{12}|}$$

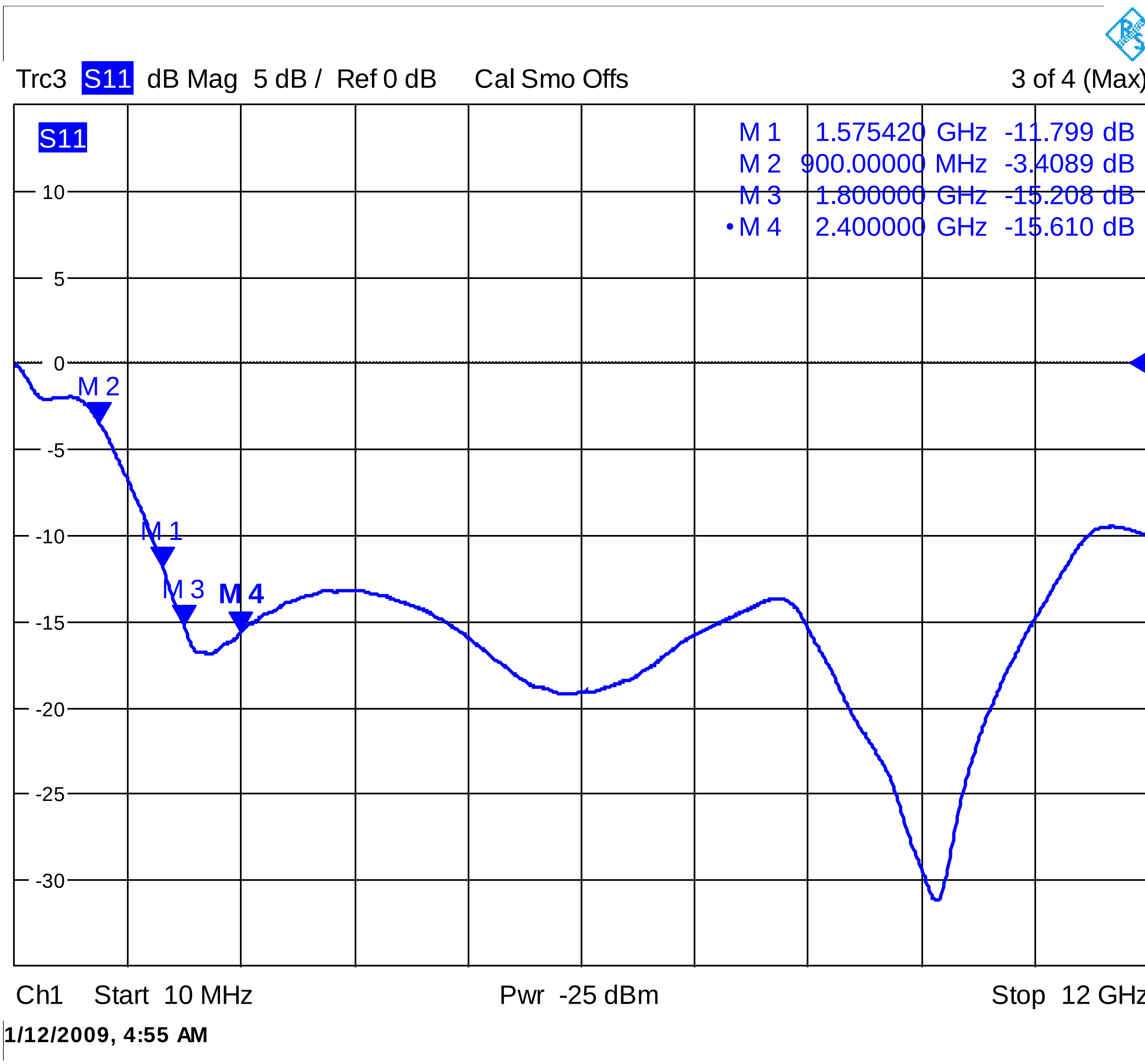
The necessary and sufficient condition for Unconditional Stability is μ_1 > 1.0. In the plot, μ_1 > 1.0 over 10 MHz – 12 GHz; **amplifier is Unconditionally Stable over 10 MHz – 12 GHz frequency range.**



[1]. "Fundamentals of Vector Network Analysis", Michael Hiebel, 4th edition 2008, pages 175 – 177, ISBN 978-3-939837-06-0

