Application Note, Rev. 1.0, January 2009

Application Note No. 173

BFR740L3RH SiGe:C Ultra Low Noise RF Transistor in 2.4 – 2.5 GHz LNA Application with 18 dB Gain, 0.7 dB Noise Figure & < 1 microsecond Turn-On / Turn-Off Time

(For 802.11b/g & 802.11n “MIMO” Wireless LAN Applications; ‘Green’, Halogen-Free Ultra-Small TSLP-3-9 Leadless Package, 0402 case size passives).

RF & Protection Devices

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Application Note No. 173

Revision History: 2009-01-29, Rev 1.0

Changes to previous version	

Trademarks

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 BFR740L3RH SiGe:C Ultra Low Noise RF Transistor in 2.4 – 2.5 GHz LNA Application with 18 dB Gain, 0.7 dB Noise Figure & < 1 µSec Turn-On / Turn-Off Time

Overview

- Infineon Technologies **BFR740L3RH** is a high gain, ultra low noise Silicon-Germanium-Carbon (SiGe:C) HBT device suitable for a wide range of Low Noise Amplifier (LNA) applications. Refer to Reference [1], BFR740L3RH datasheet, embedded on page 26 of this document.
- The circuit is targeted for 802.11b / g & 802.11n “MIMO” applications in the Wireless Local Area Network (WLAN) market, particularly for Access Points (AP’s) which require external LNA’s to fulfill high-sensitivity / long range requirements. LNA’s for this application must be able to switch on / off within about 1 microsecond (1000 nanoseconds). Charge storage (capacitance) used in this circuit is minimized to reduce on / off times. Trade-off for reduced capacitance values is a reduction in Third Order Intercept (IP_3) performance. Inductive emitter degeneration is used to improve amplifier low-frequency stability & impedance matching. Refer to Reference [2], page 26, for a general overview of charge storage & inductive emitter degeneration. **Amplifier is Unconditionally Stable (μ_1 > 1.0) from 10 MHz – 9.4 GHz, & Conditionally Stable for f > 9.4 GHz.** Refer to pages 13–14 for discussion of amplifier design trade-offs including stability margin.
- Parts count (not including BFR740L3RH transistor) = 10; 5 capacitors, 3 resistors, & 2 chip inductors. Passives are ‘0402’ case size for cost reduction (e.g. lower cost than ‘0201’). BFR740L3RH transistor package (TSLP-3-9) is RoHS – compliant, **Halogen-Free** & measures only 1 x 0.6 x 0.31mm, which is suitable for modules if smaller size passives are employed.

2 Summary Of Performance Data

(T=25 °C, network analyzer source power ≈ -25 dBm, V_{CC} = 3.0 V, V_{CE} = 2.3 V, I_C=14.7 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
2400	- 12.1	**18.2**	-22.6	-12.7	**0.7**	---	---	---	---
2441	-12.3	**18.1**	-22.5	-12.3	**0.7**	+1.4	+19.5	-9.8	+7.3
2483.5	-12.4	**17.9**	-22.5	-11.9	**0.7**	---	---	---	---

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

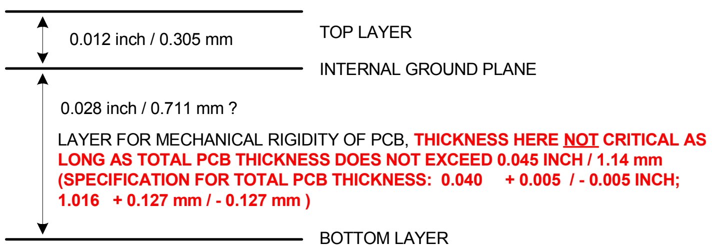
Turn-On Time: ~ 350 nanoseconds; Turn-Off Time ~ 24 nanoseconds. Please refer to pages 25 – 26.

Note: reverse isolation (dB[s12]^2) when DC power to LNA is OFF = -13.5 dB @ 2441 MHz.

3 Details of PC Board Construction

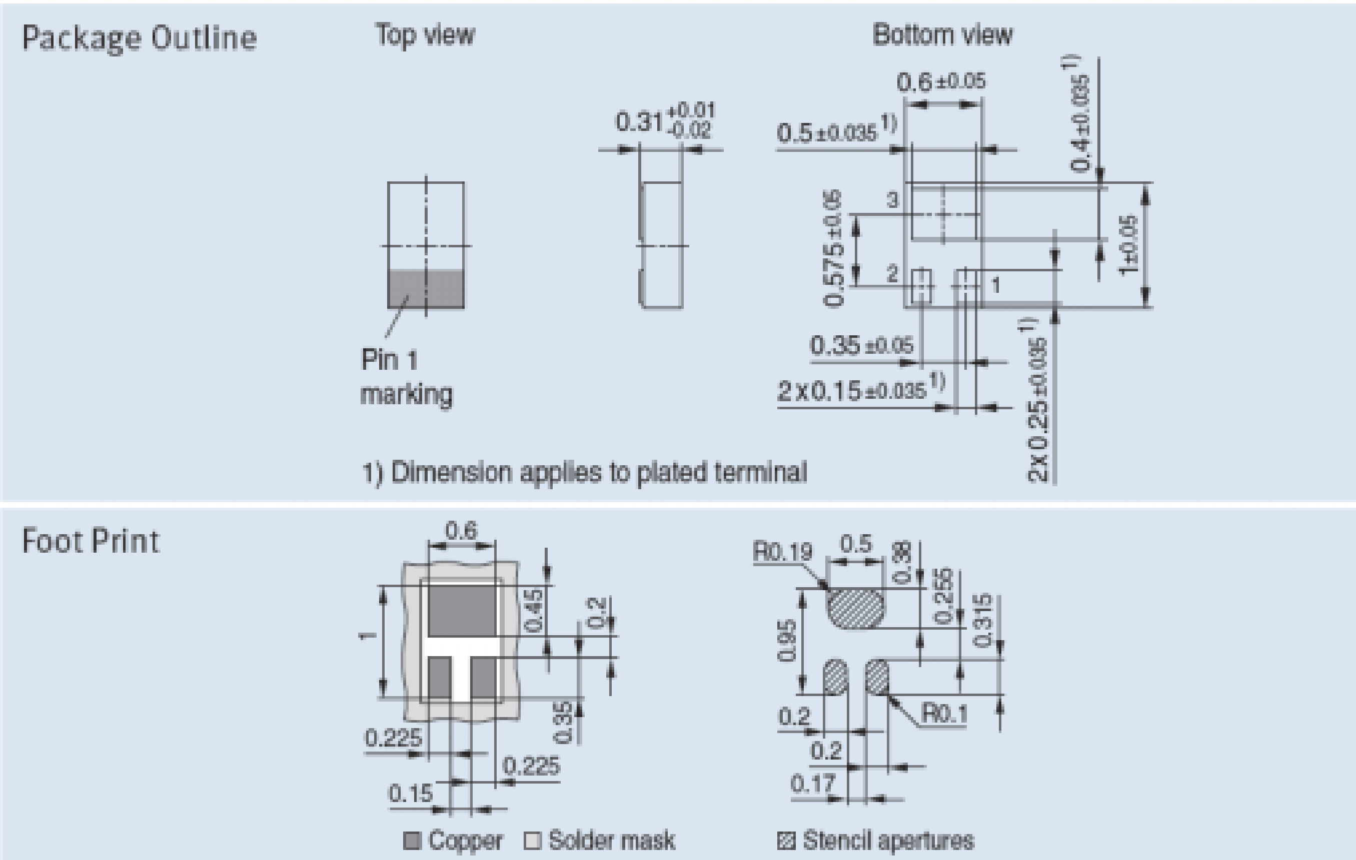
PC board uses standard, low-cost “FR4” glass-epoxy material. A cross-section diagram of the PC board is given below. The “Gerber” & other fabrication files used for the generation of the PC board shown in this app note are embedded in the “References” section of this Applications Note on page 26. [3]

