# BFP740FESD

# BFP740FESD ESD-Hardened SiGe:C Ultra Low Noise RF Transistor with 2kV ESD Rating in 5–6GHz LNA Application. 17dB Gain, 1.4dB Noise Figure & < 100ns Turn-On / Turn-Off Time

## For 802.11a & 802.11n “MIMO” Wireless LAN Applications

## Application Note AN220

Revision: Rev. 1.0
2010-07-02

RF and Protection Devices

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**Application Note AN220**

**Revision History: 2010-07-02**

**Previous Revision: prev. Rev. x.x**

| Page | Subjects (major changes since last revision) |
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# 1 Overview

The BFP740FESD 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 BFP740FESD has internal ESD-protection structures giving an ESD-survival rating of 2000 Volts per the Human Body Model (HBM), for ESD strikes of either polarity applied across any pair of terminals (Base, Emitter, Collector).

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 / long range requirements. LNA’s for this application must be able to switch on / off within about 1 microsecond (1000 nanoseconds). The 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 (IP3) performance. Amplifier is Unconditionally Stable (µ1 > 1.0) from 10 MHz – 12 GHz.

External parts count (not including BFP740F transistor) = 12; 6 capacitors, 3 resistors, and 3 chip inductors. All passives are ‘0402’ case size. BFP740FESD transistor package is RoHS – compliant and measures 1.4 x 1.2 x 0.55mm.

# 2 Typical Measurement Results

**Table 1 Electrical Characteristics (at room temperature)**

| Parameter | Symbol | Value | Unit | Comment/Test Condition |
|---|---|---|---|---|
| Frequency | Freq | 5.470 | GHz | |
| DC Voltage | Vcc | 3.0 | V | |
| DC Current | Icc | 14.8 | mA | |
| | | | | |
| Gain | G | 17.1 | dB | Network analyzer source power = -25 dBm |
| Noise Figure | NF | 1.4 | dB | Does not extract PCB loss. If PCB loss at input were extracted, NF would be ~0.2 dB lower |
| Input Return Loss | RLin | 11.4 | dB | Network analyzer source power = -25 dBm |
| Output Return Loss | RLout | 10.3 | dB | Network analyzer source power = -25 dBm |
| Reverse Isolation | IRev | 24.9 | dB | Network analyzer source power = -25 dBm<br>When DC Power to LNA is OFF: 14.2dB |
| Input P1dB | IP1dB | -8.7 | dBm | |
| Output P1dB | OP1dB | +7.4 | dBm | |
| Input IP3 | IIP3 | +0.8 | dBm | Input power -23dBm / tone, ∆f = 1MHz |
| Output IP3 | OIP3 | +17.9 | dBm | Input power -23dBm / tone, ∆f = 1MHz |