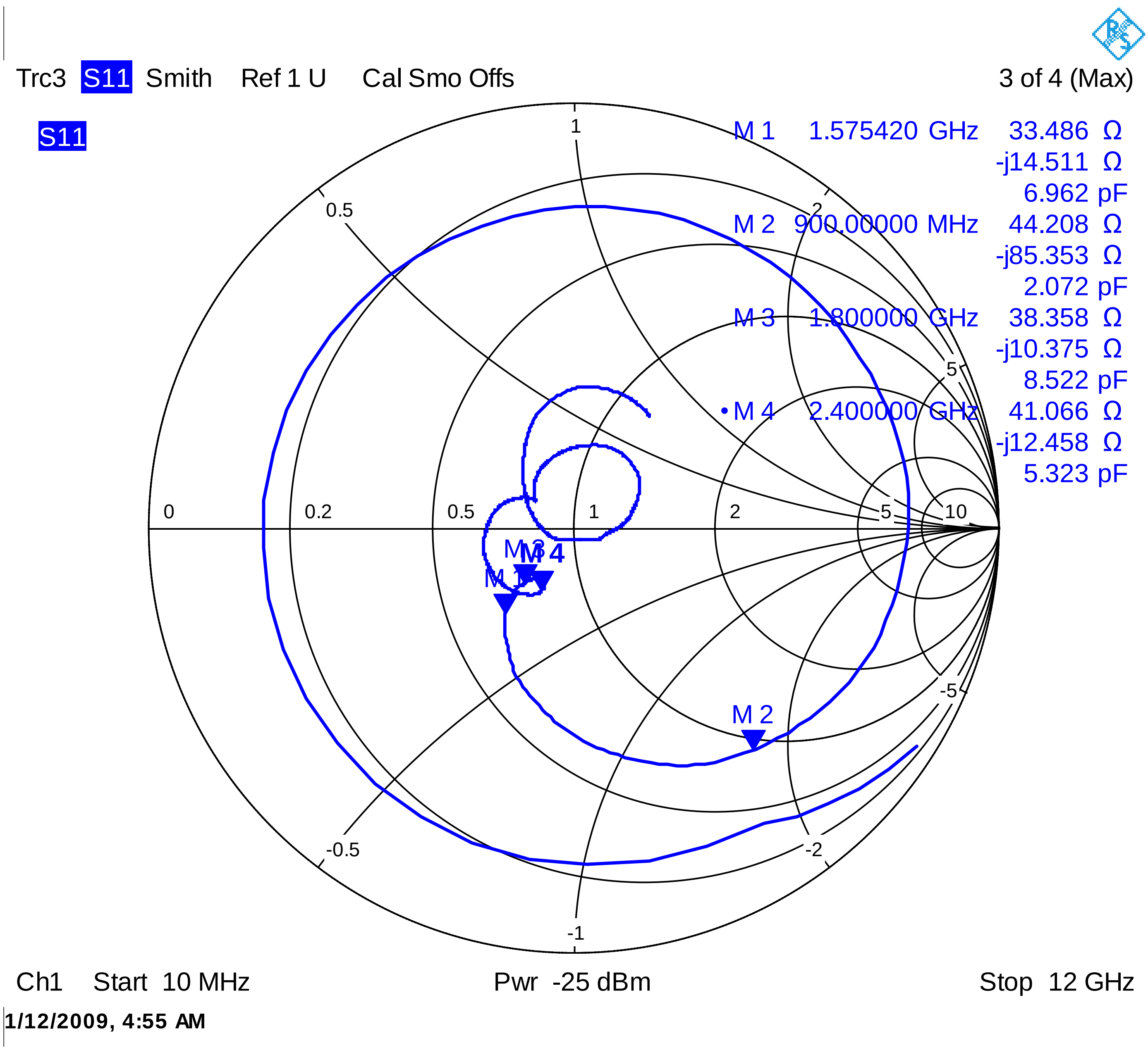
Input Return Loss, Log Mag

10 MHz – 12 GHz Sweep



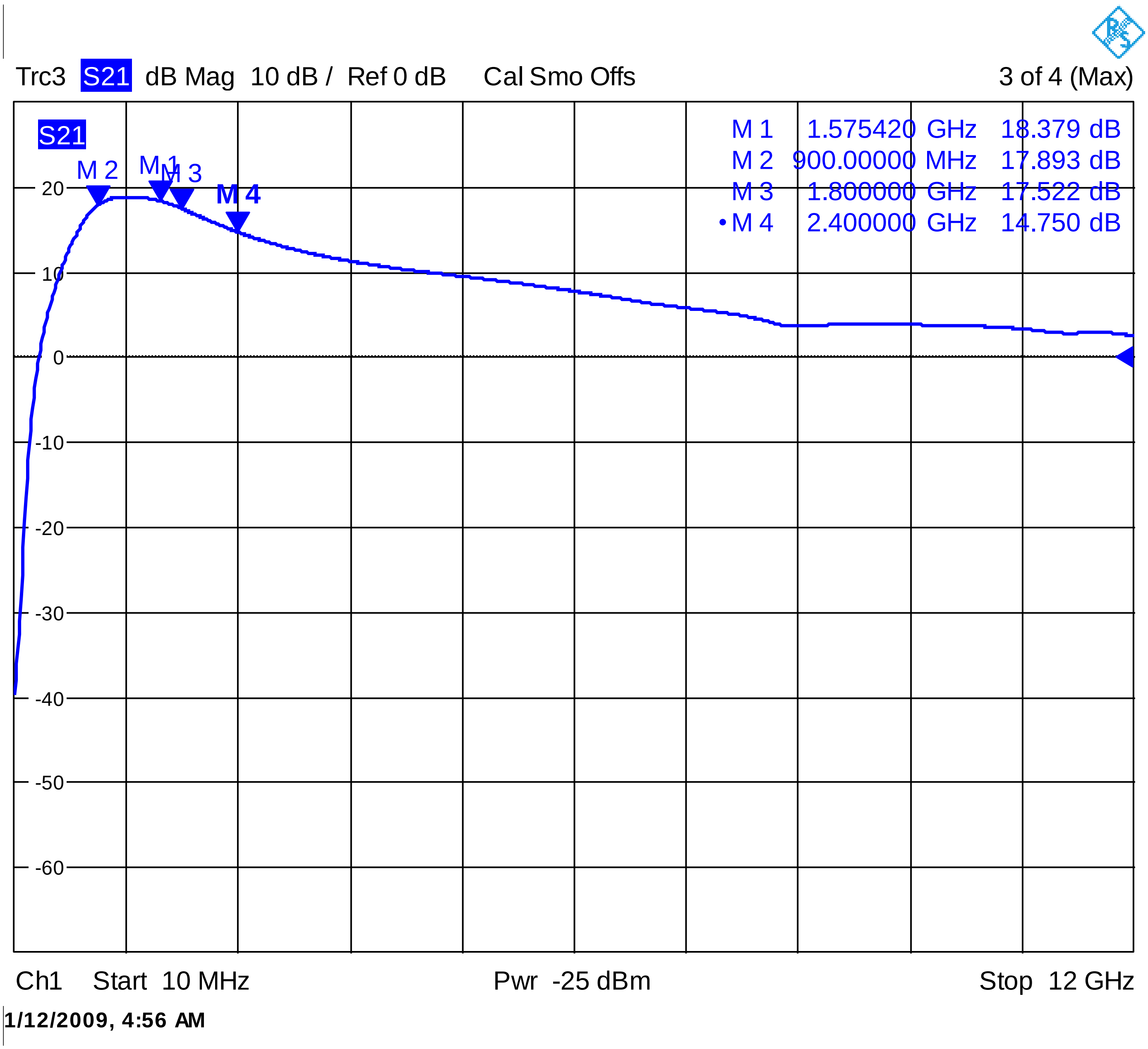
Input Return Loss, Smith Chart

Reference Plane = Input SMA Connector on PC Board
10 MHz – 12 GHz Sweep



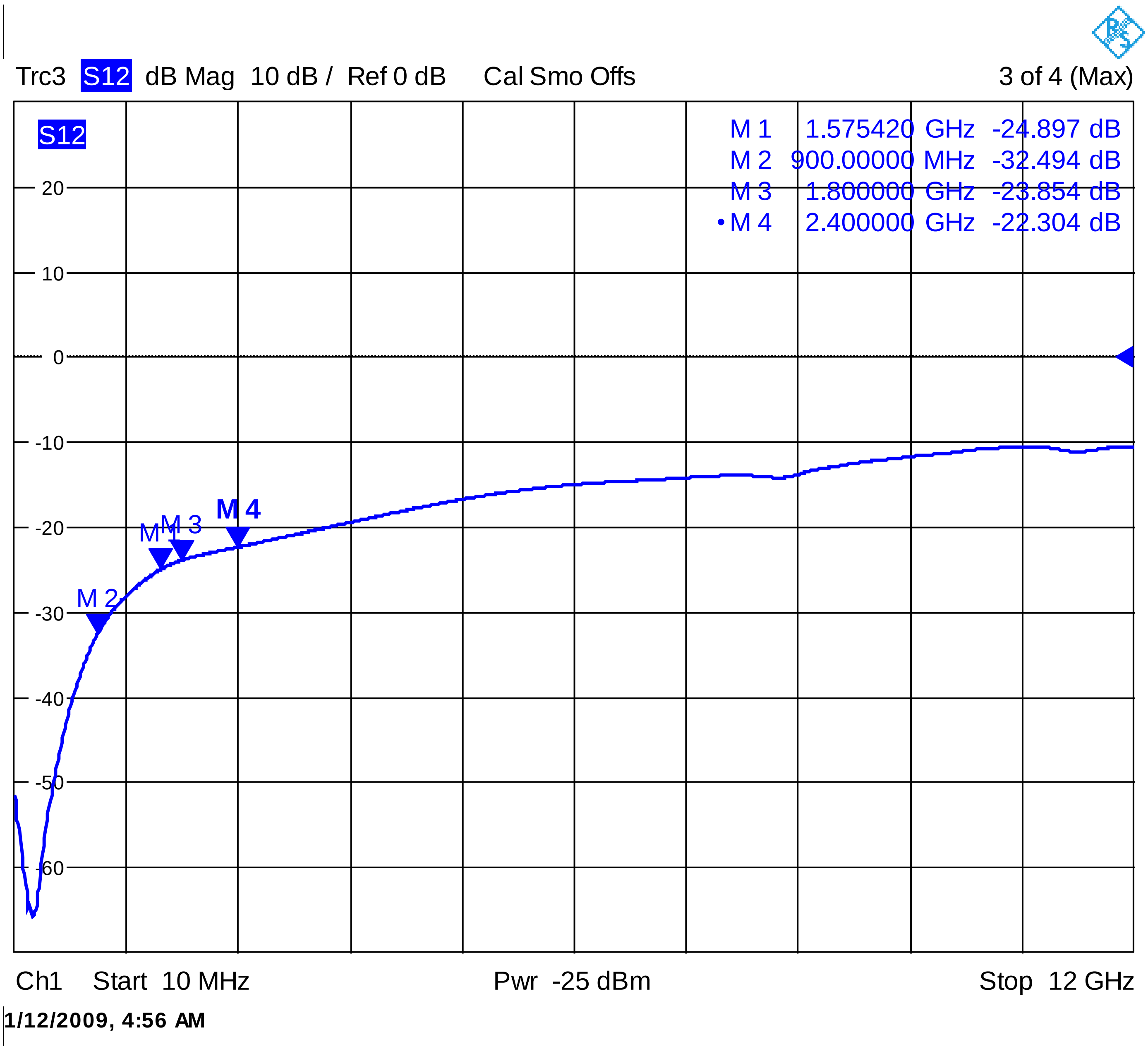
Forward Gain. Input / Output Matching Circuits of LNA reduce gain in 2.4 – 2.5 GHz band.