PCB CROSS SECTION

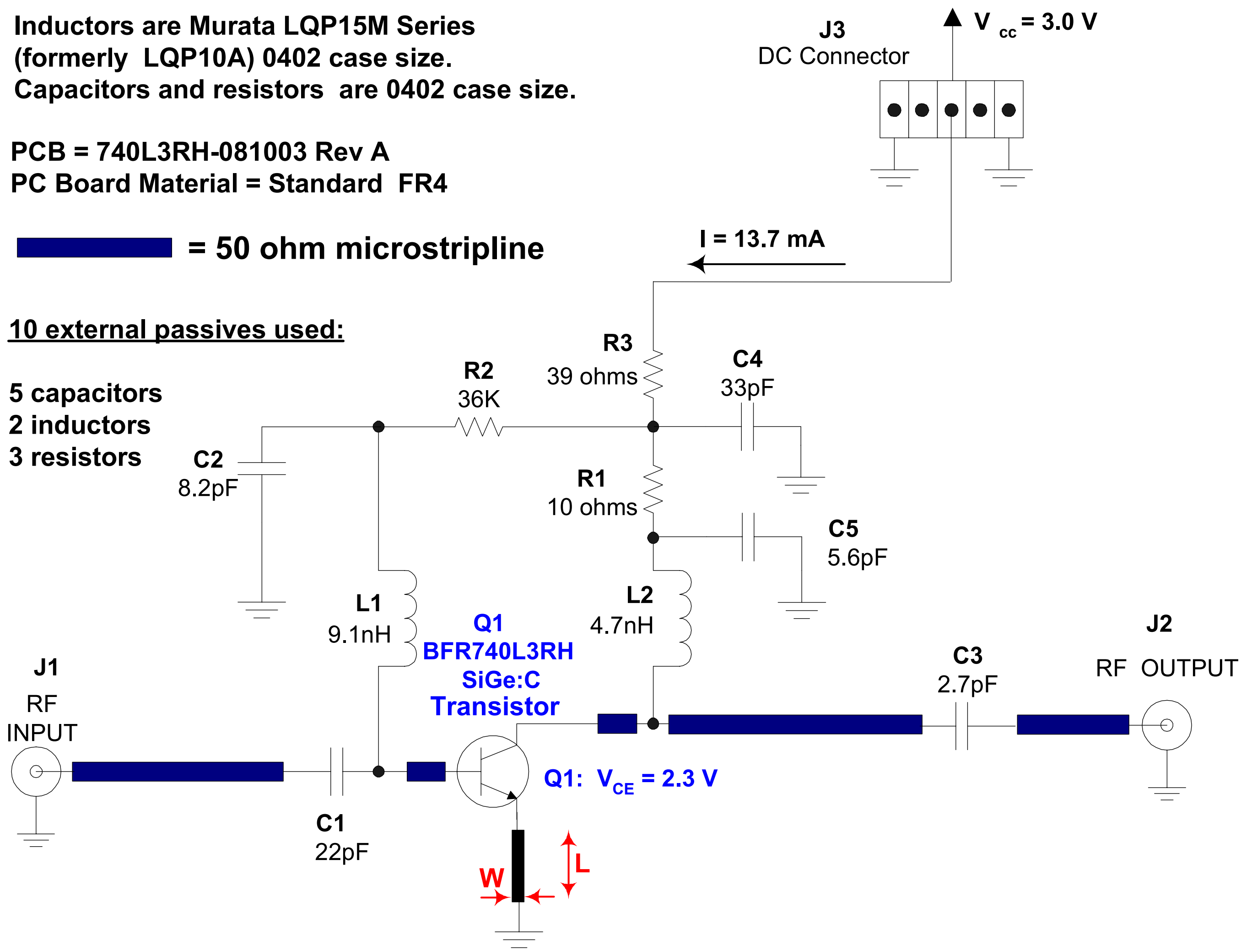


4 TSLP-3-9 Package Outline and Footprint

(Dimensions in millimeters). Note maximum package height is 0.32 mm / 0.013 inch.



5 Schematic Diagram



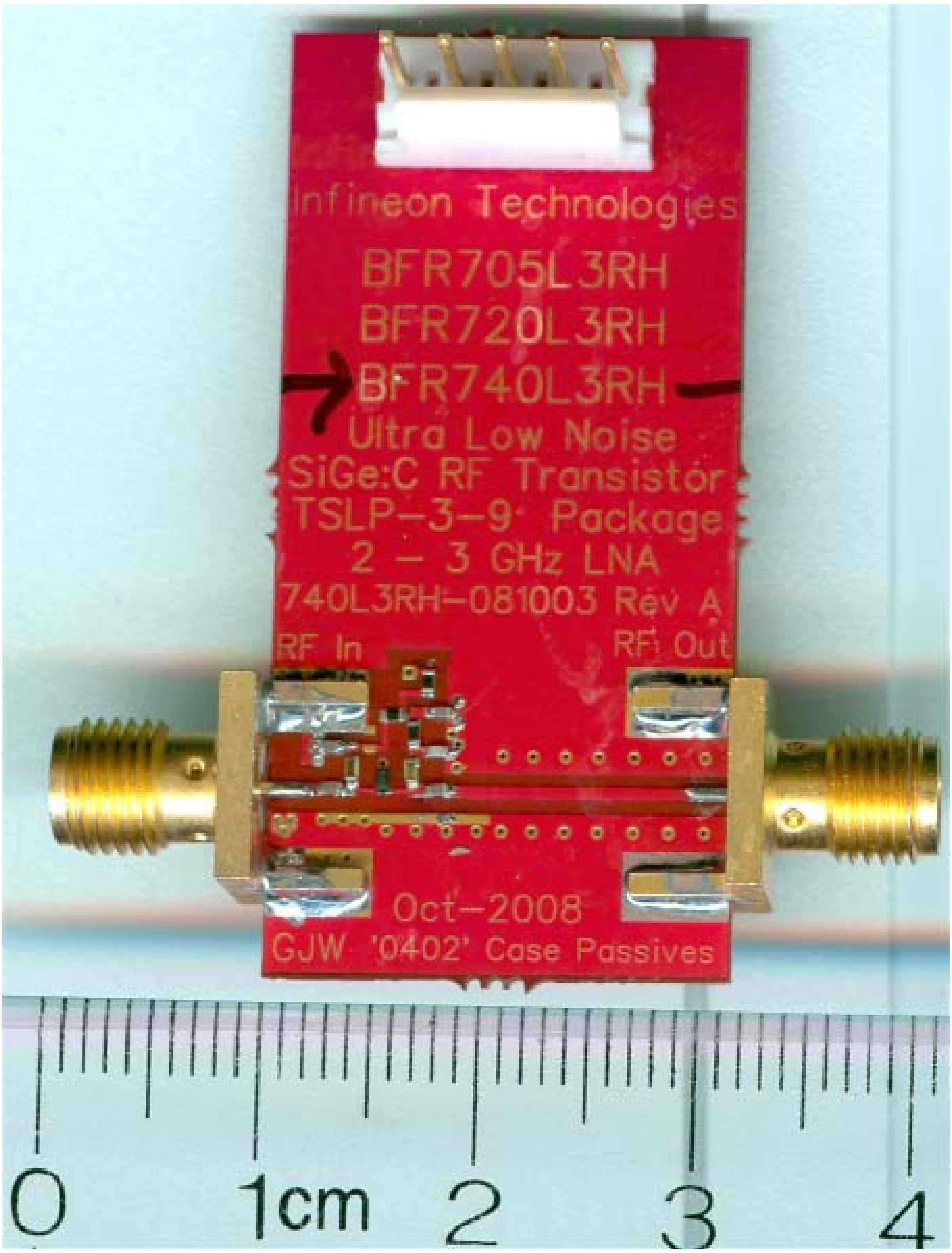
Inductive Emitter Degeneration for low frequency stability improvement, impedance matching. One microstrip inductor (PCB trace) from the transistor emitter lead to a ground via hole is used. Ground hole via diameter is 0.012 inch / 0.3mm. Microstrip inductor dimensions are: W = 0.010 inch / 0.25 mm; L = 0.010 inch / 0.25 mm, height "h" between top layer RF traces and internal ground plane is 0.012 inch / 0.3mm. Note if spacing in the user's PCB between top layer RF traces and internal ground plane is substantially greater than 0.012 inch / 0.3 mm, e.g. 0.062 inch / 1.6 mm thick, the additional via hole inductance of the thicker PCB will suffice by itself, and the microstrip inductors can be eliminated entirely. Note PCB "Gerber" fabrication files for the application board shown are attached in the "References" section on page 26 of this Applications Note.

6 Bill Of Material (BOM)

Reference Designator	Value	Description / Part #	Manufacturer	Function
C1	22pF	'0402' chip capacitor	Various	Input DC block; also using cap above Self-Resonant Frequency makes it have some net inductive reactance at 2.4 GHz to slightly improve input match
C2	8.2pF	'0402' chip capacitor	Various	RF Decoupling / blocking cap
C3	2.7pF	'0402' chip capacitor	Various	Output DC block; also influences output and input match
C4	33pF	'0402' chip capacitor	Various	RF decoupling / blocking cap
C5	5.6pF	'0402' chip capacitor	Various	RF decoupling / blocking cap; also influences output match and amplifier stability margin
L1	9.1nH	'0402' case size chip inductor Murata LQP15M Series or equivalent	Murata	RF Choke at LNA input (for DC bias to base). Also has some influence on input match due to relatively low value
L2	4.7nH	'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	10 Ω	'0402' chip resistor	Various	For RF stability improvement.
R2	36KΩ	'0402' chip resistor	Various	DC biasing (base current).
R3	39Ω	'0402' chip resistor	Various	DC biasing (provides DC negative feedback to stabilize DC operating point over temperature variation, transistor h_{FE} variation, etc.)
Q1	**---**	**BFR740L3RH SiGe:C Low Noise RF Transistor, TSLP-3-9 Reduced Height, 'Green', Halogen Free Leadless 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 # 740L3RH-081003 Rev A	Infineon Technologies	Printed Circuit Board

7 Scanned Images of PC Board

View of Entire PC Board



Close-In View of LNA Section. Note BFR740L3RH transistor package (TSLP-3-9) is approximately the same dimensions as a standard "0402' case size passive, but with a lower height of only 0.31mm typical. For Module applications, the user may wish to select '0201' case passives to reduce required circuit area and height. '0402' case size passives were selected here so as to reduce cost.

8 Noise Figure Measurement Data

Noise Figure Plot, from Rohde and Schwarz FSEK3 + FSEM30

Rohde & Schwarz FSEK3 29 Jan 2009

Noise Figure Measurement

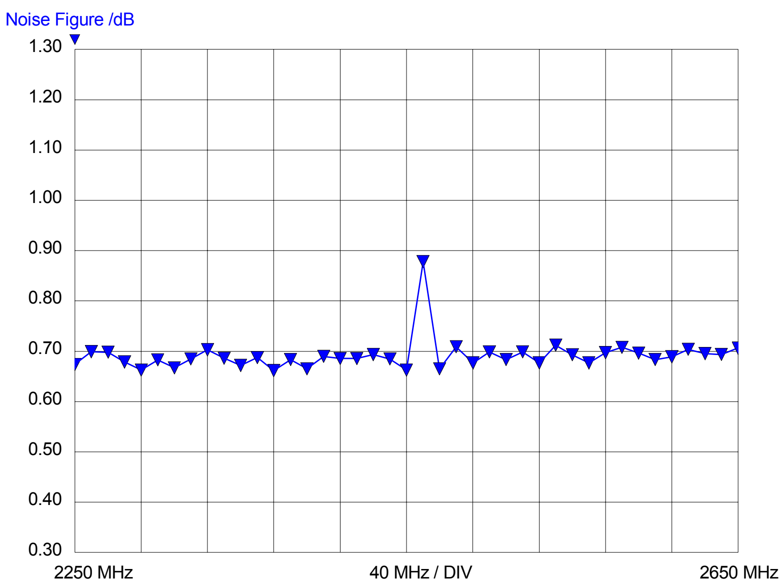
EUT Name:	BFR740L3RH 2.4 - 2.5 GHz LNA, Fast Switching / Fast Turn ON-OFF Time
Manufacturer:	Infineon Technologies
Operating Conditions:	T=25 C, V = 3.0V, Vce = 2.3V, I = 13.7mA
Operator Name:	Gerard Wevers
Test Specification:	WLAN 802.11b / g / n AN173
Comment:	PCB = 740L3RH-081003 Rev A; Preamp = MITEQ SMC-02 29 January 2009

