# Application Note No. 169

## BFP740 SiGe:C Ultra Low Noise RF Transistor in 5 – 6 GHz LNA Application with 15 dB Gain, 1.3 dB Noise Figure & ~ 100 nanosecond Turn-On / Turn-Off Time

(For 802.11a & 802.11n “MIMO” Wireless LAN Applications)

Small Signal Discretes

Never stop thinking

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**Application Note No. 169**

**Revision History: 2008-11-18, Rev 1.0**

| **Previous Version:** | |
|---|---|
| **Page** | **Subjects (major changes since last revision)** |
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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 BFP740 SiGe:C Ultra Low Noise RF Transistor in 5 – 6 GHz LNA Application with 15 dB Gain, 1.3 dB Noise Figure & 100 nanosecond Turn-On / Turn-Off Time

**Overview**

- Infineon Technologies **BFP740** 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.

- The circuit shown in this document is targeted for 802.11a & 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 / low Bit Error Rate (BER) / long range requirements. LNA’s for this application must be able to switch on / off within about 1 microsecond, or 1000 nanoseconds. Charge storage (capacitance) used in the circuit is minimized to reduce turn-on / turn-off times. Trade-off for reduced capacitance values is a reduction in Third Order Intercept ($IP_3$) performance. **Amplifier is Unconditionally Stable ($\mu_1$ > 1.0) from 10 MHz – 12 GHz.**

- External parts count (not including BFP740 transistor) = 12; 6 capacitors, 3 resistors, and 3 chip inductors. All passives are ‘0402’ case size. BFP740 transistor package is RoHS – compliant, industry-standard SOT343 / type.

# 2 Summary Of Performance Data

(T=25 °C, network analyzer source power ≈ -25 dBm, $V_{CC}$ = 3.0 V, $V_{CE}$ = 2.2 V, $I_C$=13.3 mA, $Z_S$=$Z_L$=50 Ω )

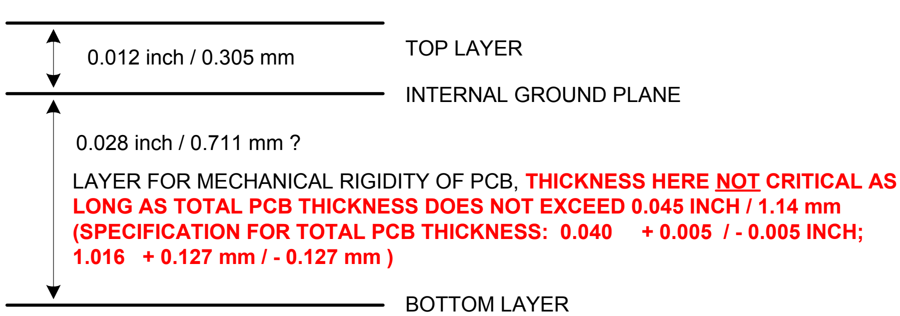
| Frequency MHz | dB[s11]$^2$ | dB[s21]$^2$ | dB[s12]$^2$ | dB[s22]$^2$ | * NF dB | ** $IIP_3$ dBm | ** $OIP_3$ dBm | $IP_{1dB}$ dBm | $OP_{1dB}$ dBm |
|---|---|---|---|---|---|---|---|---|---|
| **5150** | - 11.3 | **15.2** | -21.8 | -9.7 | **1.3** | --- | --- | --- | --- |
| **5470** | -16.7 | **15.1** | -21.0 | -16.2 | **1.3** | +9.3 | +24.4 | -6.2 | +7.9 |
| **5825** | -10.4 | **14.3** | -20.9 | -17.3 | **1.4** | --- | --- | --- | --- |
| **2500** | - 2.5 | **8.3** | - 39.0 | - 2.5 | **---** | --- | --- | --- | --- |

*** does not extract PCB loss. If PCB loss (at input) were extracted, noise figure would be ~ 0.2 dB lower.**
**Note: reverse isolation ( dB[s12]$^2$ ) when DC power to LNA is OFF = -10.3 dB @ 5470 MHz.**

# 3 Details of PC Board Construction

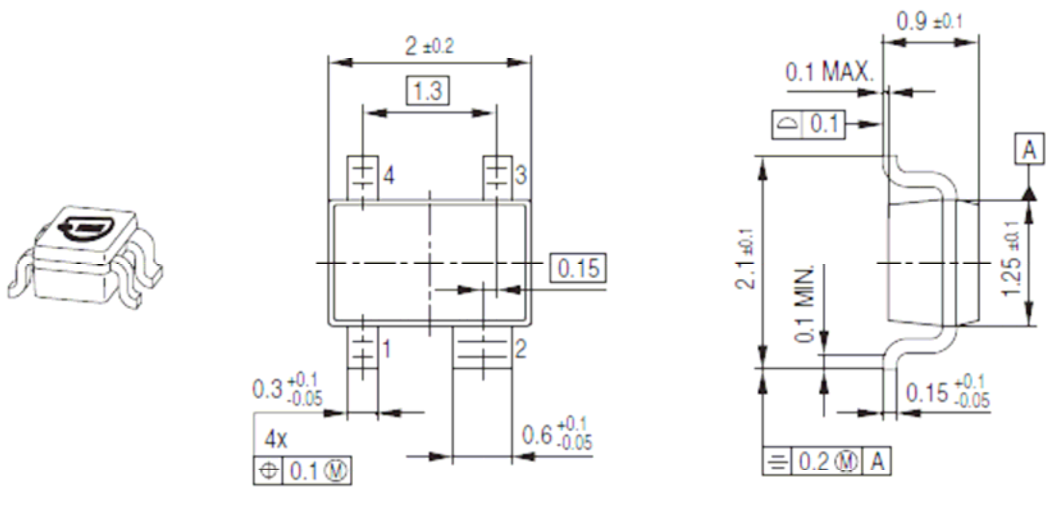
PC board is fabricated from standard, low-cost “FR4” glass-epoxy material. A cross-section diagram of the PC board is given below.