# 3 Schematic Diagram

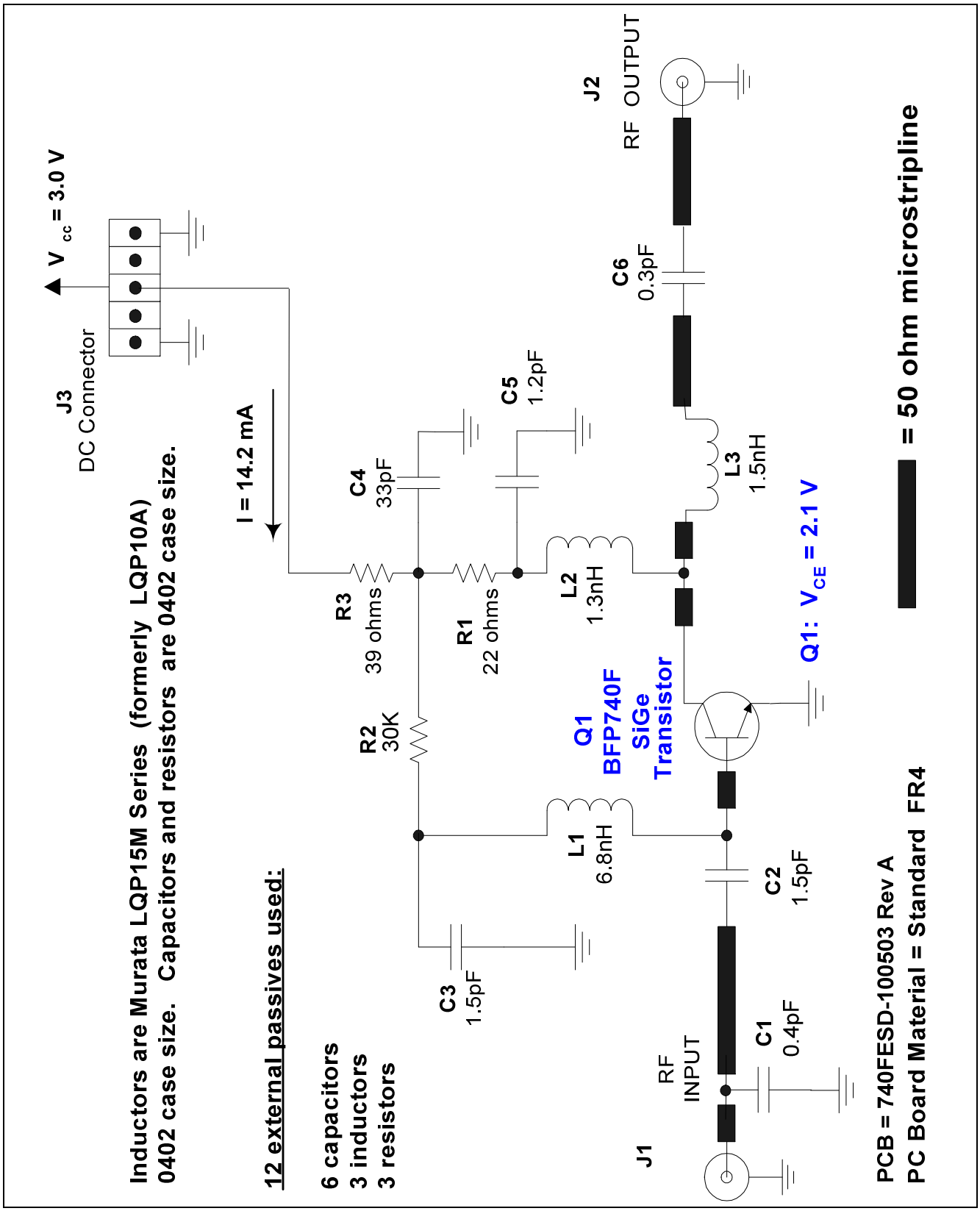



**Figure 1 Schematic Diagram**

# 4 Bill of Material

**Table 2 Bill-of-Materials**

| Symbol | Value | Unit | Size | Manufacturer | Comment |
|---|---|---|---|---|---|
| C1 | 0.4 | pF | 0402 | Murata GRM1555C1HR30BZ01D or equivalent | Input matching |
| C2 | 1.5 | pF | 0402 | various | Input DC block, input matching |
| C3 | 1.5 | pF | 0402 | various | RF decoupling / blocking cap |
| C4 | 33 | pF | 0402 | various | RF decoupling / blocking cap |
| C5 | 1.2 | pF | 0402 | various | RF decoupling / blocking cap |
| C6 | 0.3 | pF | 0402 | Murata GRM1555C1HR30BZ01D or equivalent | Output DC block and output matching. Also influences input match. |
| L1 | 6.8 | nH | 0402 | Murata LQP15M series | RF Choke at LNA input (for DC bias to base). |
| L2 | 1.3 | nH | 0402 | Murata LQP15M series | RF Choke at LNA output, for DC bias to collector. Also influences matching and stability. |
| L3 | 1.5 | nH | 0402 | Murata LQP15M series | Output matching; also influences input match. |
| R1 | 22 | Ω | 0402 | various | For RF stability improvement |
| R2 | 30 | kΩ | 0402 | various | DC biasing (base). |
| R3 | 39 | Ω | 0402 | various | DC biasing (provides DC negative feedback to stabilize DC operating point over temperature variation, transistor $h_{FE}$ variation, etc.) |
| Q1 | BFP740FESD | | TSFP-4 | 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 # 740F-080919 Rev A | | | Infineon Technologies | Printed Circuit Board |

# 5 Measured Graphs

The reference plane of all data displayed here are the input and output SMA connectors of the evaluation board. This means all PCB losses and SMA connector losses are included.