Analyzer

RF Att:	0.00 dB	RBW :	1 MHz	Range:	30.00 dB
Ref Lvl:	-51.00 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

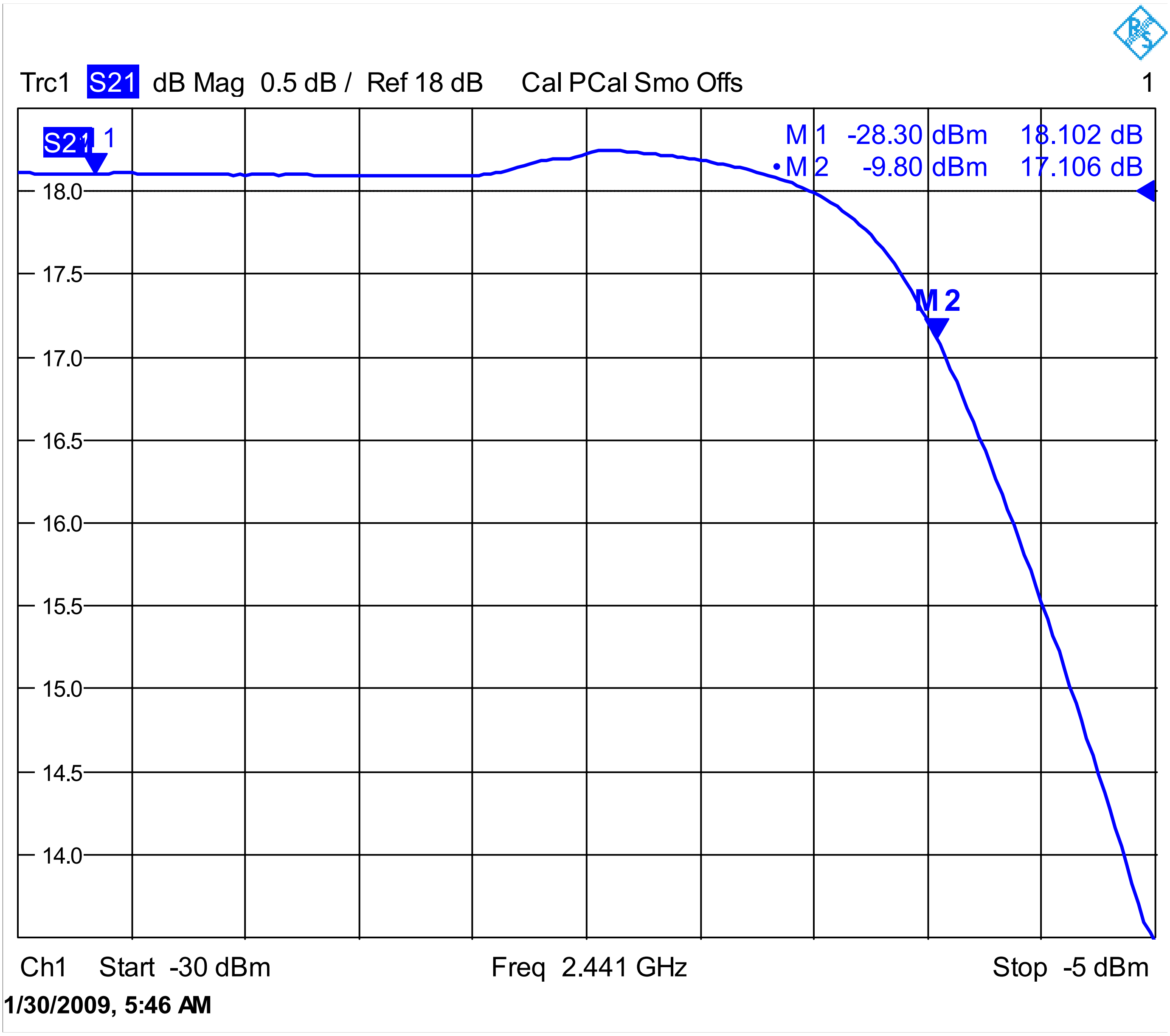
Frequency	Nf	Temp
2250 MHz	0.67 dB	48.7 K
2260 MHz	0.70 dB	50.6 K
2270 MHz	0.70 dB	50.6 K
2280 MHz	0.68 dB	49 K
2290 MHz	0.66 dB	47.8 K
2300 MHz	0.68 dB	49.4 K
2310 MHz	0.67 dB	48.1 K
2320 MHz	0.68 dB	49.5 K
2330 MHz	0.70 dB	50.9 K
2340 MHz	0.69 dB	49.6 K
2350 MHz	0.67 dB	48.5 K
2360 MHz	0.69 dB	49.7 K
2370 MHz	0.66 dB	47.7 K
2380 MHz	0.68 dB	49.4 K
2390 MHz	0.66 dB	48 K
2400 MHz	0.69 dB	49.9 K
2410 MHz	0.69 dB	49.6 K
2420 MHz	0.69 dB	49.6 K
2430 MHz	0.69 dB	50.2 K
2440 MHz	0.68 dB	49.5 K
2450 MHz	0.66 dB	47.8 K
2460 MHz	0.88 dB	65 K
2470 MHz	0.66 dB	48 K
2480 MHz	0.71 dB	51.4 K
2490 MHz	0.68 dB	48.9 K
2500 MHz	0.70 dB	50.6 K
2510 MHz	0.68 dB	49.4 K
2520 MHz	0.70 dB	50.6 K
2530 MHz	0.68 dB	48.9 K
2540 MHz	0.71 dB	51.6 K
2550 MHz	0.69 dB	50.1 K
2560 MHz	0.68 dB	48.9 K
2570 MHz	0.70 dB	50.5 K
2580 MHz	0.71 dB	51.3 K
2590 MHz	0.70 dB	50.4 K
2600 MHz	0.68 dB	49.4 K
2610 MHz	0.69 dB	49.8 K
2620 MHz	0.70 dB	51 K
2630 MHz	0.70 dB	50.3 K
2640 MHz	0.69 dB	50.2 K
2650 MHz	0.71 dB	51.2 K

9 Amplifier Compression Point Measurement

Gain Compression at 2441 MHz, V_{CC} = +3.0 V, I = 13.7mA, V_{CE} = 2.3V, T = 25°C:
ZVB20 Vector Network Analyzer is set up to sweep input power to LNA in a "Power Sweep" at a fixed frequency of 2441 MHz. ZVB20 Port 1, which provides INPUT power to drive the LNA, has its power level calibrated ("SOURCE POWER CAL") with the NRP-Z21 power sensor to ensure power level accuracy with the reference plane at the RF input connector of the amplifier (DUT). X-axis of VNA screen-shot below shows input power to LNA swept from –30 to –5 dBm.

Input 1 dB compression point = - 9.8 dBm

Output 1dB compression point = -9.8 dBm + (Gain–1dB) = -9.8 dBm + 17.1 dB = **+7.3 dBm**



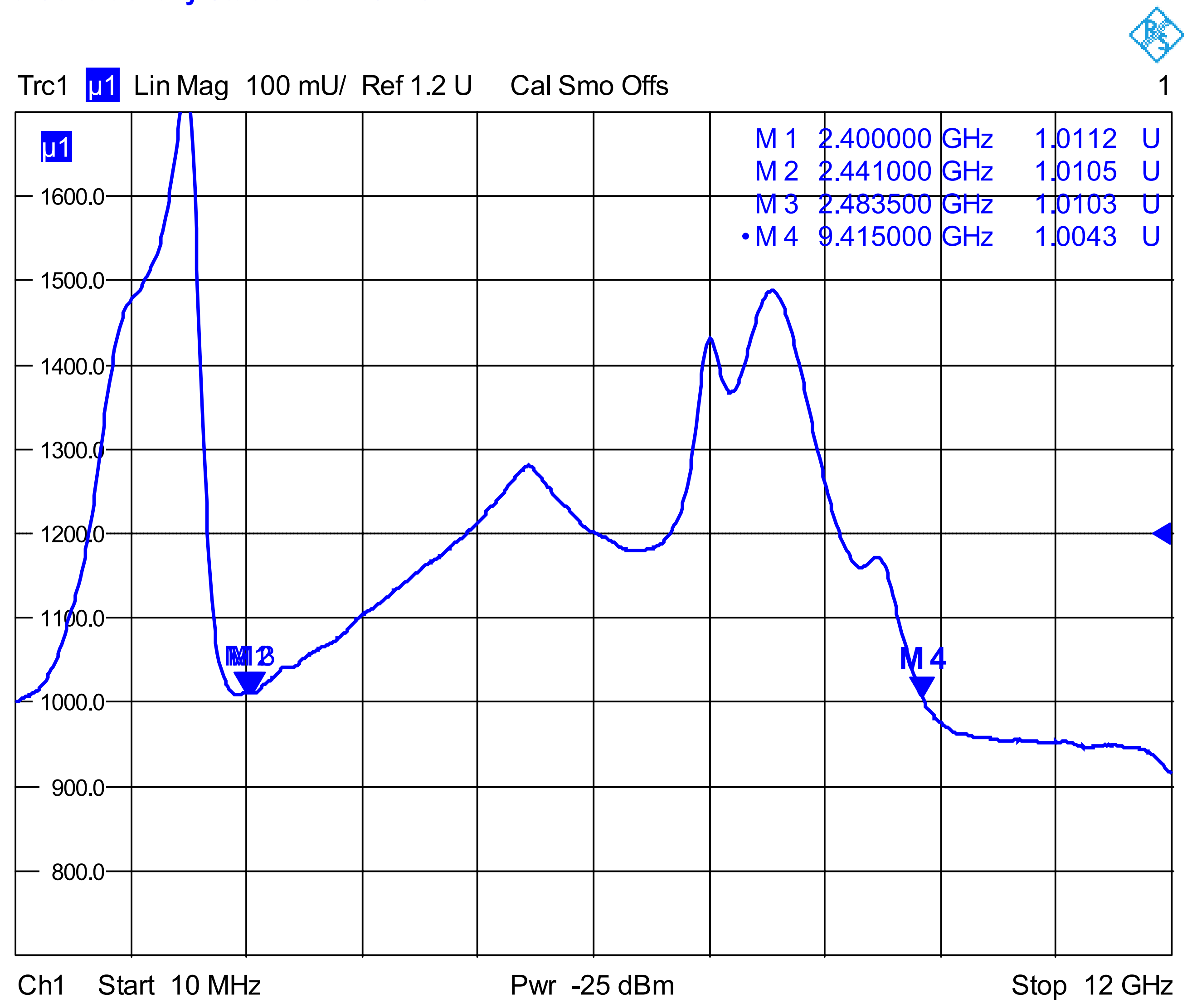
10 Amplifier Stability, Gain, Return Loss and Reverse Isolation Plots