**PCB CROSS SECTION**

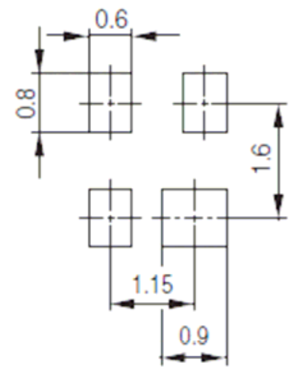


# 4 SOT343 Package Outline & Footprint. Dimensions in millimeters (mm).

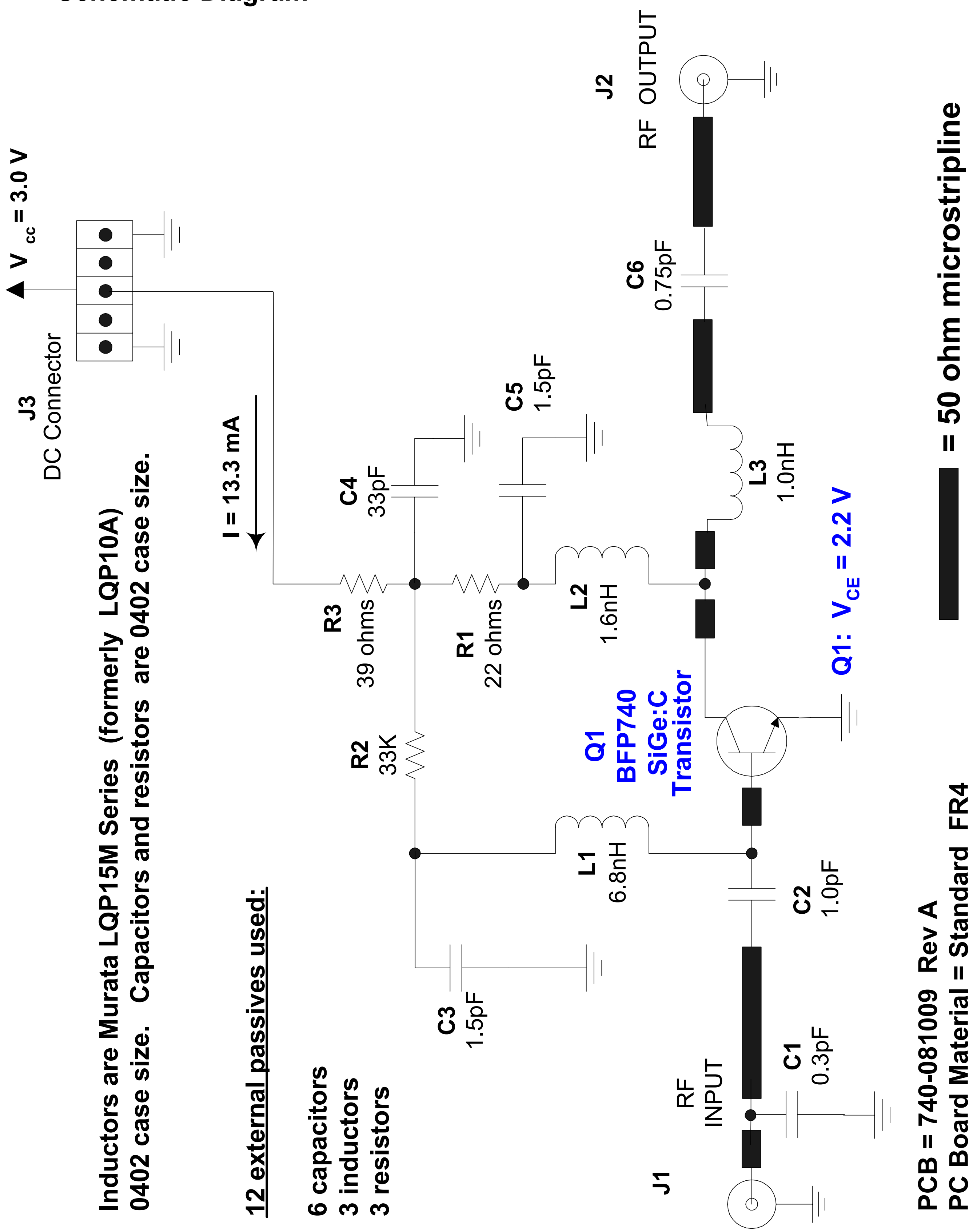
## Package Outline




## Foot Print



## 5 Schematic Diagram

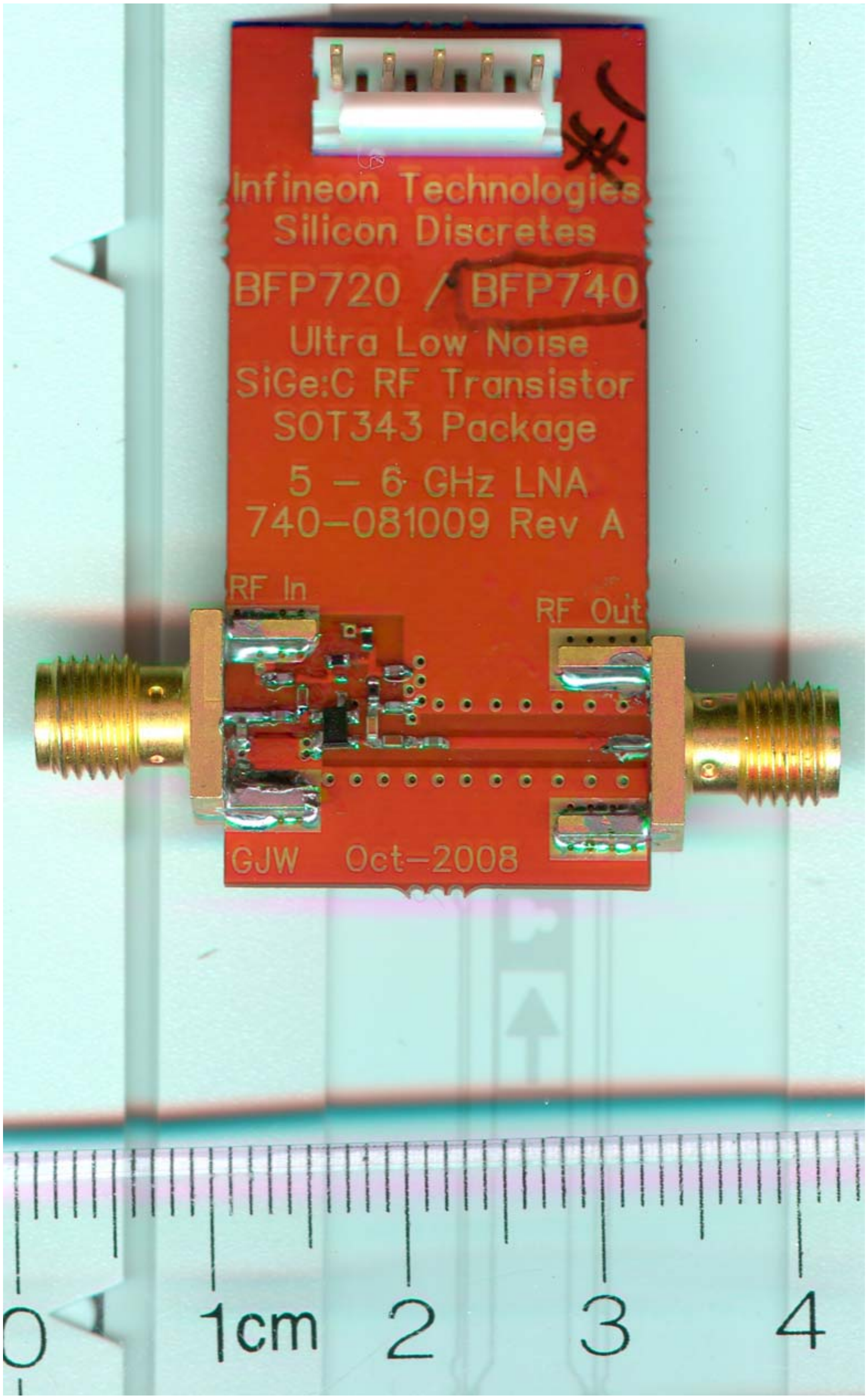


# 6 Bill Of Material (BOM)

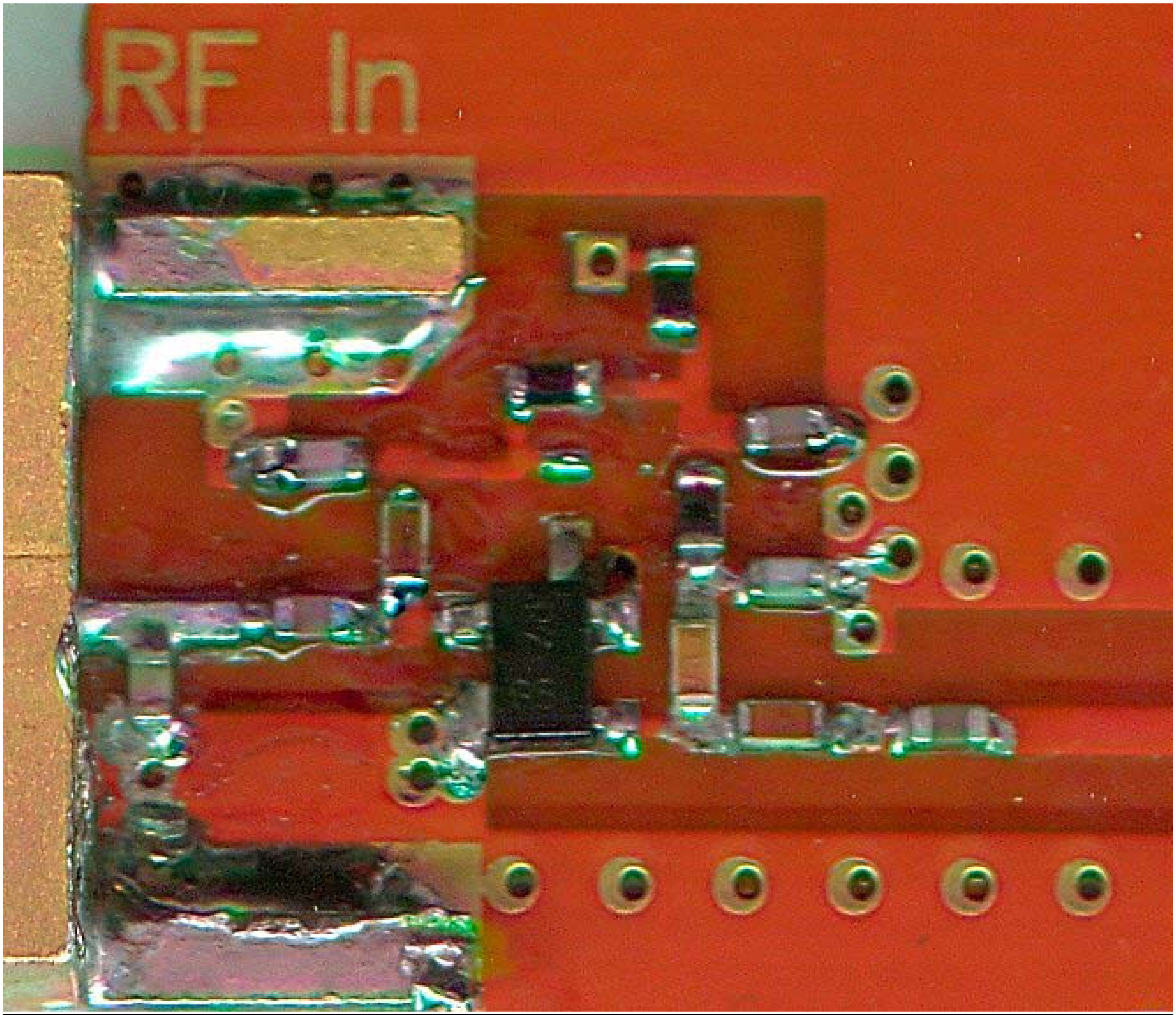
| Reference Designator | Value | Description / Part # | Manufacturer | Function |
|---|---|---|---|---|
| C1 | 0.3pF | 0.3pF, 50V, COG '0402' case size capacitor<br>Murata GRM1555C1HR30BZ01D or equivalent | Murata, AVX, etc. | Input Match |
| C2 | 1.0pF | '0402' chip capacitor | Various | Input DC block, Input Matching |
| C3 | 1.5pF | '0402' chip capacitor | Various | RF decoupling / blocking cap |
| C4 | 33pF | '0402' chip capacitor | Various | RF decoupling / blocking cap |
| C5 | 1.5pF | '0402' chip capacitor | Various | RF decoupling / blocking cap |
| C6 | 0.75pF | '0402' chip capacitor | Various | Output DC block and output matching. Also influences input match. |
| | | | | |
| L1 | 6.8nH | 6.8nH '0402' case size chip inductor<br>Murata LQP15M Series or equivalent | Murata | RF Choke at LNA input (for DC bias to base). |
| L2 | 1.6nH | 1.6nH '0402' case size chip inductor<br>Murata LQP15M series or equivalent | Murata | RF 'Choke' at LNA output, for DC bias to collector. Also influences matching and stability. |
| L3 | 1.0nH | 1.0nH '0402' case size chip inductor<br>Murata LQP15M series or equivalent | Murata | Output matching; also influences input match. |
| | | | | |
| R1 | 22Ω | '0402' chip resistor | Various | For RF stability improvement. |
| R2 | 33kΩ | '0402' chip resistor | Various | DC biasing (base). |
| 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** | **---** | **BFP740 SiGe:C Low Noise RF Transistor, SOT343 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 # 740-081009 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 18 Nov 2008