10 MHz – 12 GHz Sweep



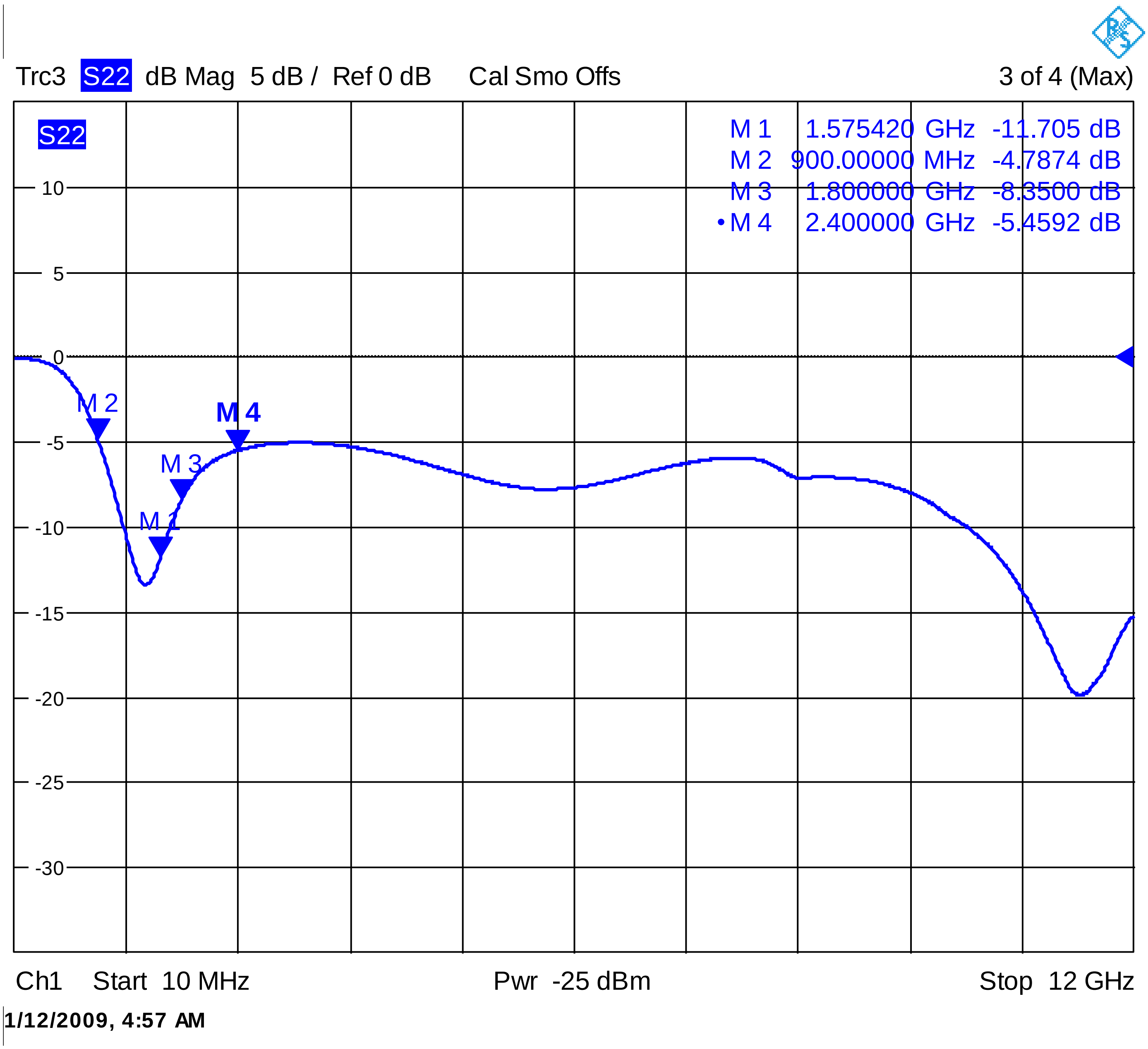
Reverse Isolation

10 MHz – 12 GHz Sweep



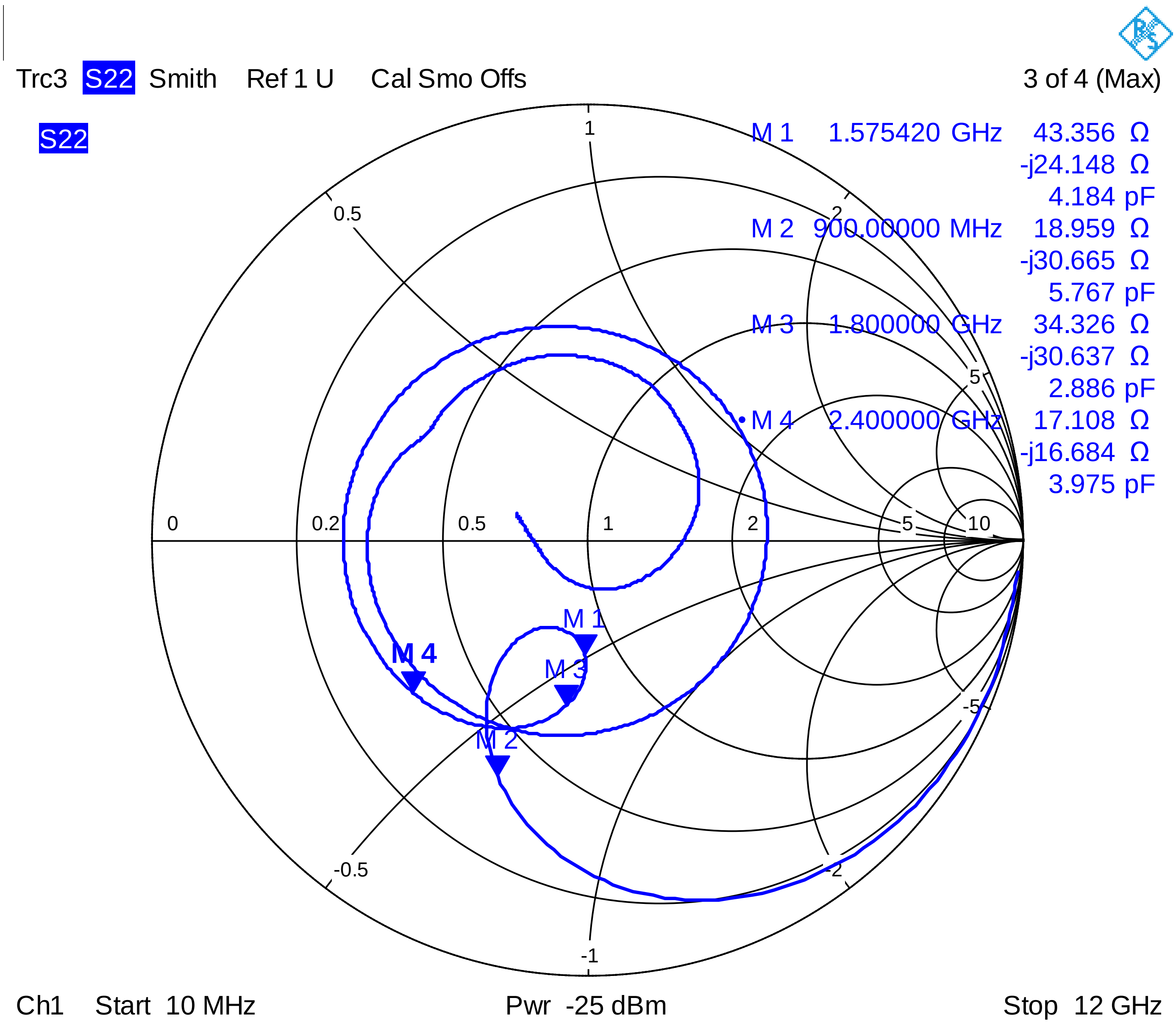
Output Return Loss, Log Mag

10 MHz to 12 GHz Sweep



Output Return Loss, Smith Chart