Amplifier Stability - Plot of Stability Factor "μ_1" :

Rohde and Schwarz ZVB Network Analyzer Calculates and plots stability factor "μ_1" of the BFP740F 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 $\mu_1 > 1.0$. In the plot, $\mu_1 > 1.0$ over 10 MHz – 12 GHz; **amplifier is Unconditionally Stable over 10 MHz – 9.4 GHz frequency range, and Conditionally Stable for f > 9.4 GHz.**



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

Notes on Amplifier Stability Trade-offs with respect to inductive emitter degeneration:

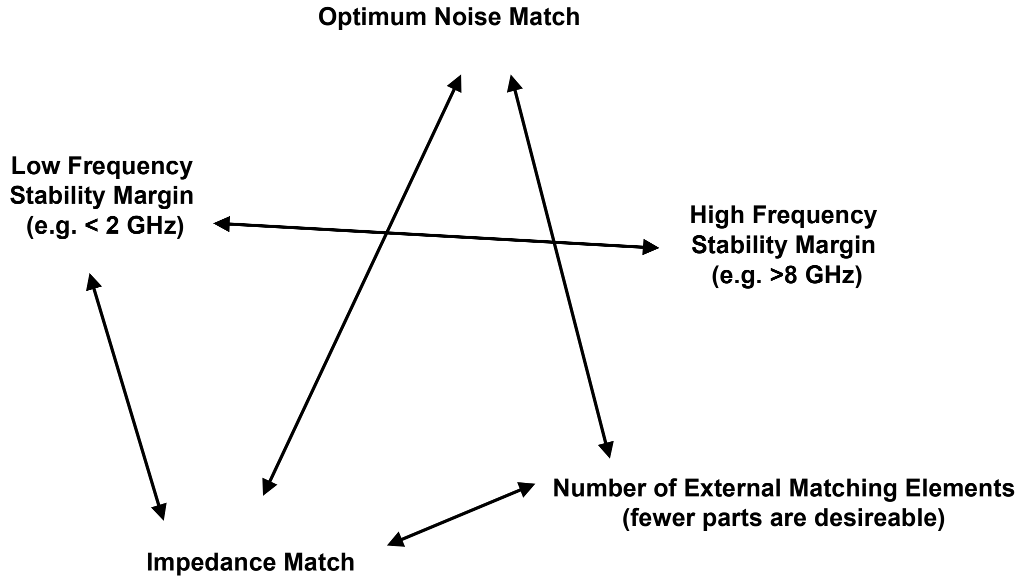
- Using inductive emitter degeneration – e.g. intentionally placing a small amount if additional inductance in the transistor's ground path (emitter) involves design trade-offs. These trade-offs are best illustrated in the diagram below. A detailed discussion is given in Reference [2], which is embedded on page 26 of this applications note.

- The circuit shown in this application note represents a "**good compromise**" between high & low frequency stability, low noise figure, good impedance matching to a 50 Ω system, and minimal external parts count, with regard to the amount of inductive emitter degeneration used.

- Although the stability factor μ_1 dips below 1.0 above 9.4 GHz, μ_1 still remains > 0.9 out to 12 GHz, meaning the regions on the Smith Chart representing potentially unstable source & load impedances above 9.4 GHz are quite small. Furthermore, *the amplifier's gain falls off rather quickly with increasing frequency, being only 3 – 4 dB at 12 GHz.* These two conditions mean the risk of oscillation is very low in a real-life application circuit.

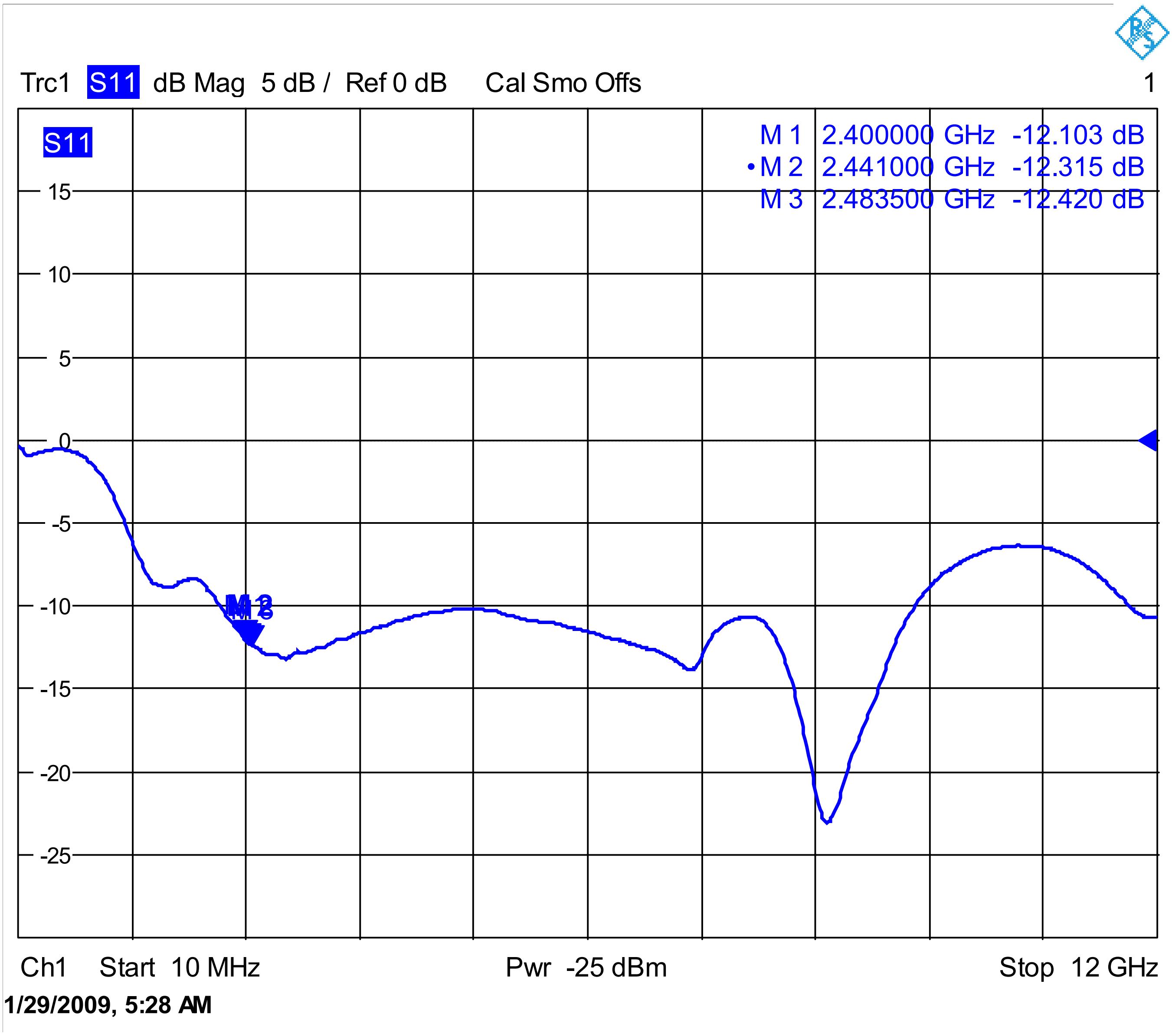
- **Key design criteria for the end user is his or her PCB layer stackup**. If the end user's PCB has significantly different thickness between top layer RF trace and internal ground plane than the 0.3 mm / 0.012 inch as shown in this applications note, the amount of emitter degeneration used on the top layer of the board will have to be modified, and can best be determined via use of an RF / Microwave simulation tool using the supplied BFR740L3RH S-parameters, available on the Infineon website (see link on page 3 of this applications note). For example, if the end-user has a two layer structure with 1.6 mm / 0.062 inch between the RF layer and ground plane, there will be significantly more ground via hole inductance relative to the ground hole inductance in the PC board shown in this Applications Note. Therefore, for the thicker PCB, the microstrip inductor on the top layer between the BFR740L3RH emitter pad and the ground via should be eliminated entirely. On the other hand, if the end-user's PCB has a "thinner" cross section, with less distance between RF and ground layers, the microstrip inductor may need to be lengthened.