Noise Figure Measurement

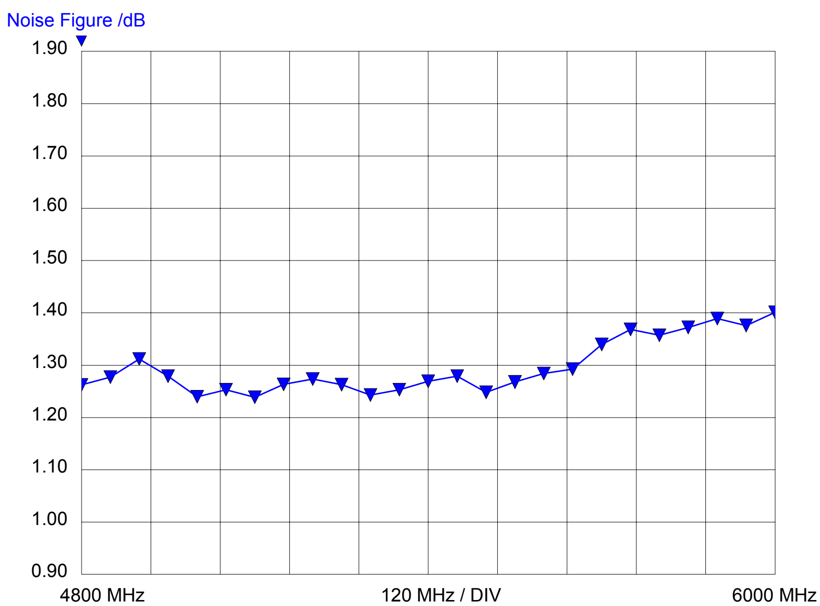
| | |
|---|---|
| EUT Name: | BFP740 5 - 6 GHz LNA, Fast Switching / Fast Turn ON-OFF Time |
| Manufacturer: | Infineon Technologies |
| Operating Conditions: | T=25 C, V = 3.0V, Vce = 2.2V, I = 13.2mA |
| Operator Name: | Gerard Wevers |
| Test Specification: | WLAN 802.11n, 802.11n |
| Comment: | PCB = 740-081009 Rev A; Preamp = MITEQ AFS3-04000800-10-ULN<br>18 November 2008 |

Analyzer

| | | | | | |
|---|---|---|---|---|---|
| RF Att: | 0.00 dB | RBW : | 1 MHz | Range: | 30.00 dB |
| Ref Lvl: | -45.00 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 4 – 8 GHz LNA**

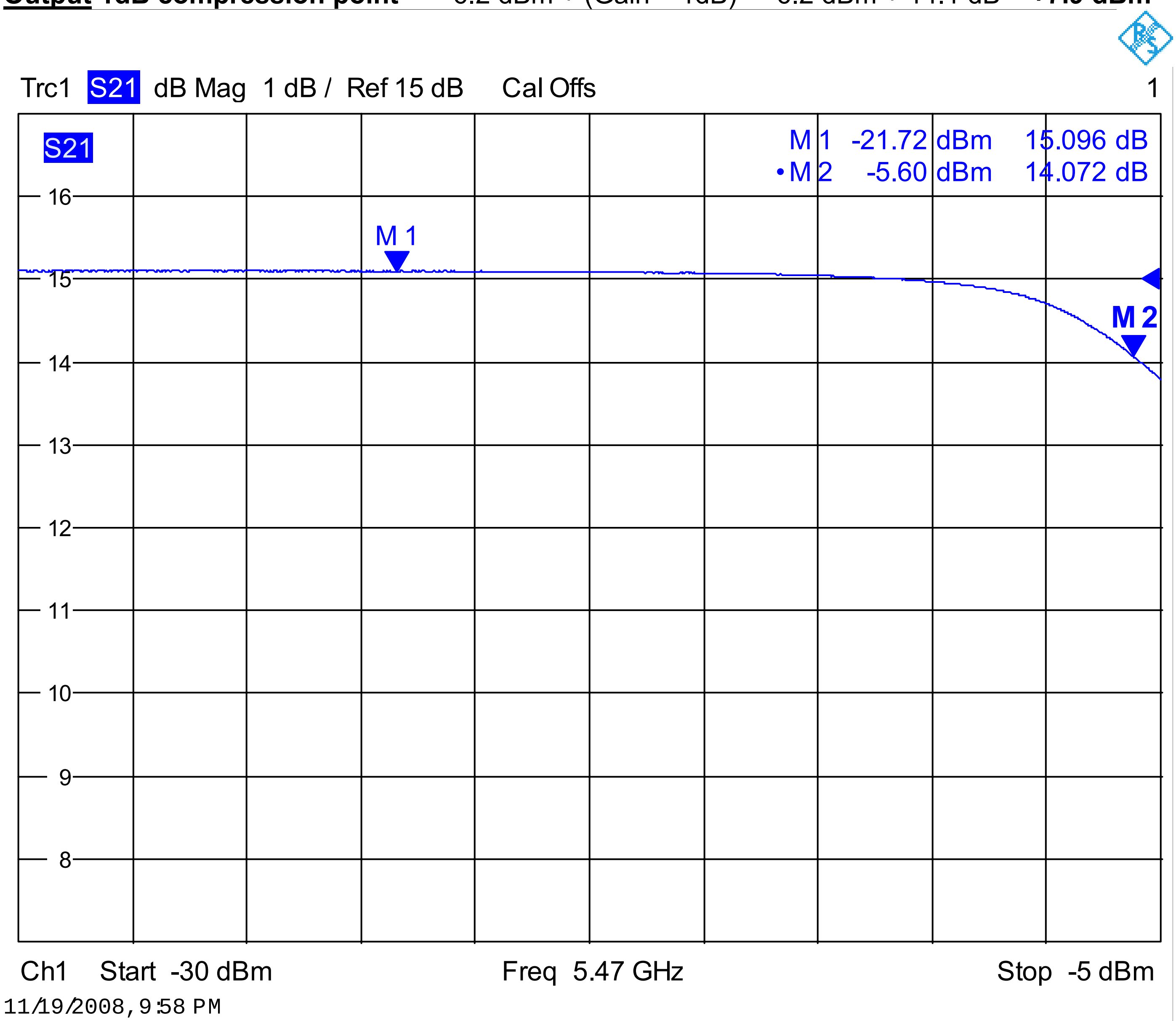
| Frequency | Nf | Temp |
|---|---|---|
| 4800 MHz | 1.26 dB | 97.8 K |
| 4850 MHz | 1.28 dB | 99.2 K |
| 4900 MHz | 1.31 dB | 102.3 K |
| 4950 MHz | 1.28 dB | 99.3 K |
| 5000 MHz | 1.24 dB | 95.8 K |
| 5050 MHz | 1.25 dB | 97 K |
| 5100 MHz | 1.24 dB | 95.7 K |
| 5150 MHz | 1.26 dB | 97.9 K |
| 5200 MHz | 1.27 dB | 98.8 K |
| 5250 MHz | 1.26 dB | 97.9 K |
| 5300 MHz | 1.24 dB | 96.1 K |
| 5350 MHz | 1.25 dB | 97 K |
| 5400 MHz | 1.27 dB | 98.5 K |
| 5450 MHz | 1.28 dB | 99.3 K |
| 5500 MHz | 1.25 dB | 96.5 K |
| 5550 MHz | 1.27 dB | 98.3 K |
| 5600 MHz | 1.28 dB | 99.7 K |
| 5650 MHz | 1.29 dB | 100.5 K |
| 5700 MHz | 1.34 dB | 104.8 K |
| 5750 MHz | 1.37 dB | 107.4 K |
| 5800 MHz | 1.36 dB | 106.4 K |
| 5850 MHz | 1.37 dB | 107.8 K |
| 5900 MHz | 1.39 dB | 109.3 K |
| 5950 MHz | 1.38 dB | 108.1 K |
| 6000 MHz | 1.40 dB | 110.4 K |

# 9 Amplifier Compression Point Measurement

**Gain Compression at 5470 MHz, $V_{CC}$ = +3.0 V, I = 13.3mA, $V_{CE}$ = 2.2V, T = 25°C:**
Rohde & Schwarz ZVB20 Vector Network Analyzer is set up to sweep input power to LNA at a fixed frequency of 5470 MHz. X-axis of VNA screen-shot below shows input power to LNA being swept from –30 to –5 dBm. ZVB20 output power is checked / verified against HP E4419A power meter; ZVB20 output power is ≅ 0.6 dB lower than indicated on ZVB20 due to test cable loss. Therefore, a 0.6 dB offset is needed.