Reference Plane = Output SMA Connector on PC Board
10 MHz to 12 GHz Sweep



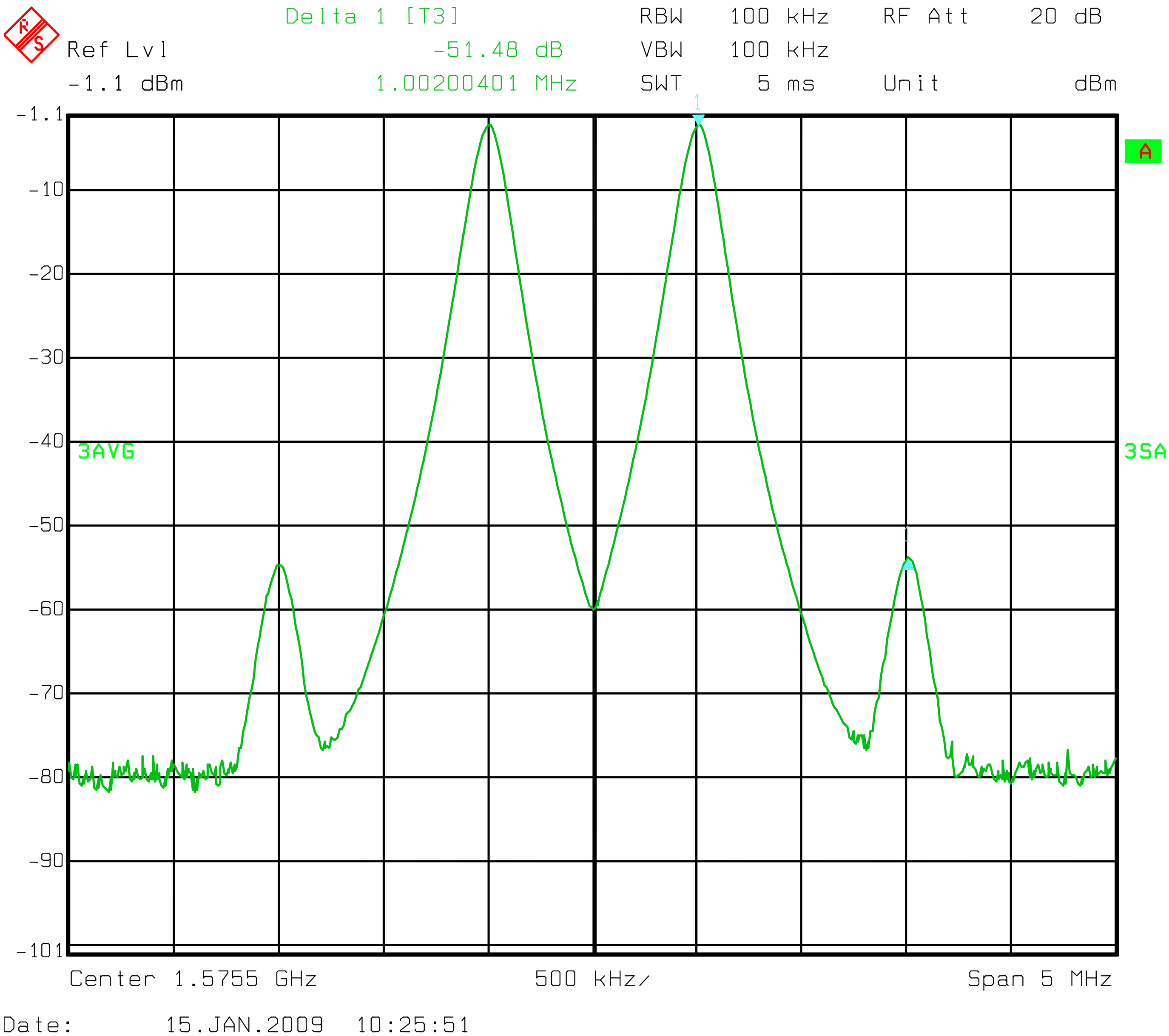
1/12/2009, 4:57 AM

11 Amplifier In-Band Third Order Intercept (TOI) Measurement

In-Band Third Order Intercept (IIP_3) Test.