Some LNA Design Trade - Offs



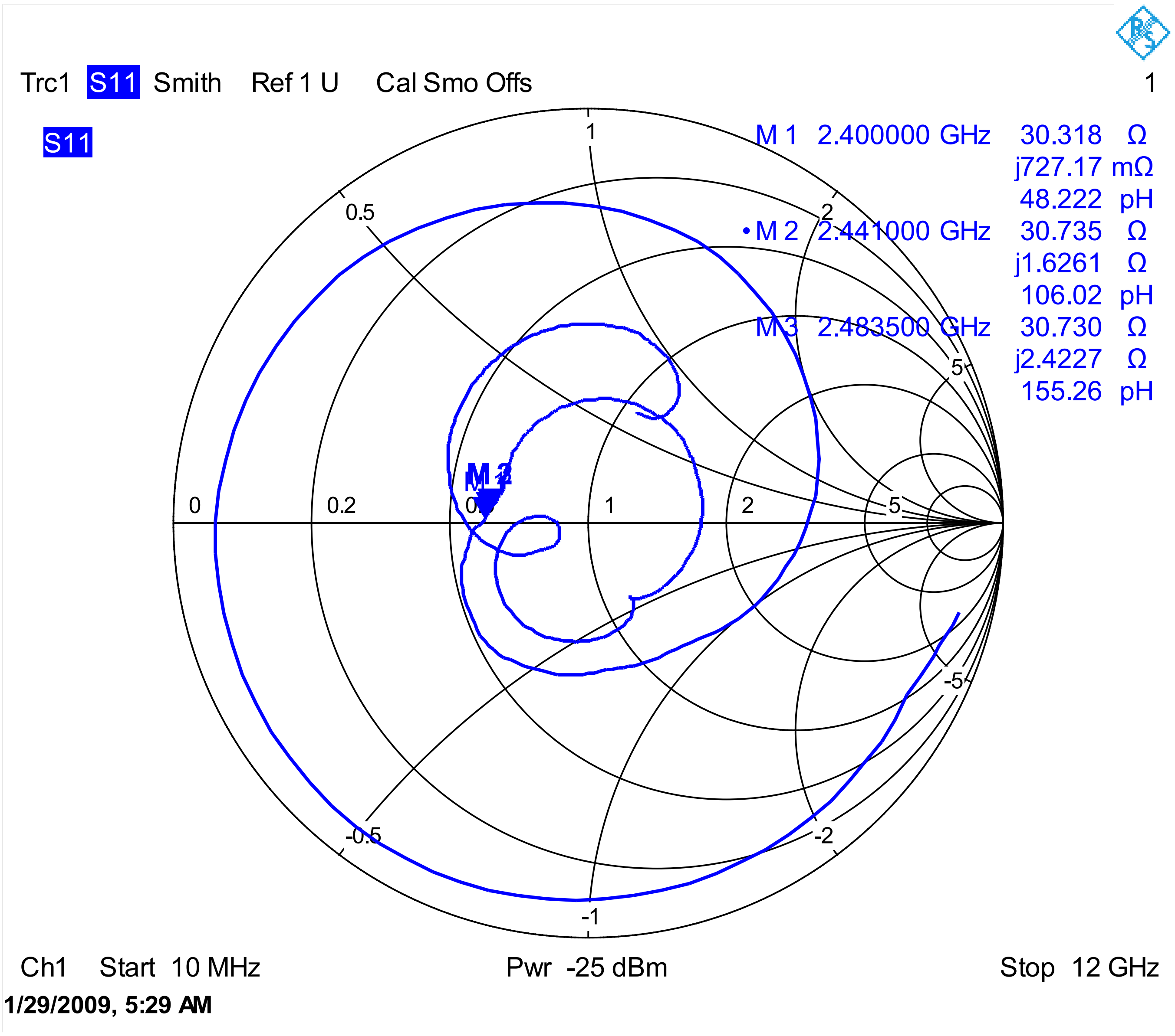
Input Return Loss, Log Mag

10 MHz – 12 GHz Sweep



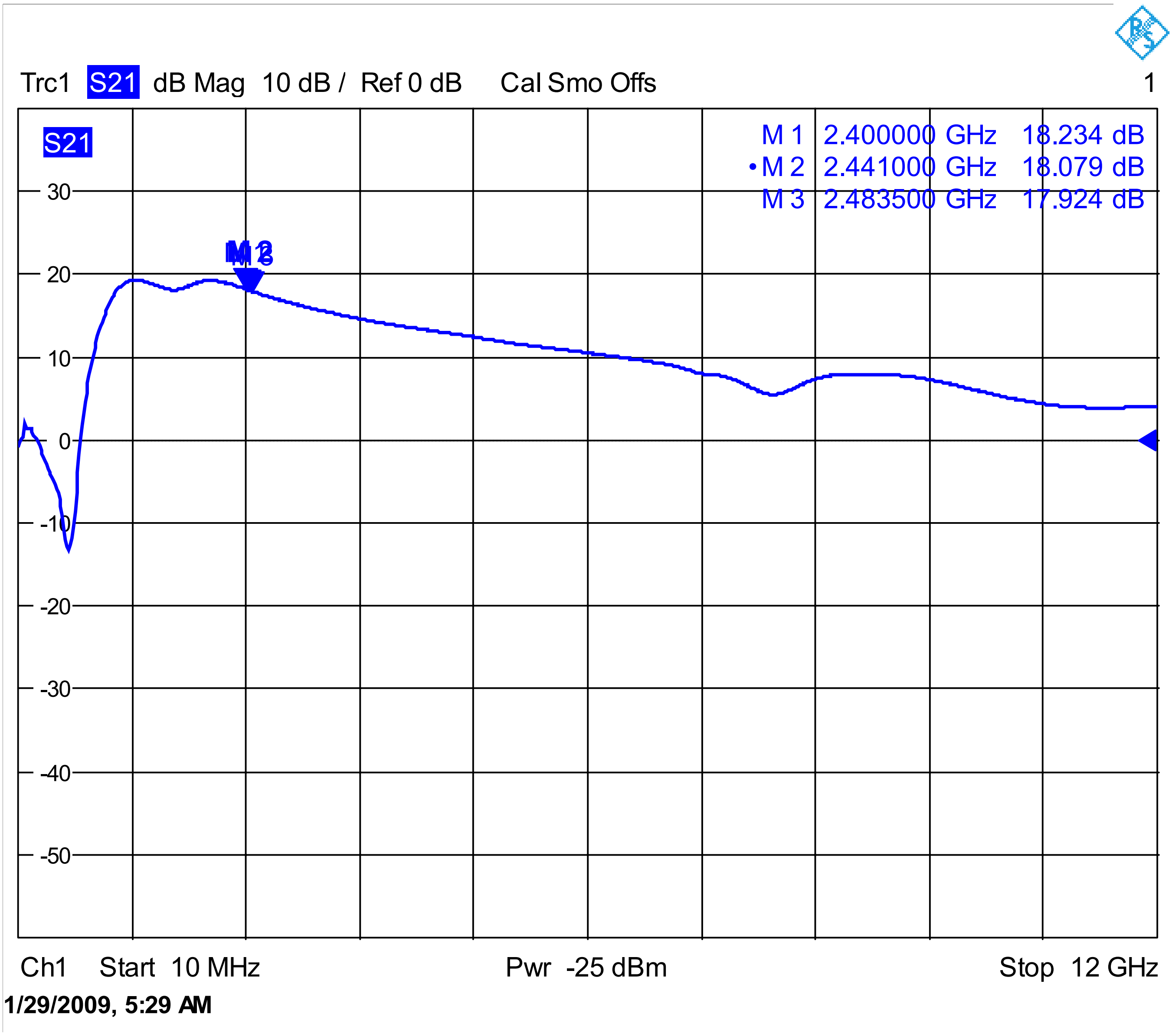
Input Return Loss, Smith Chart

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



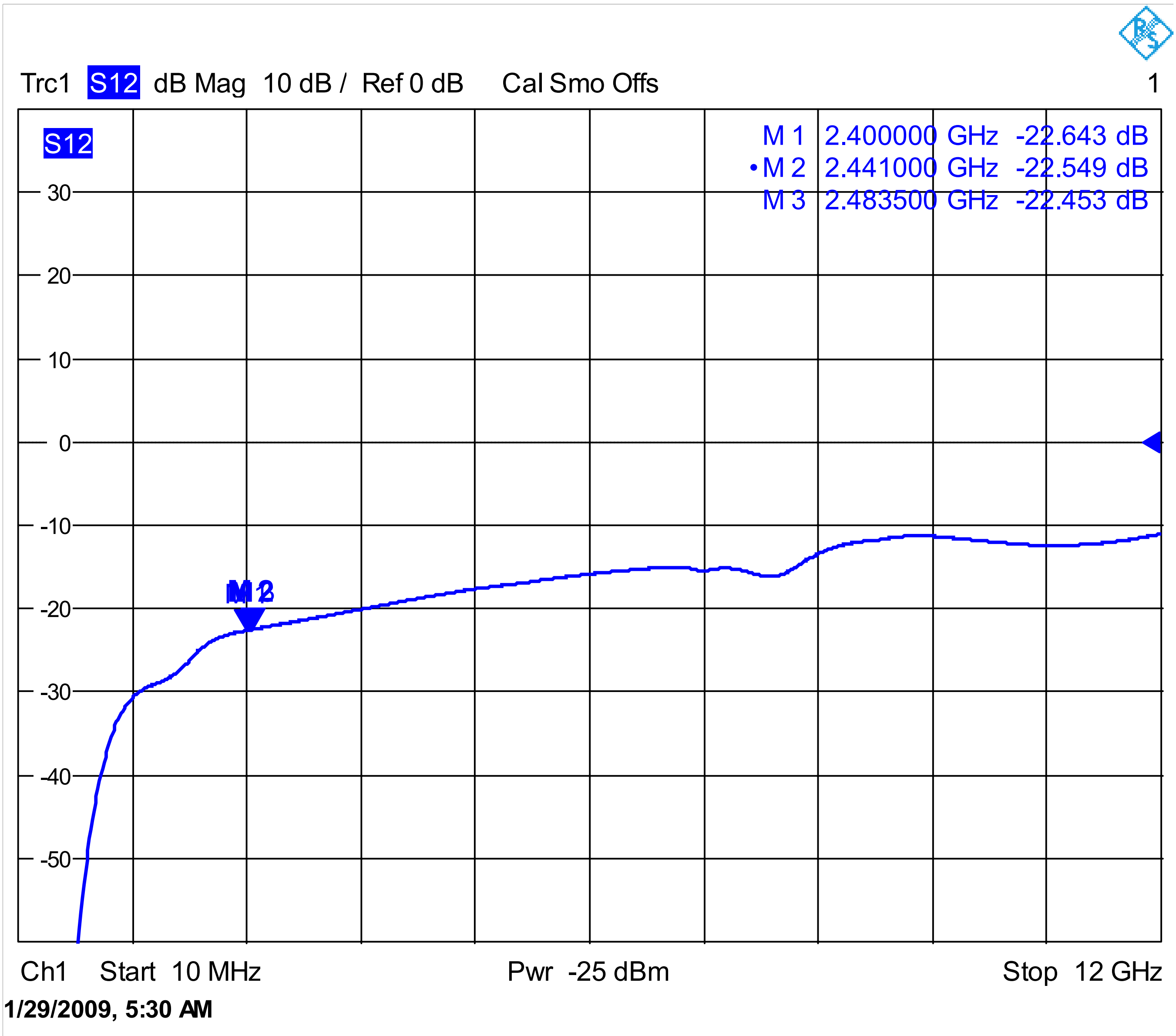
Forward Gain.