**Input 1 dB compression point** = - 5.6 dBm – 0.6 dB offset = **- 6.2 dBm**

**Output 1dB compression point =** - 6.2 dBm + (Gain – 1dB) = -6.2 dBm + 14.1 dB = **+7.9 dBm**



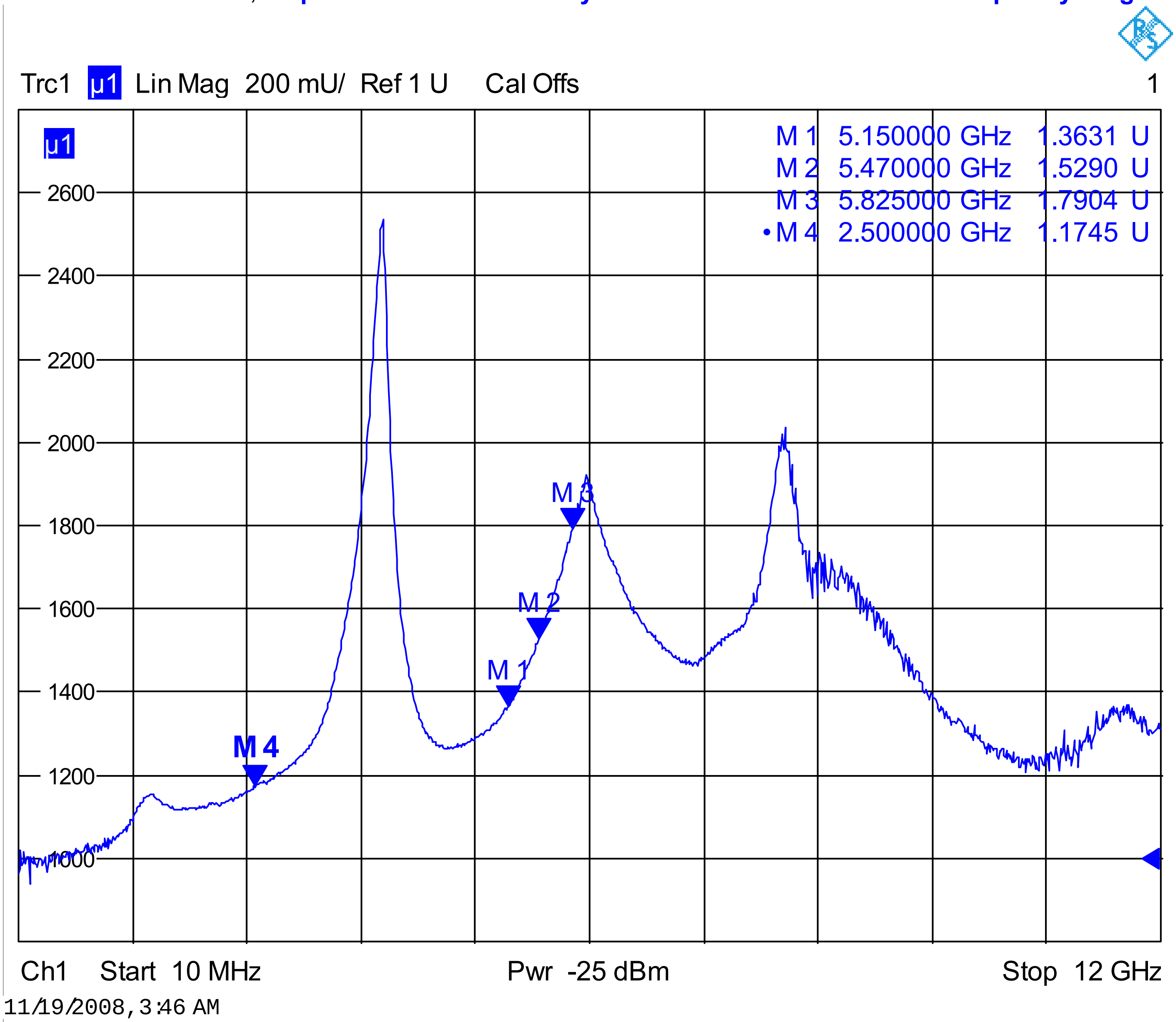
# 10 Amplifier Stability, Gain, Return Loss and Reverse Isolation Plots

**Amplifier Stability - Plot of Stability Factor "$\mu_1$" :**

Rohde and Schwarz ZVB Network Analyzer Calculates and plots stability factor **"$\mu_1$"** of the BFP740F amplifier in real time. Stability Factor $\mu_1$ is defined as follows [1]:

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

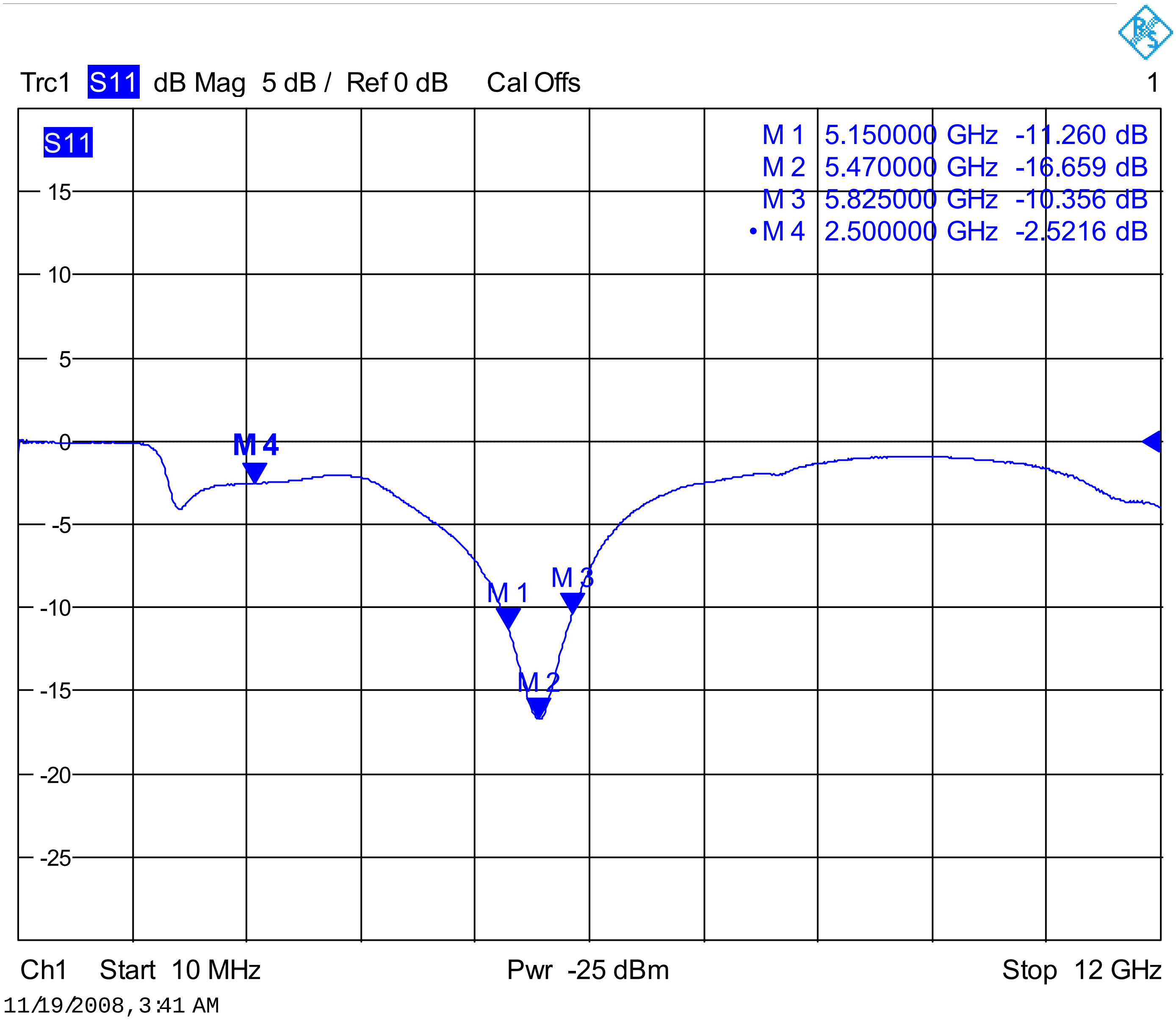
**The necessary and sufficient condition for Unconditional Stability is $\mu_1 > 1.0$.** In the plot, $\mu_1 > 1.0$ over 10 MHz – 12 GHz; **amplifier is Unconditionally Stable over 10 MHz – 12 GHz frequency range.**