Input Stimulus: f_1=1575 MHz, f_2=1576 MHz, - 20 dBm each tone.

Input IP_3 = -20 + (51.5 / 2) = +5.8 dBm. Output IP_3 = +5.8 dBm + 18.4 dB gain = +24.2 dBm.



12 Amplifier Out-Of-Band Third Order Intercept Measurement

Amplifier Two-Tone Test (Third Order Product which falls @ GPS L1 Frequency 1575.42 MHz):

This test is a check for a Third-Order distortion product which falls on top of desired GPS "L1" frequency of 1575.42 MHz. Input Tones are as follows:
f_1 = L1 + 138 MHz = 1713.42 MHz, -16 dBm
f_2 = L1 + 276 MHz = 1851.42 MHz, -16 dBm

One third order product ($2f_1$-f_2) generated in the LNA due to the amplifier third-order nonlinearities can fall right at the desired 1575.42 MHz frequency, as follows:

$2f_1 - f_2$ = 2(1713.42MHz) – 1851.42 MHz = 1575.42 MHz

Photo of Input Test Tones, from signal generators

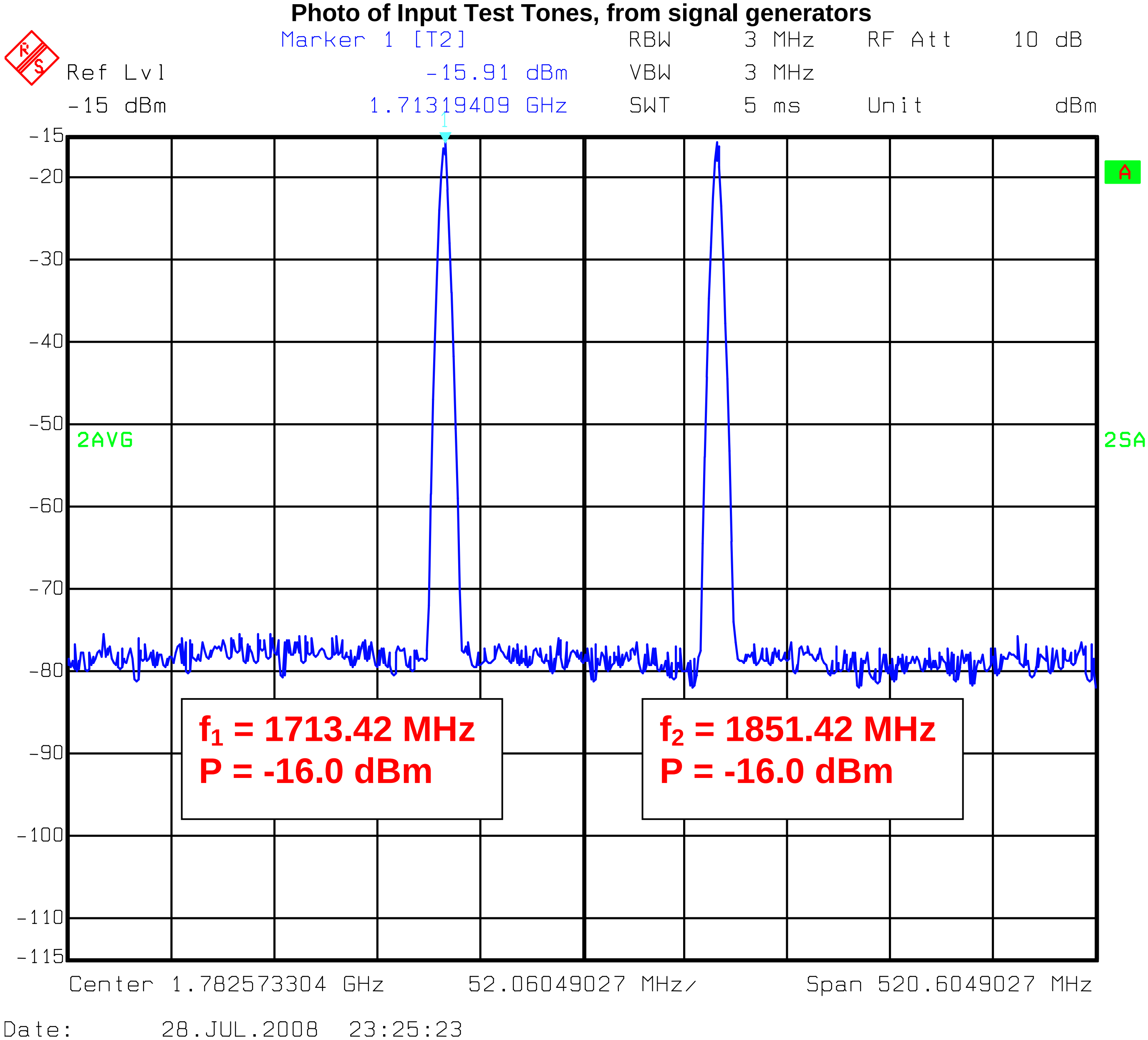
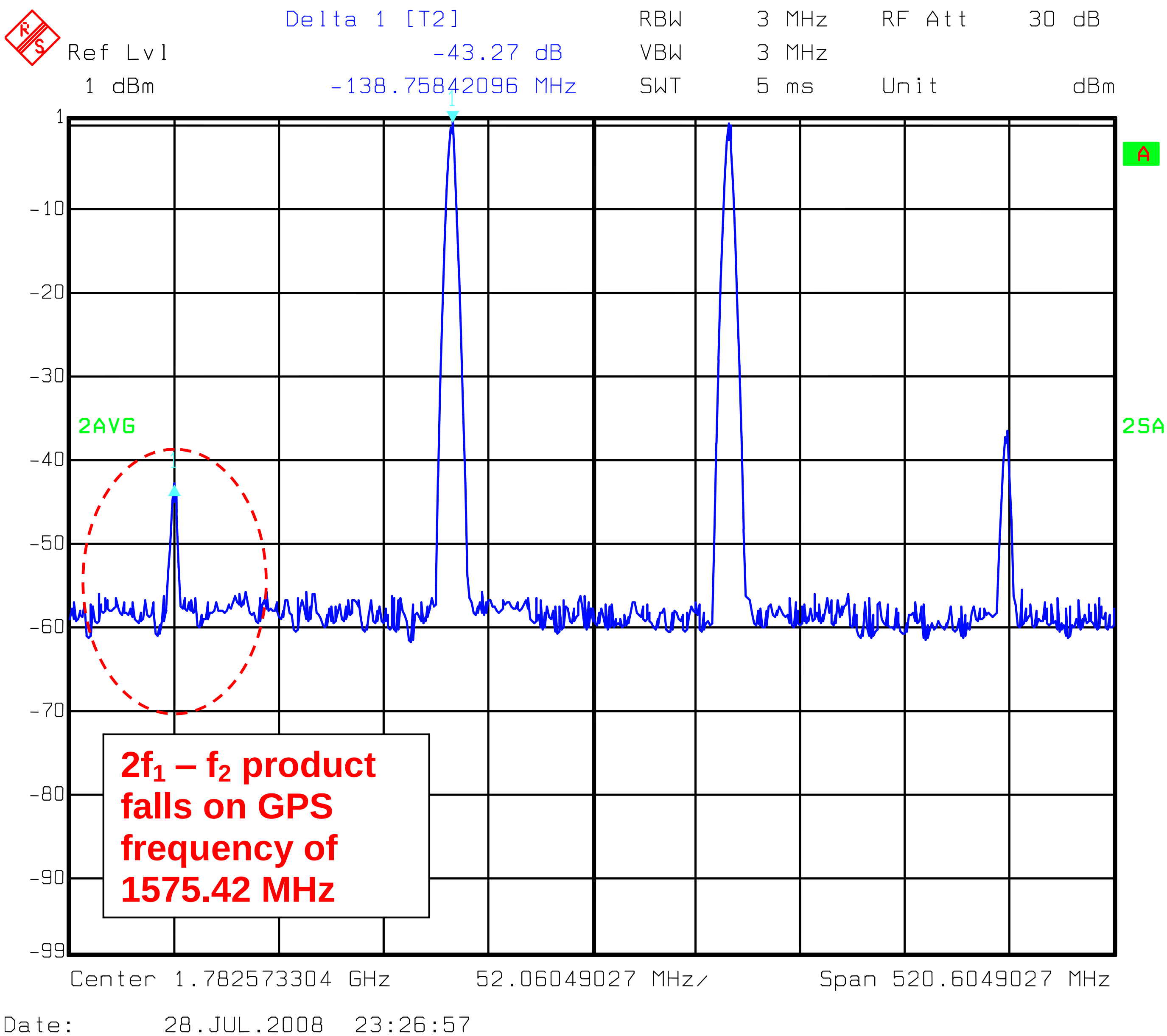