10 MHz – 12 GHz Sweep



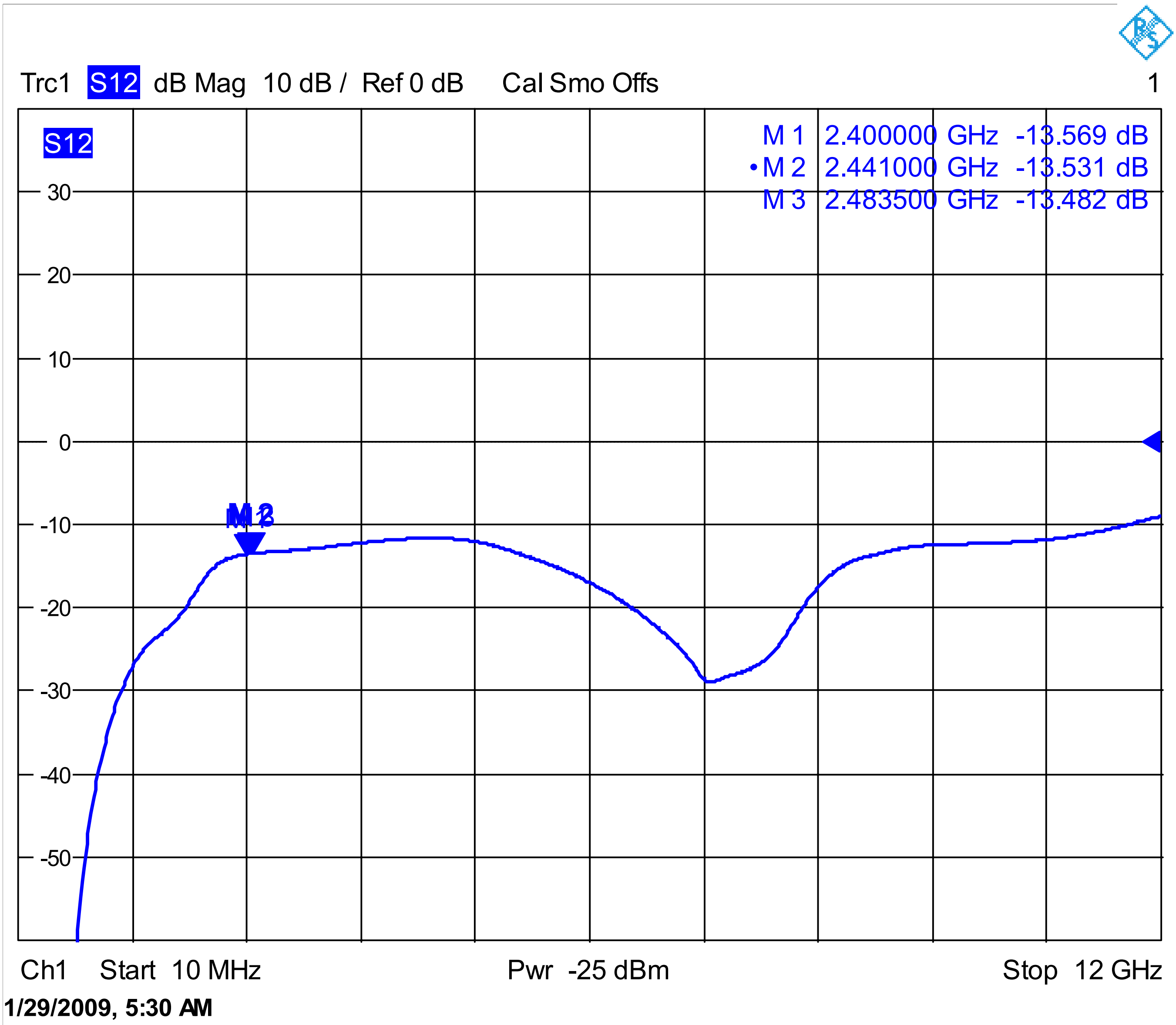
Reverse Isolation

10 MHz – 12 GHz Sweep



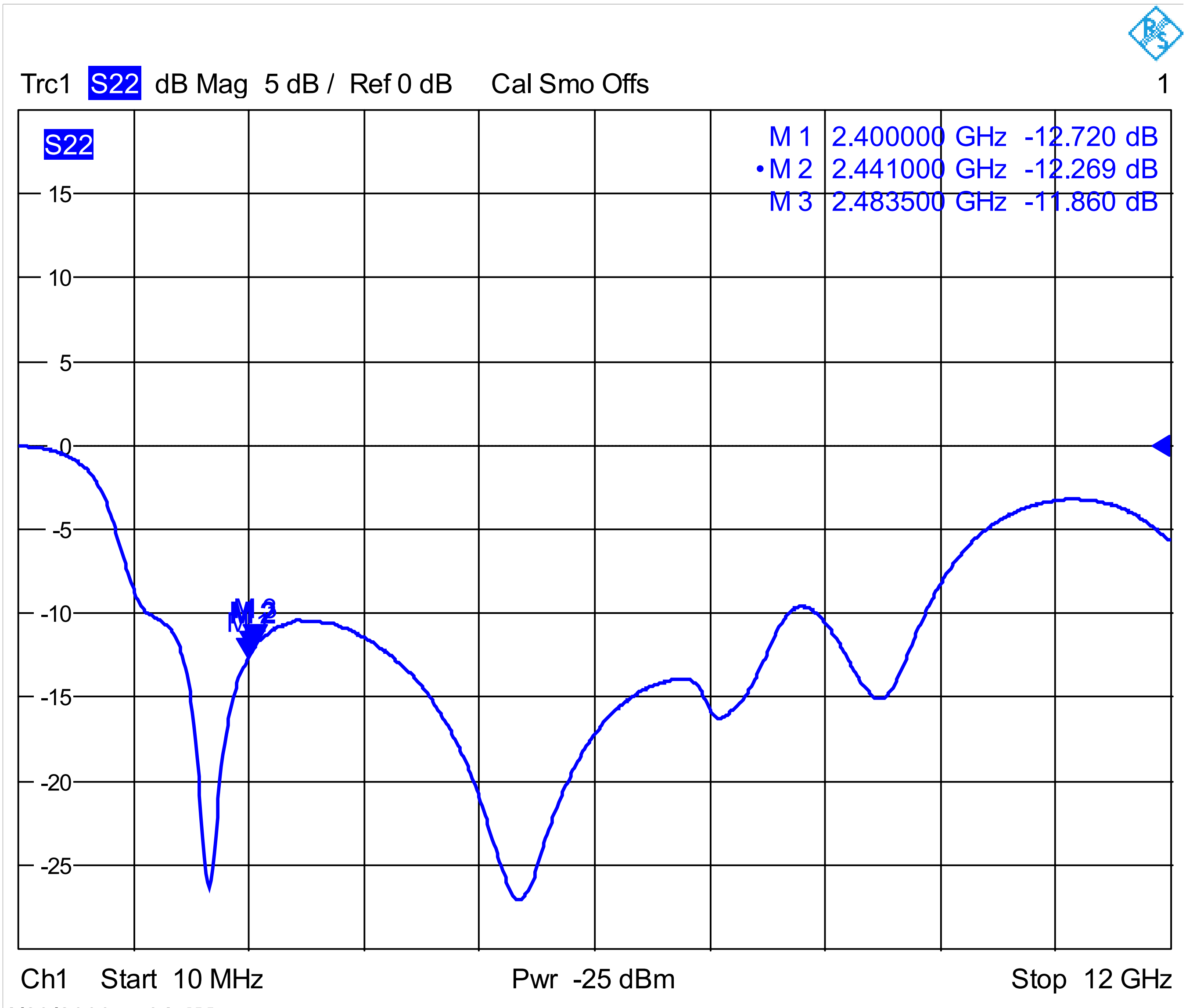
Reverse Isolation, AMPLIFIER DC POWER TURNED OFF.