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

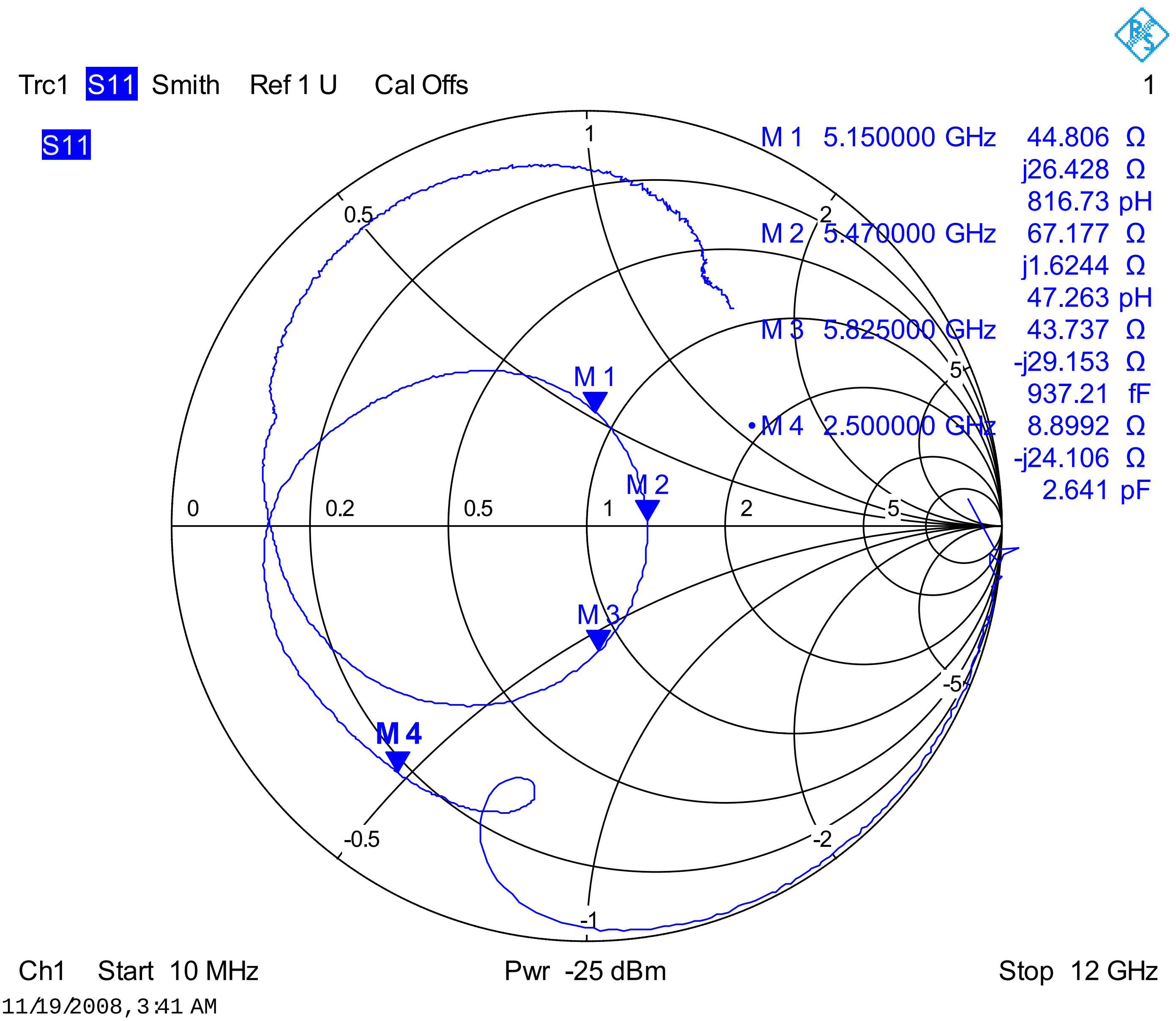
## Input Return Loss, Log Mag

**10 MHz – 12 GHz Sweep**



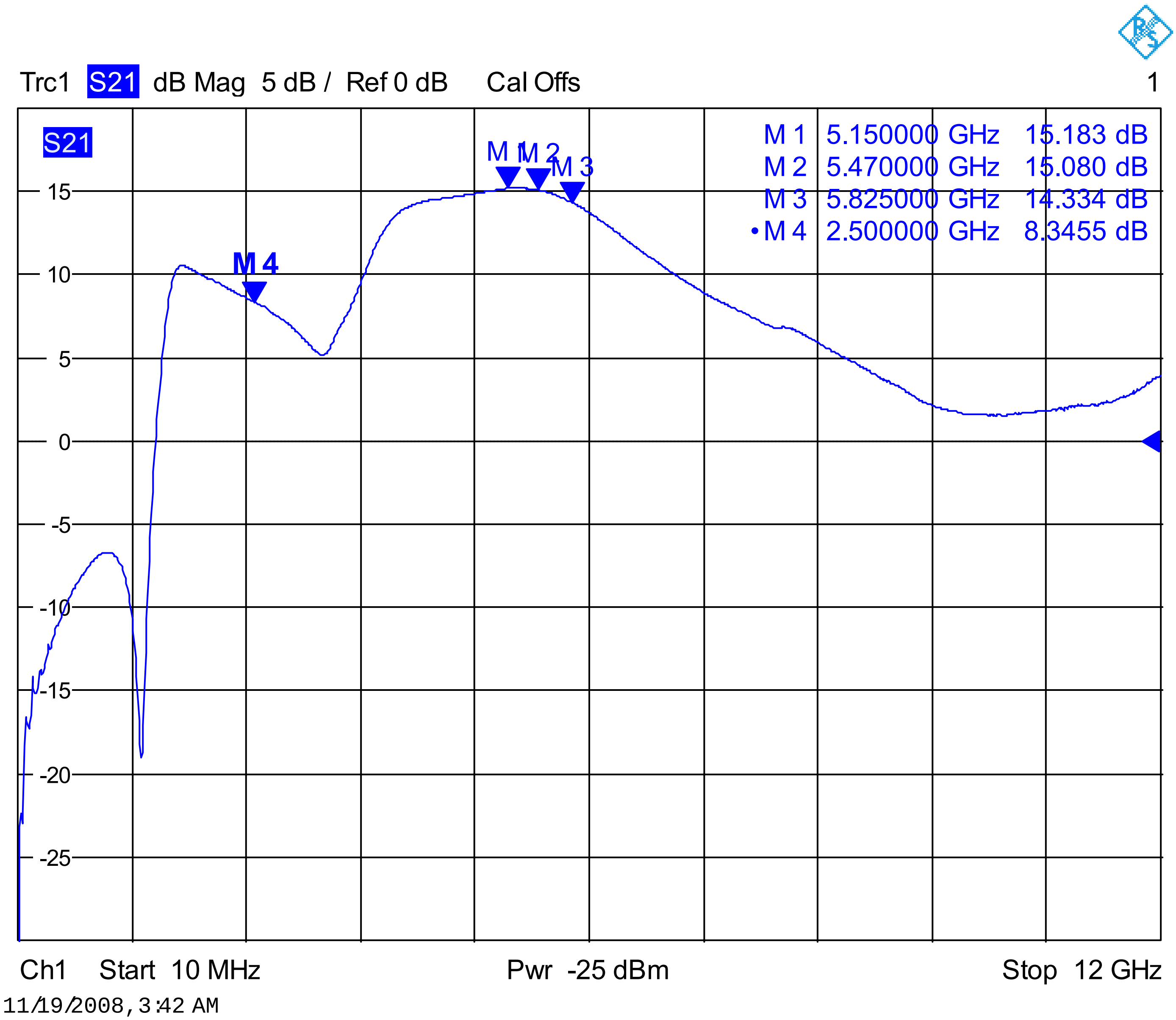
## Input Return Loss, Smith Chart

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



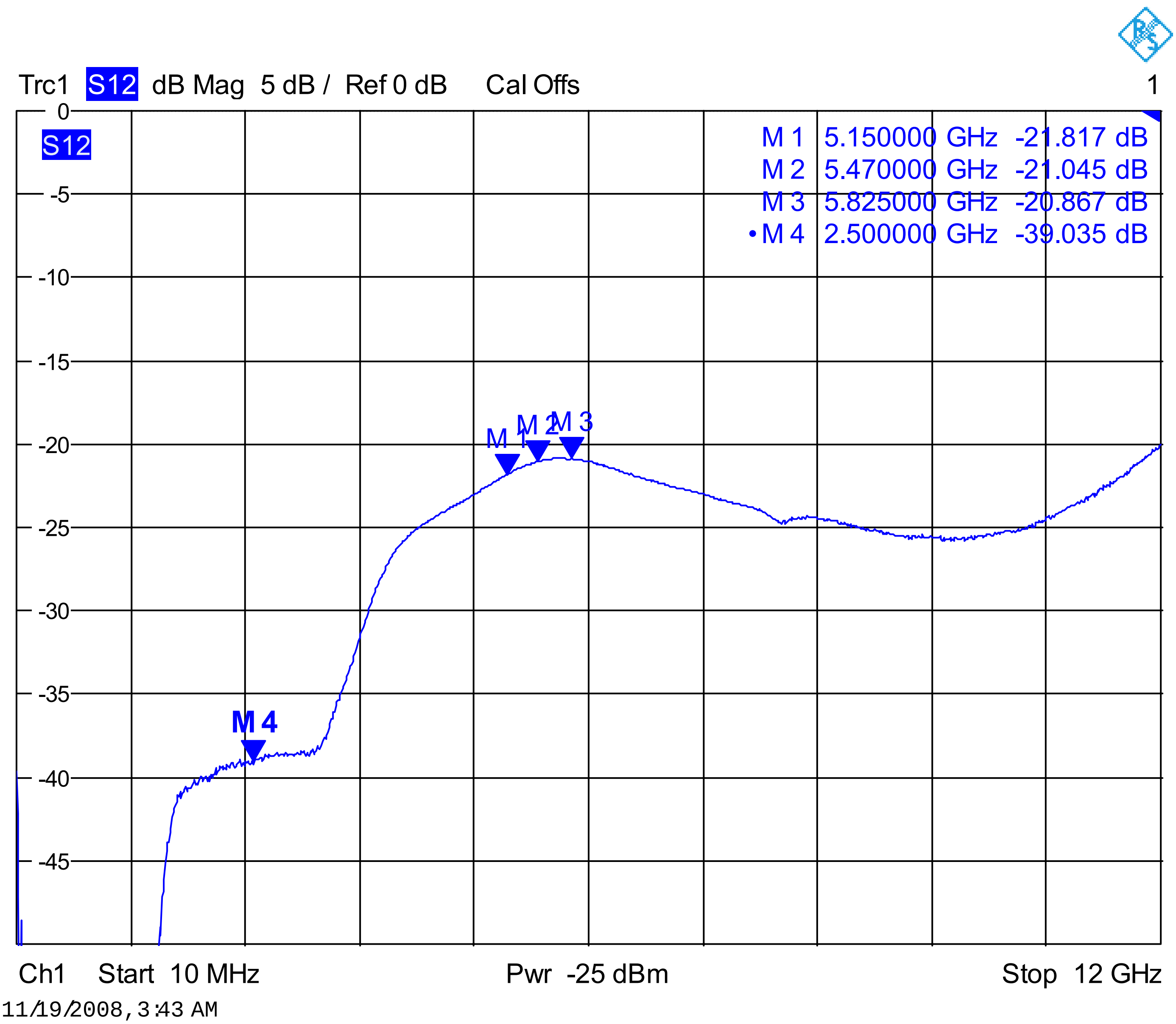