Photo below shows **partial output spectrum** of the LNA after being driven by test tones shown on previous page. Markers are placed at the peak input tone and the "Left Hand" Third Order Product which falls at 1575 MHz. The difference in amplitudes ("delta") is read. Note the product $2f_1 - f_2$ is 54.2 dB below the input test tone.

The Input Third Order Intercept (IIP3) with respect to the left-side IM product at 1575.42 MHz is as follows:

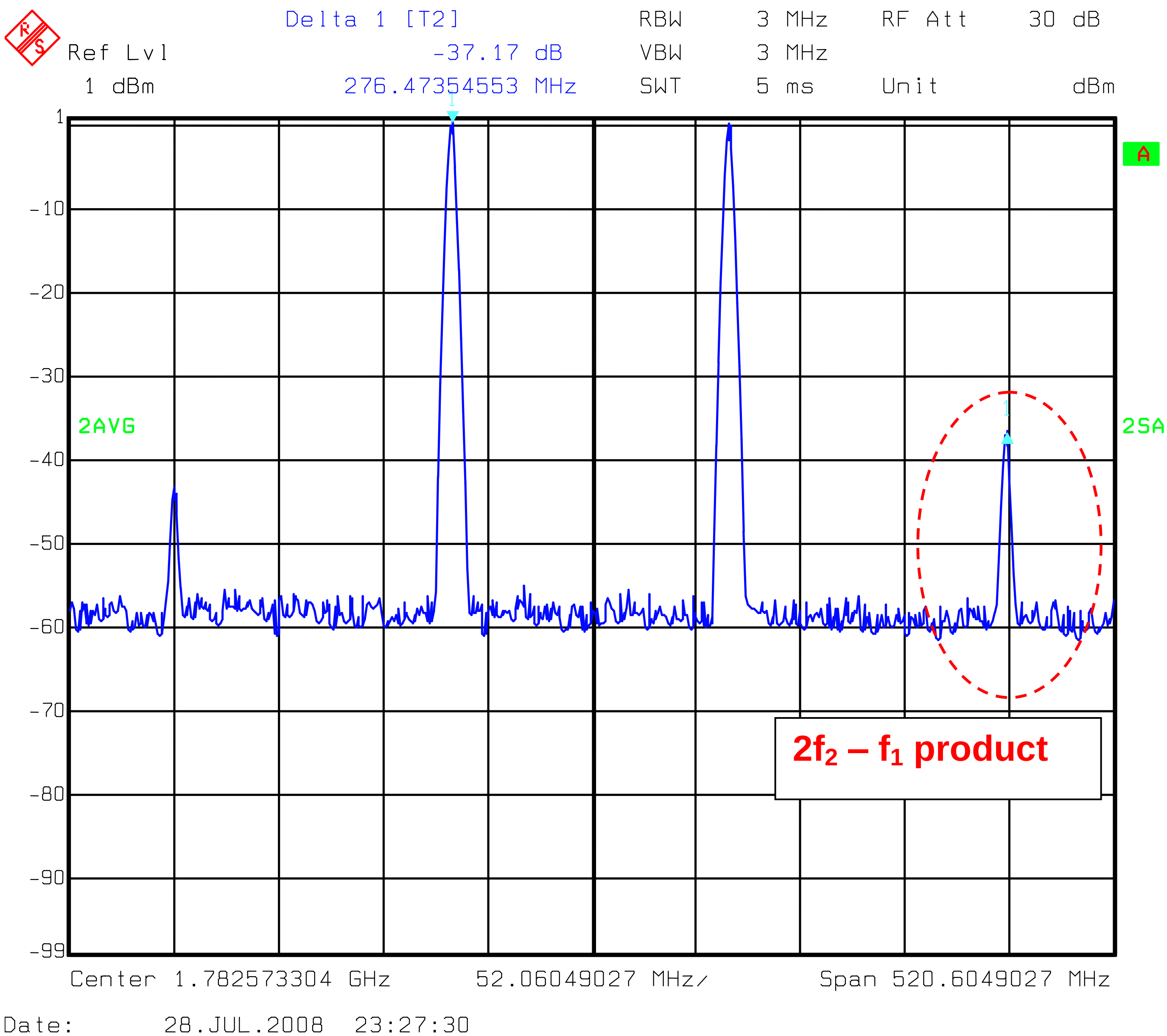
IIP_3 = -16 dBm + (43.3 / 2) = +5.7 dBm.



This additional image below shows the partial **output spectrum** of the LNA subjected to the input test tones shown two pages back, however the markers are placed at the peak tone and the "Right Hand" Third Order Product which falls at 1989.42 MHz. This "right-hand side" product is likely less relevant to GPS receivers as it is "far away" (in terms of frequency) from the desired "L1" GPS frequency of 1575.42 MHz. Note the product $2f_2 - f_1$ is 37.2 dB below the input test tone.