10 MHz – 12 GHz Sweep



Output Return Loss, Log Mag

10 MHz to 12 GHz Sweep



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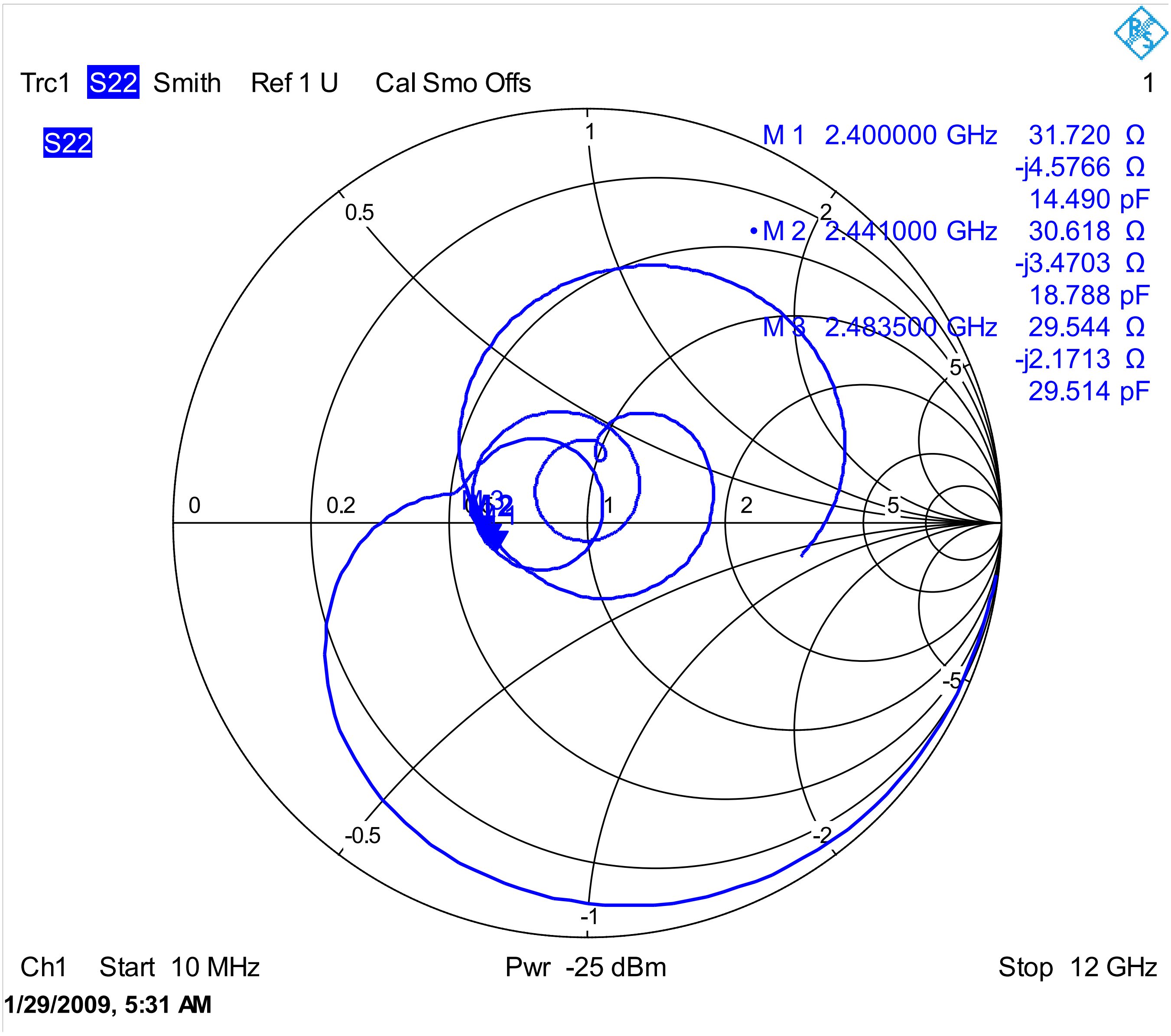
Output Return Loss, Smith Chart

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

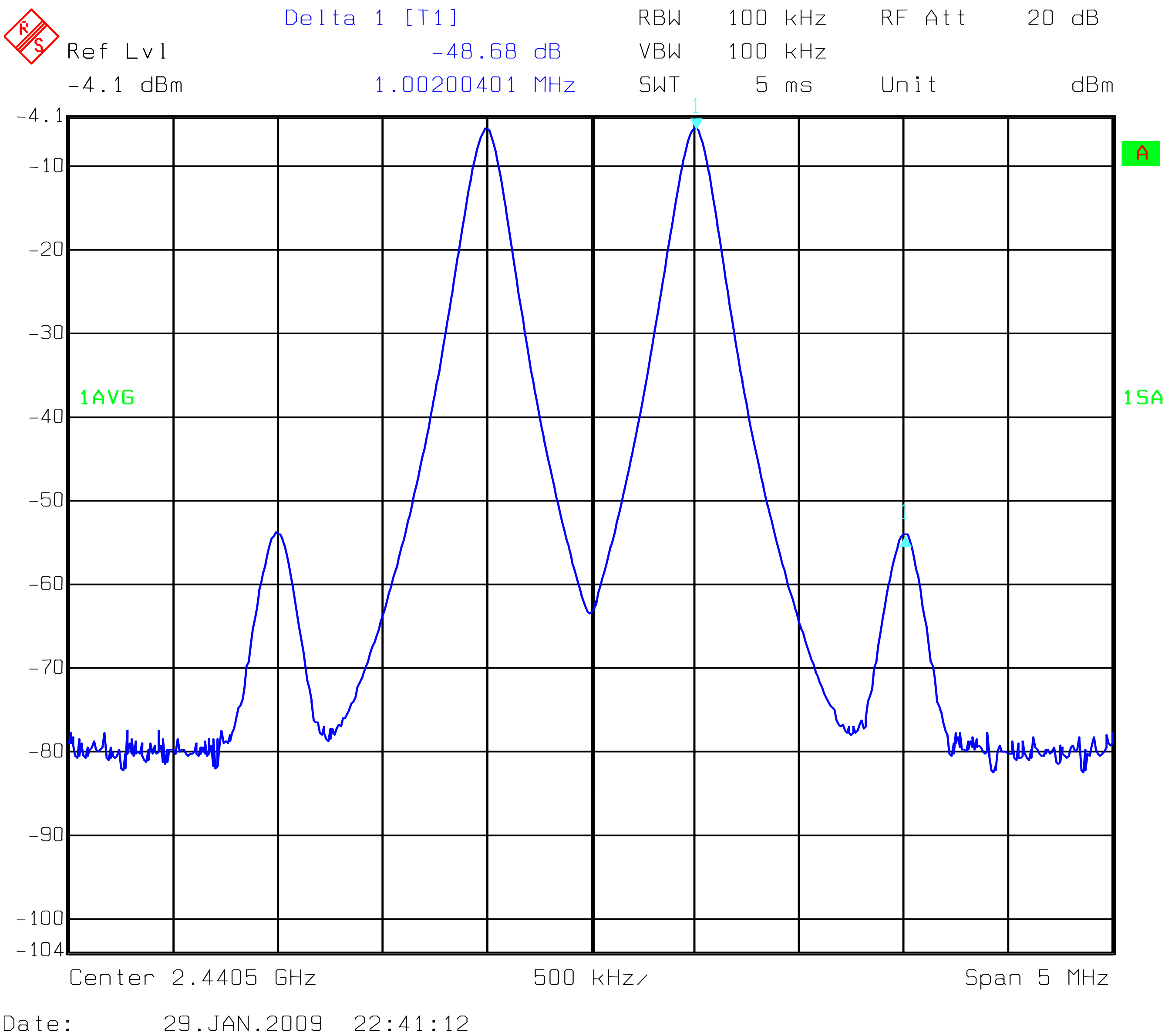


11 Amplifier Third Order Intercept (TOI) Measurement

In-Band Third Order Intercept (IIP_3) Test.

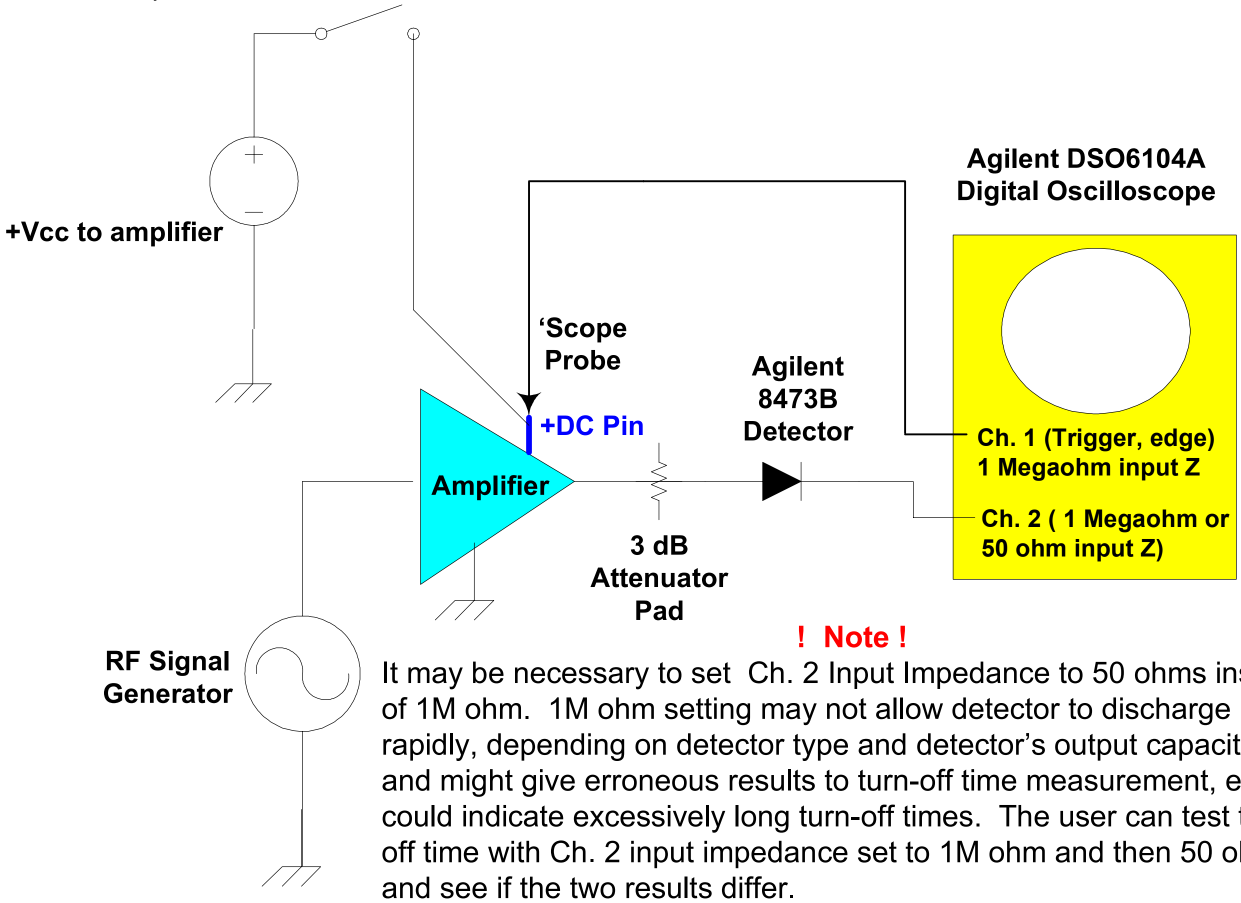
Input Stimulus: f_1=2440 MHz, f_2=2441 MHz, -23 dBm each tone.

Input IP_3 = -23+(48.7 / 2) = +1.4 dBm. Output IP_3 = +1.4 dBm + 18.1 dB gain = +19.5 dBm.