**Forward Gain. Input / Output Matching Circuits of LNA reduce gain in 2.4 – 2.5 GHz band.**

**10 MHz – 12 GHz Sweep**



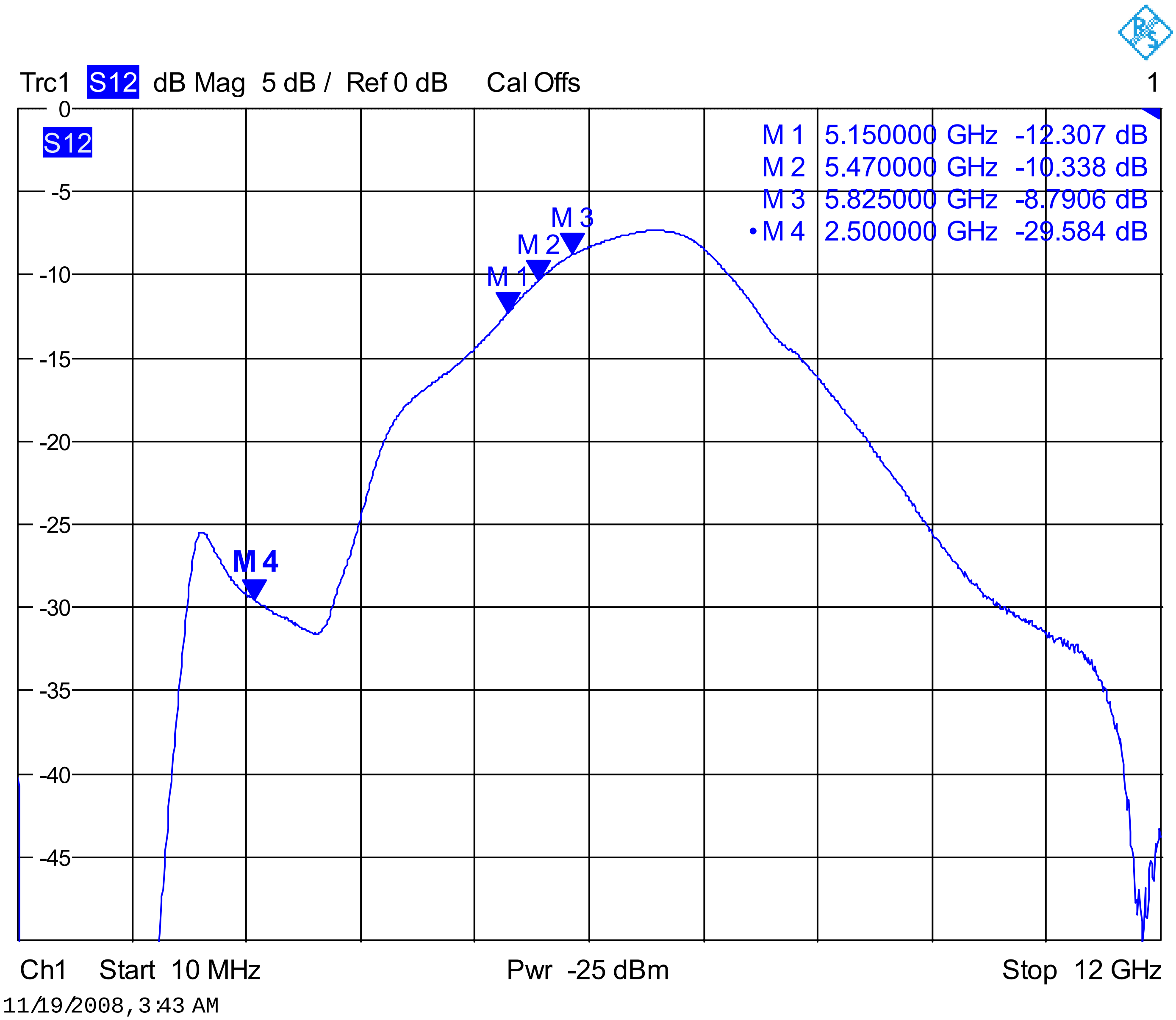
**Reverse Isolation**

**10 MHz – 12 GHz Sweep**



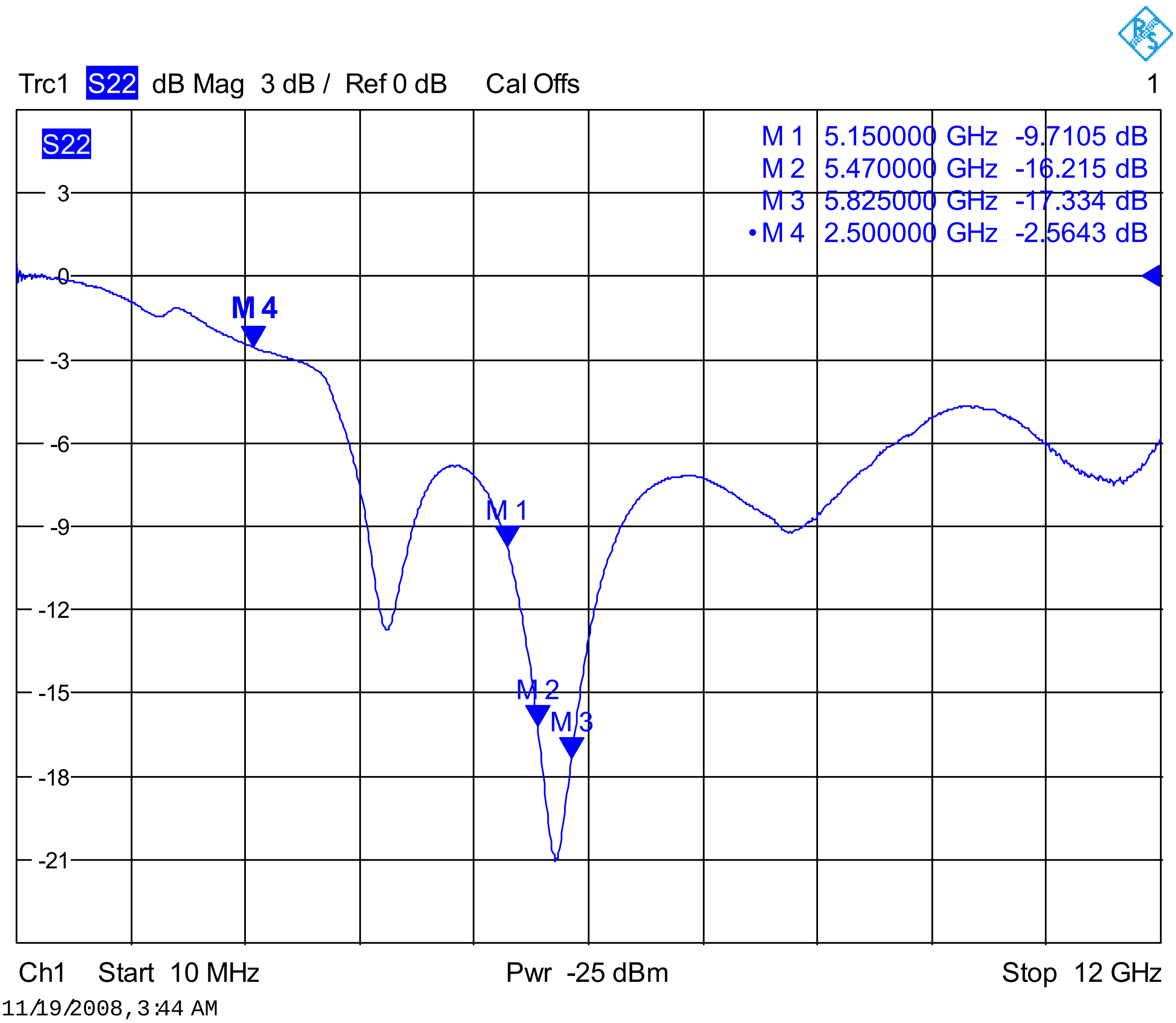
**Reverse Isolation, AMPLIFIER DC POWER TURNED OFF.**