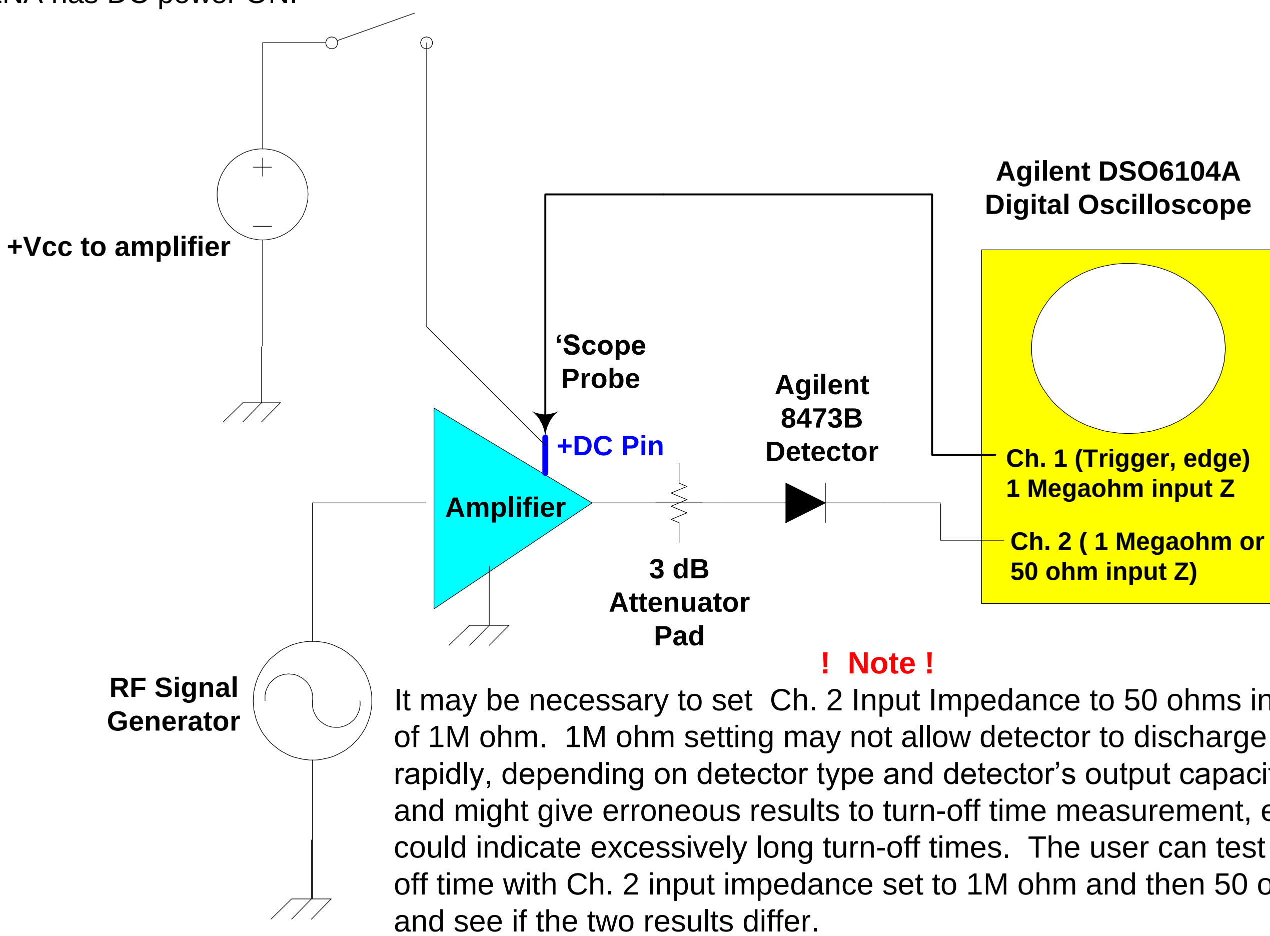
The Input Third Order Intercept (IIP_3) with respect to the right-side IM_3 product at 1989.42 MHz is as follows:

IIP_3 (right side) = -16 dBm + (37.2 / 2) = +2.6 dBm.



13 Amplifier Turn-On / Turn-Off Time Measurements

The amplifier is tested for turn-on / turn-off time. See diagram below. The RF signal generator runs continuously at a power level sufficient to drive the output of the LNA to approximately 0 dBm when the LNA has DC power ON.



! Note !

It may be necessary to set Ch. 2 Input Impedance to 50 ohms instead of 1M ohm. 1M ohm setting may not allow detector to discharge rapidly, depending on detector type and detector's output capacitance, and might give erroneous results to turn-off time measurement, e.g. could indicate excessively long turn-off times. The user can test turn-off time with Ch. 2 input impedance set to 1M ohm and then 50 ohms and see if the two results differ.

1. **Signal Generator set such that output power of Amplifier is ~ 0 dBm when LNA is powered ON**

2. **Channel 1 of oscilloscope monitors input power supply voltage to Amplifier (+1.8, +2.8 or +3.0 volts ON, depending on the amplifier, and 0 volts when OFF). Hook oscilloscope probe to +Vcc pin on amplifier to monitor Vcc rising / falling edge.**

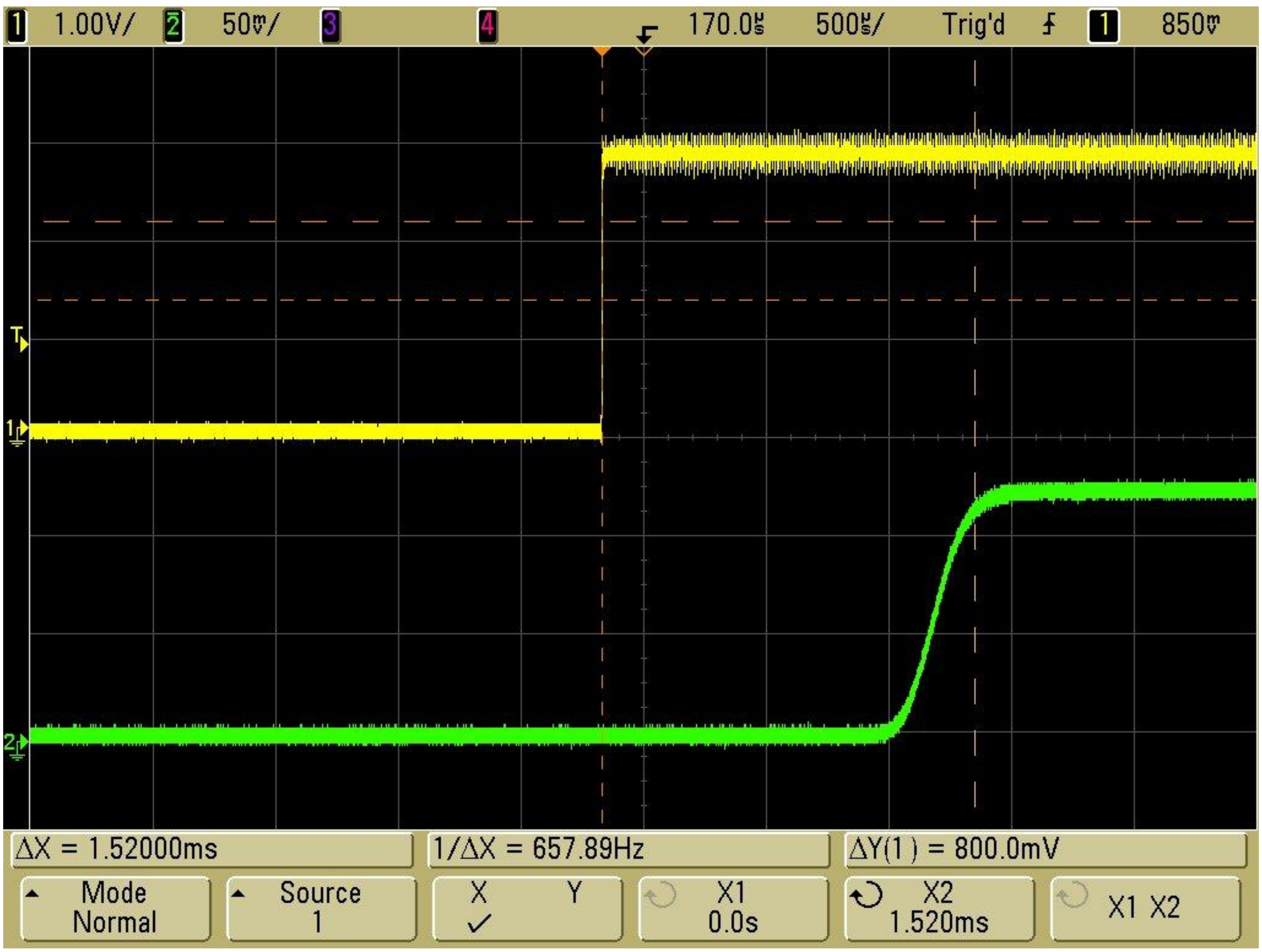
3. **Channel 2 of oscilloscope monitors rectified RF output of Amplifier**