12 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.

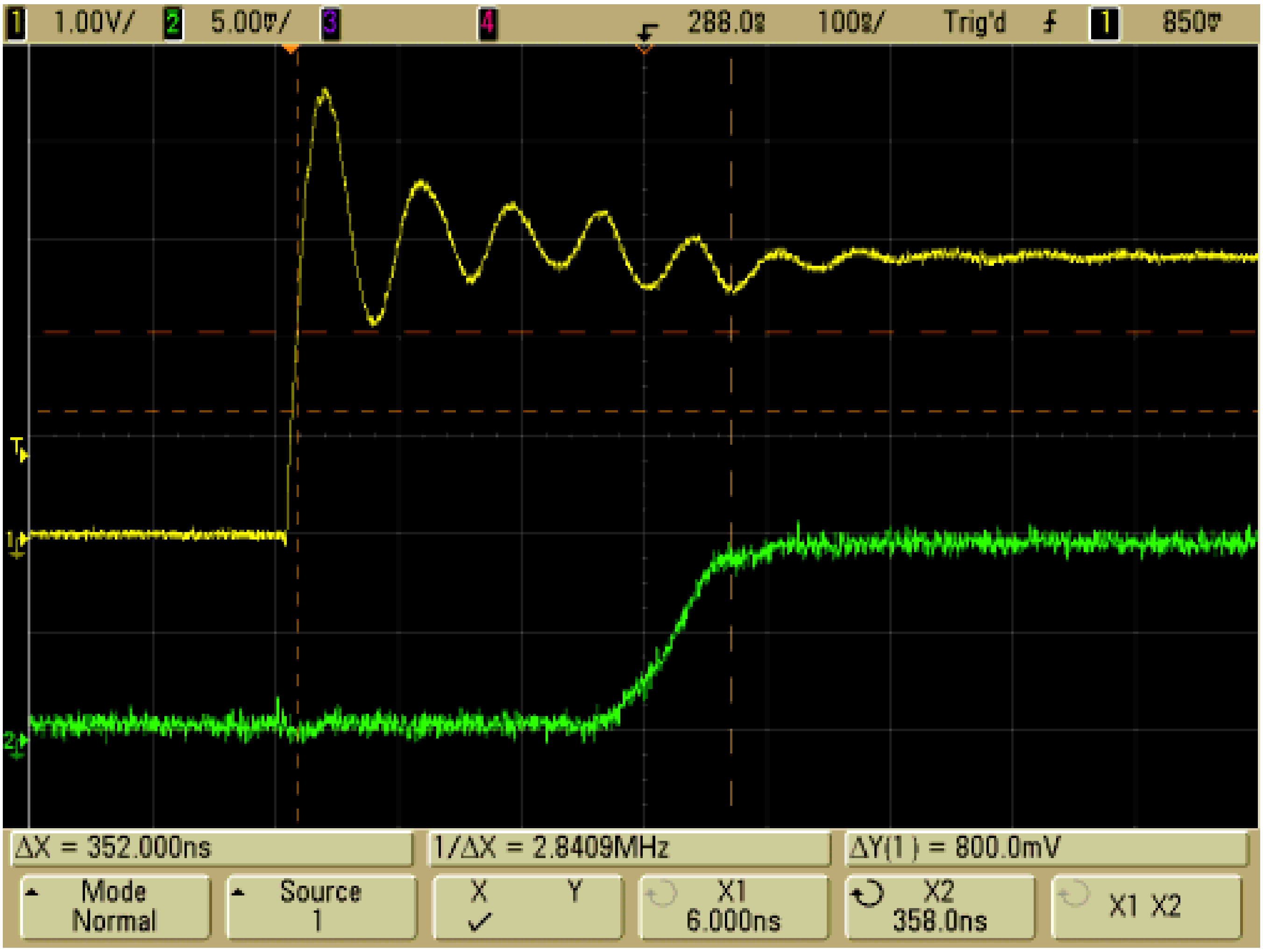
3. Channel 2 of oscilloscope monitors rectified RF output of Amplifier

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:

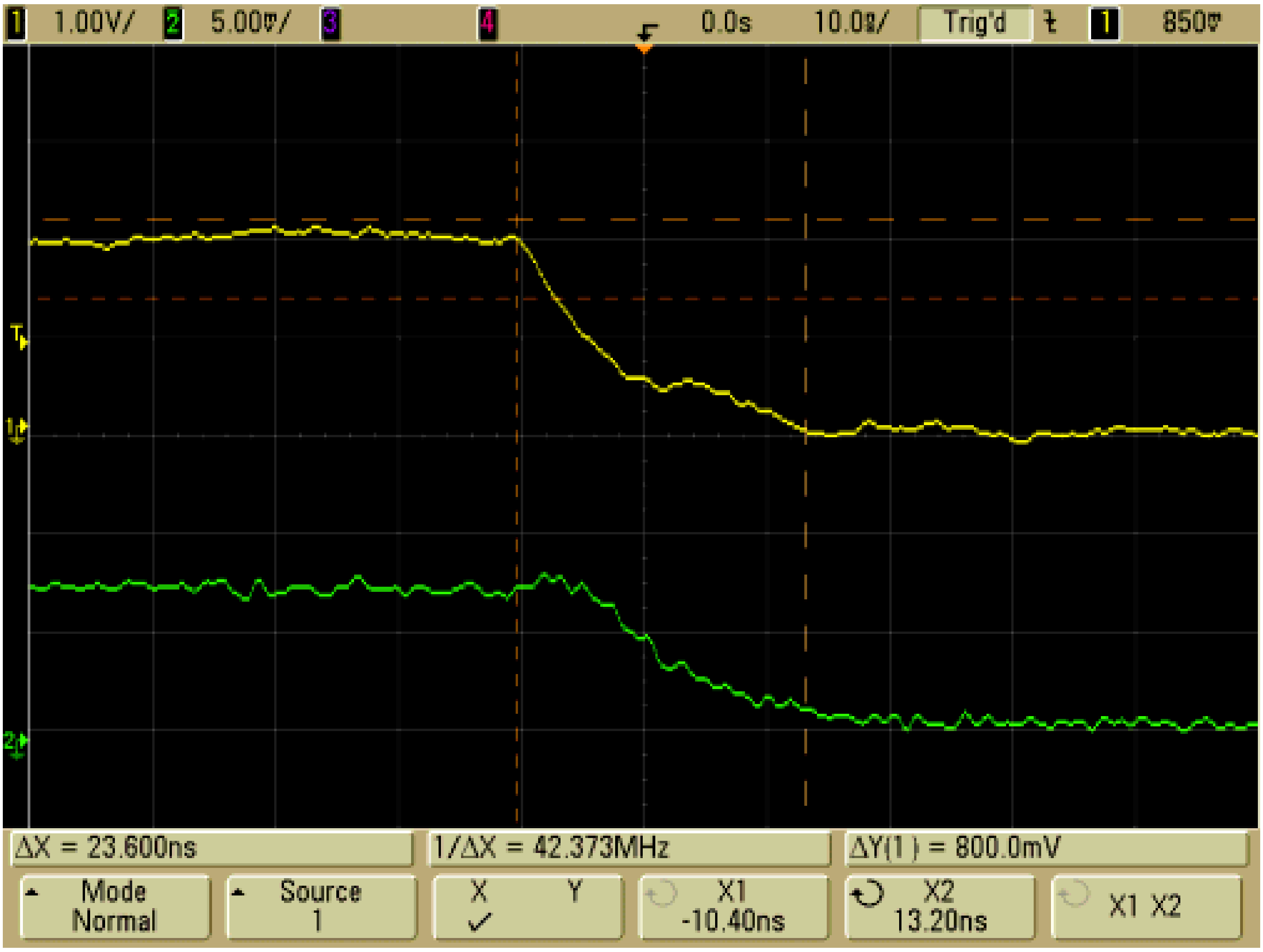
Refer to oscilloscope screen-shot below. Upper trace (yellow, Channel 1) is the DC power supply turn-on step waveform whereas the lower trace (green, Channel 2) is the rectified RF output signal of the LNA stage. Note ringing of power supply voltage at turn-on. **Amplifier turn-on time is aproximately 350 nanoseconds, or ~ 0.4 microseconds.** Main source of time delay in the LNA turn-on event are the R-C time constants formed by (R3 * C4), [(R2+R3) * C2], etc. Charge storage has been minimized in this circuit so as to speed up turn on and turn off times. (Refer to Schematic diagram on page 6). Note that the input impedance of the oscilloscope for Channel 2, which senses the rectified RF output power of the amplifier, is set to 1M ohm for this picture. Note both 50 ohm and 1M ohm input impedances where tested for turn-on time and there was no appreciable differences in results for turn-on time measurement.



b) Turn-Off Time:

Upper trace (Channel 1, yellow color) is the falling edge of the DC power supply voltage. Rectified RF output signal (Channel 2, lower green trace) takes **about ~ 24 nanoseconds, or 0.024 microseconds,** to settle out after power supply is turned off.

Note that input impedance of digital oscilloscope which senses RF Detector Diode output (Channel 2) is set to 50 ohms for this plot, as if a 1 M ohm input impedance were used, the Schottky diode detector would have to discharge through the large 1M ohm impedance, which would result in erroneously long turn-off times.



13 References

Note – the references below are embedded into this document and may be opened from within Adobe Acrobat ® by double-clicking on the respective paper clip icon.

[1]. BFR740L3RH Datasheet, Infineon Technologies AG.

[2]. "A High IIP3 Low Noise Amplifier for 1900 MHz Applications Using the SiGe BFP620 Transistor". Applied Microwaves and Wireless, July 2000.

Pages 2 – 4 discusses the use of Inductive Emitter Degeneration and additional charge storage (capacitance) to stabilize and linearize LNA's using Silicon Bipolar RF Transistors. Unlike the LNA shown in this reference, the LNA used in this Applications Note (AN173) had to minimize use of charge storage in order to achieve fast ON / OFF times.

[3]. The embedded ZIP-format file below contains Gerber, Drill and Fabrication Drawing files for the Printed Circuit Board shown in this Applications Note.