**10 MHz – 12 GHz Sweep**



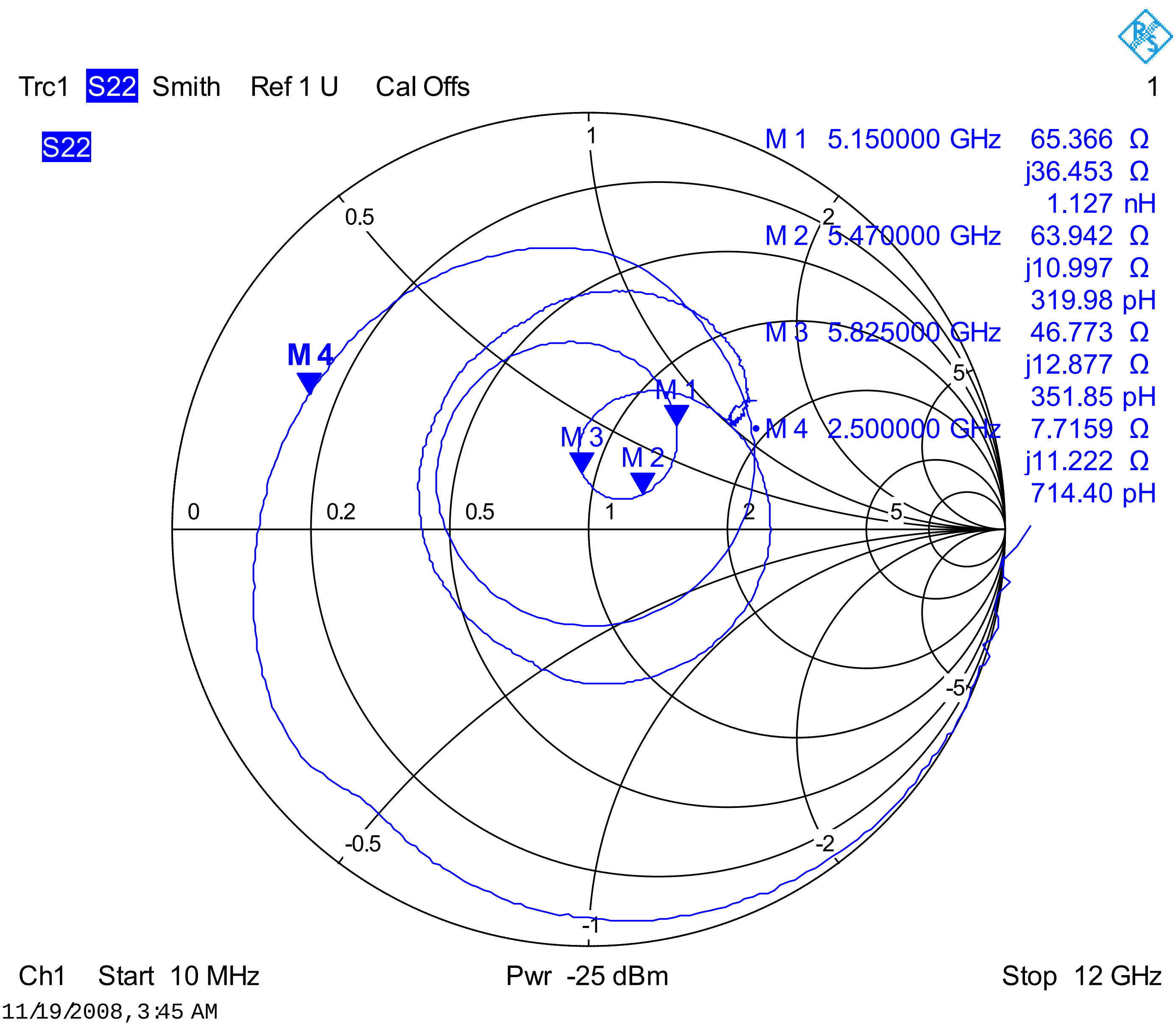
**Output Return Loss, Log Mag**

**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**

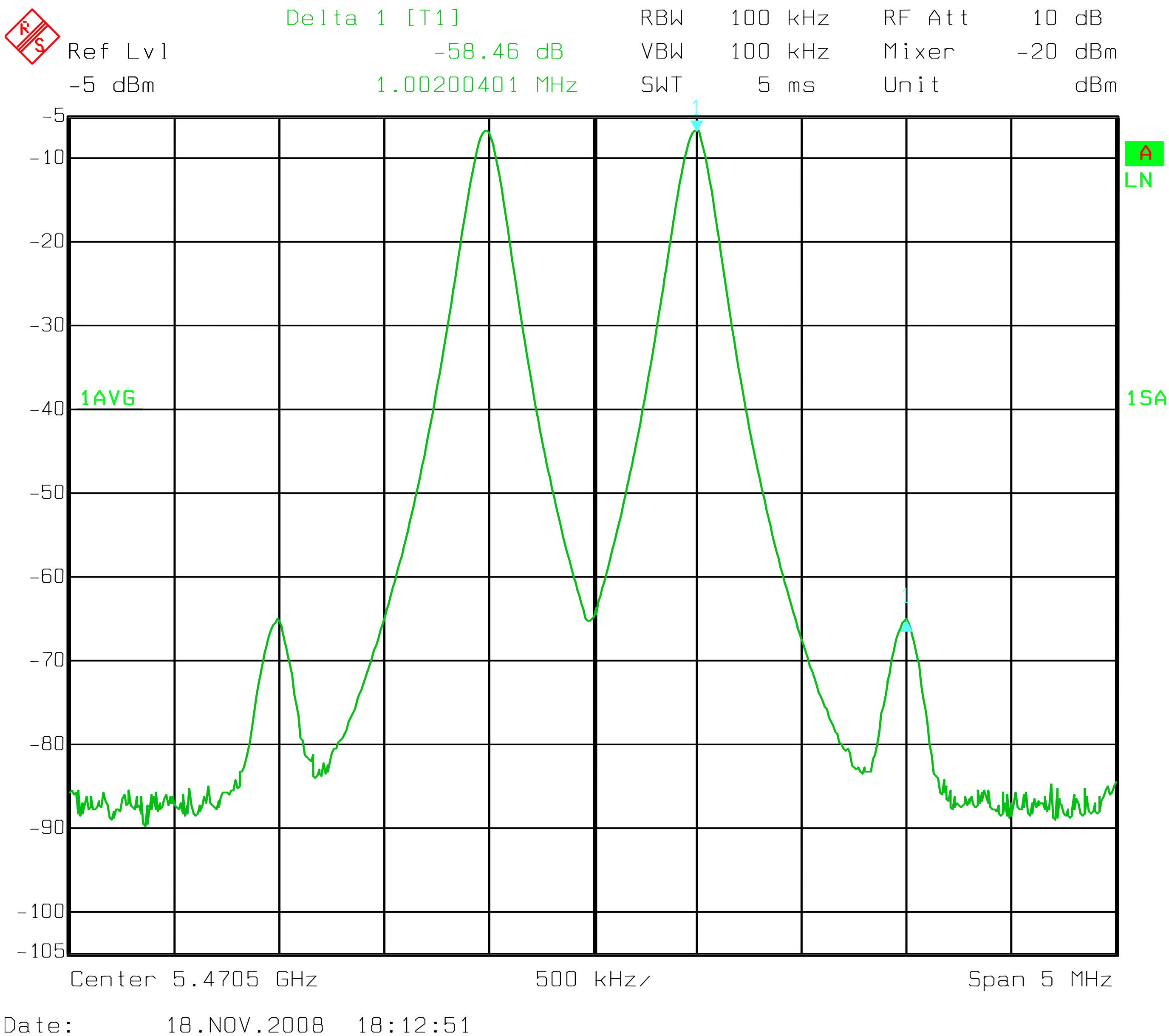


# 11 Amplifier Third Order Intercept (TOI) Measurement

## In-Band Third Order Intercept ($IIP_3$) Test.

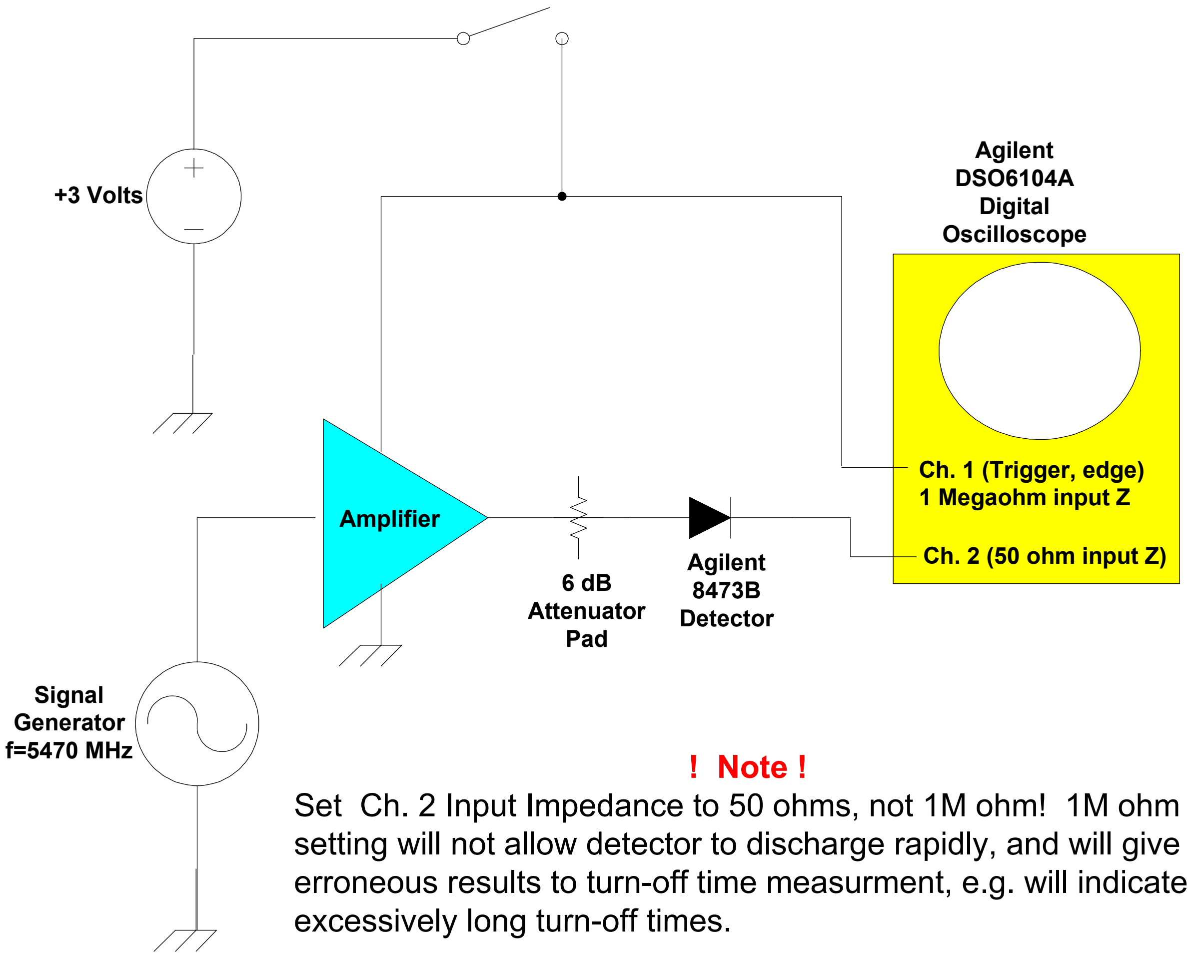
**Input Stimulus: $f_1$=5470 MHz, $f_2$=5471 MHz, -20 dBm each tone.**

**Input $IP_3$ = -20 + (58.5 / 2) = +9.3 dBm. Output $IP_3$ = +9.3 dBm + 15.1 dB gain = +24.4 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 !**

Set Ch. 2 Input Impedance to 50 ohms, not 1M ohm! 1M ohm setting will not allow detector to discharge rapidly, and will give erroneous results to turn-off time measurment, e.g. will indicate excessively long turn-off times.

**1. Signal Generator set such that output power of BFP740F LNA is approx. 0 dBm when LNA is powered ON**

**2. Channel 1 of oscilloscope monitors input power supply voltage to Amplifier (+3.0 volts when ON, ~ 0 volts when OFF)**

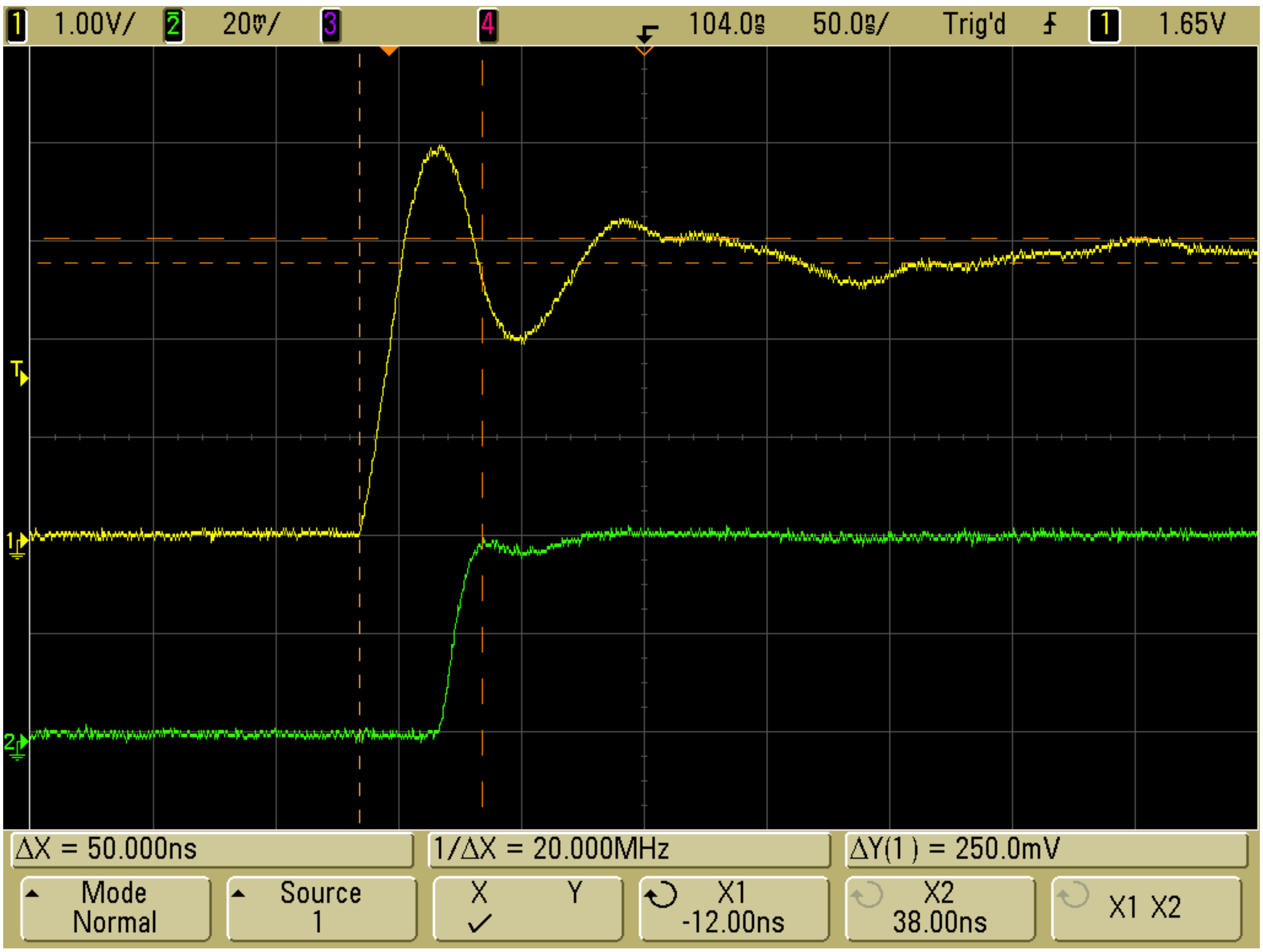
**3. Channel 2 of oscilloscope monitors rectified RF output of Amplifier**

**4. To make measurement of turn-on time, turn power supply OFF, reset o'scope, setup trigger to trigger on rising edge of Ch.1**

**5. To make measurement of turn-off time, turn power supply ON, reset o'scope, setup trigger to trigger on falling edge of Ch. 1**

## 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. **Amplifier turn-on time is aproximately 50 nanoseconds, or 0.05microseconds.** Main source of time delay in the LNA turn-on and turn-off events are the R-C time constants formed by (R3 * C4), [(R2+R3) * C3], 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).



**b) Turn-Off Time:**

Rectified RF output signal (lower green trace) takes **approximately ~ 125 nanoseconds, or ~0.1 microseconds** to settle out after power supply is turned off. Note that input impedance of digital oscilloscope which senses RF Detector Diode output is set to 50 ohms, rather than 1 Megaohm, to permit RF Detector Diode to rapidly discharge after Amplifier is turned off.

If input impedance of oscilloscope is set to 1 Megaohm, the RF Detector will have to discharge thorugh this 1 Megaohm impedance, giving excessively long results for turn-off times.