4. **To make measurement of turn-on time, leave DC power supply on, disconnect and "ground" +Vcc line to discharge amplifier, then insert Vcc line back into power supply. This method will eliminate turn on time transient of power supply itself. Set up trigger of O'Scope to trigger on rising edge of Ch.1**

5. **To make measurement of turn-off time, with supply ON, reset o'scope, setup trigger to trigger on falling edge of Ch. 1, and simply remove +Vcc line / wire from the power supply input to turn amplifier OFF.**

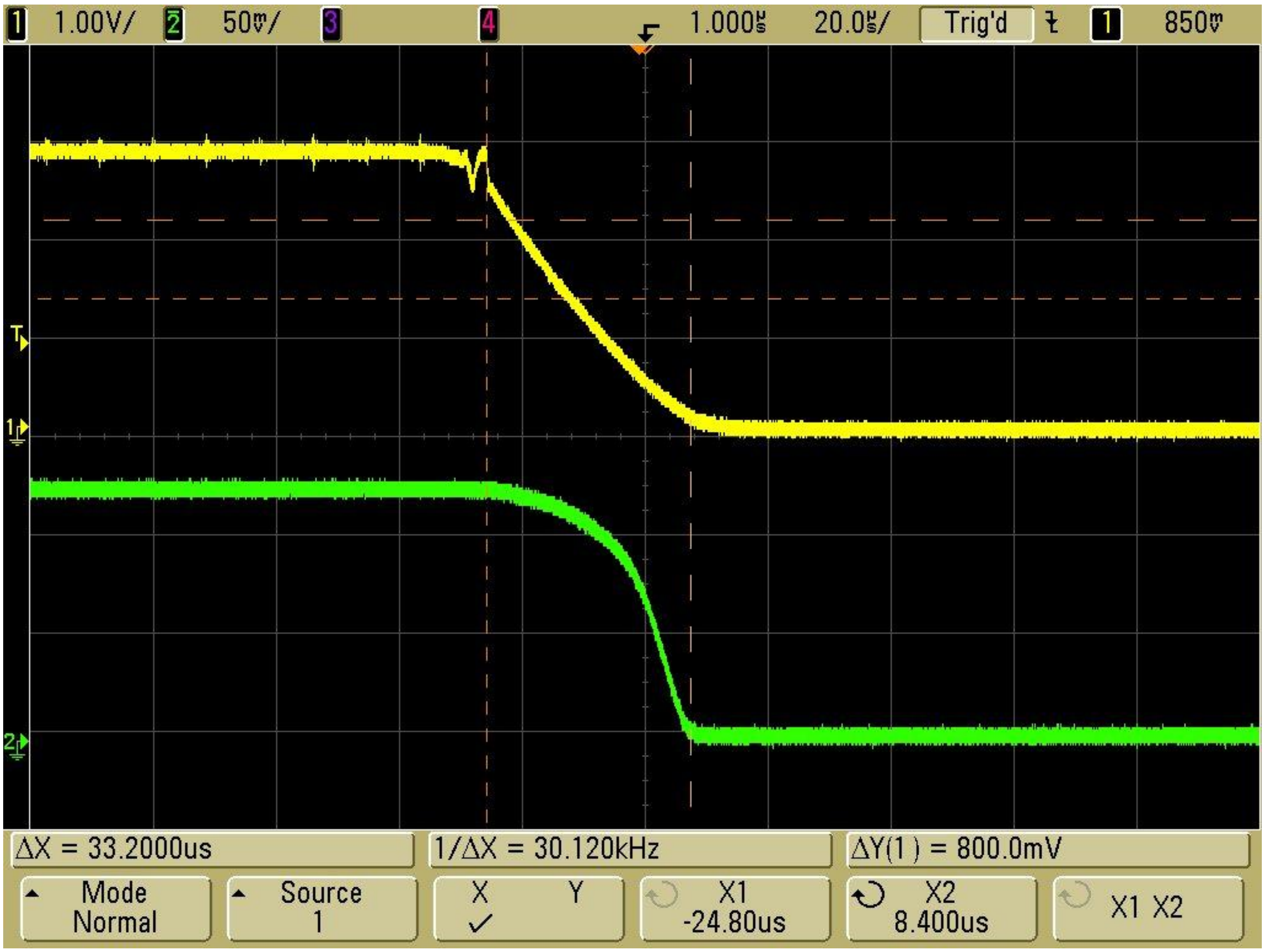
a) Turn On Time:

Refer to oscilloscope screen-shot below. Upper trace (yellow, Channel 1) is DC power supply turn-on step waveform whereas lower trace (green, Channel 2) is rectified RF output signal of the LNA stage. **Amplifier turn-on time is aproximately 1.5 milliseconds, or 1500 microseconds.** Main source of time delay in the LNA turn-on and turn-off events are the R-C time constants formed by (R2 + R3) x C4 and R3 x C5. Additional Charge Storage (e.g. relatively large values of C3 and C5) help to reduce Third-Order distortion levels but increase turn-on / turn-off times of the amplifier. (Please refer to Schematic diagram on page 6).



b) Turn-Off Time:

Rectified RF output signal (lower green trace) takes **approximately ~ 30 microseconds** to settle out after power supply is turned off.



14 References

[1]. *“A High IIP_3 Low Noise Amplifier for 1900 MHz Applications Using the SiGe BFP620 Transistor”.* Applied Microwave and Wireless, July 2000. The article explains how additional charge-storage (capacitance) placed across base-emitter and collector-emitter junctions can reduce the levels of third-order products generated during a two-tone intermodulation test; refer to the section entitled “Effect of adding additional charge storage across the base-emitter junction” on pages 3 and 4.

[2]. BFP640F Datasheet, Infineon Technologies AG.

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