## 5.1 Noise Figure

Rohde & Schwarz

25 Jun 2010

Noise and Gain Measurement

| | |
|---|---|
| EUT Name: | BFP740FESD 5 - 6 GHz LNA, Fast Switching / Fast Turn ON Turn OFF time |
| Manufacturer: | Infineon Technologies |
| Operating Conditions: | Vcc = 3.0 V, Vce = 2.1V, I = 14.2mA |
| Operator Name: | Gerard Wevers |
| Test Specification: | WLAN 802.11n |
| Comment: | PCB = 740FESD-100503 Rev A<br>22 June 2010 |

Analyzer

| | | | | | |
|---|---|---|---|---|---|
| RF Att: | 0.00 dB | RBW : | 1 MHz | Range: | 30.00 dB |
| Ref Lvl: | -46.00 dBm | VBW : | 100 Hz | Ref Lvl auto: | ON |

Measurement

| | | | | | |
|---|---|---|---|---|---|
| 2nd stage corr: | ON | Mode: | Direct | ENR: | 346A173.ENR |

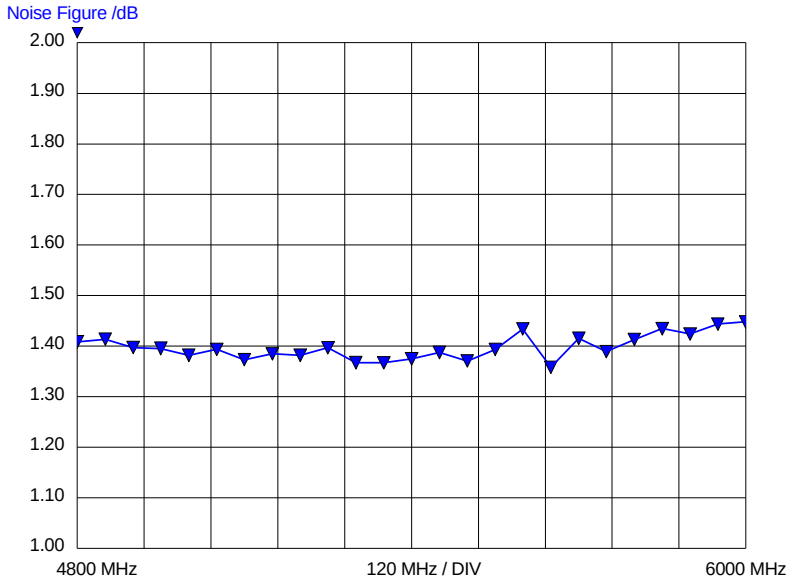



**Figure 2 Noise Figure Plot, from Rohde and Schwarz FSEK3 + FSEM30**

**Table 3 Noise Figure, Tabular Data[1]**

| Frequency / MHz | NF / dB | Noise Temperature / K |
|---|---|---|
| 4800 | 1.41 | 111.1 |
| 4850 | 1.41 | 111.5 |
| 4900 | 1.4 | 110.1 |
| 4950 | 1.4 | 109.9 |
| 5000 | 1.38 | 108.6 |
| 5050 | 1.39 | 109.7 |
| 5100 | 1.37 | 107.8 |
| 5150 | 1.38 | 108.9 |
| 5200 | 1.38 | 108.6 |
| 5250 | 1.4 | 110 |
| 5300 | 1.37 | 107.3 |
| 5350 | 1.37 | 107.3 |
| 5400 | 1.37 | 108 |
| 5450 | 1.39 | 109.1 |
| 5500 | 1.37 | 107.6 |
| 5550 | 1.39 | 109.7 |
| 5600 | 1.43 | 113.4 |
| 5650 | 1.36 | 106.5 |
| 5700 | 1.42 | 111.7 |
| 5750 | 1.39 | 109.3 |
| 5800 | 1.41 | 111.5 |
| 5850 | 1.43 | 113.5 |
| 5900 | 1.42 | 112.5 |
| 5950 | 1.44 | 114.4 |
| 6000 | 1.45 | 114.7 |

[1] Taken with Rohde & Schwarz FSEM30 + FSEK3; System Preamplifier: MITEQ 4-8 GHz LNA

## 5.2 1 dB Compression Point

Gain Compression at 5470 MHz, VCC = +3.0 V, I = 14.2mA, VCE = 2.1V, 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 over sweep range is calibrated at end of test cable (reference plane at input SMA connector to Amplifier Under Test) with Rohde & Schwarz NRP-Z21 power sensor.

**Input 1 dB compression point = - 8.7 dBm**

**Output 1dB compression point =** - 8.7 dBm + (Gain – 1dB) = -8.7 dBm + 16.1 dB = **+7.4 dBm**

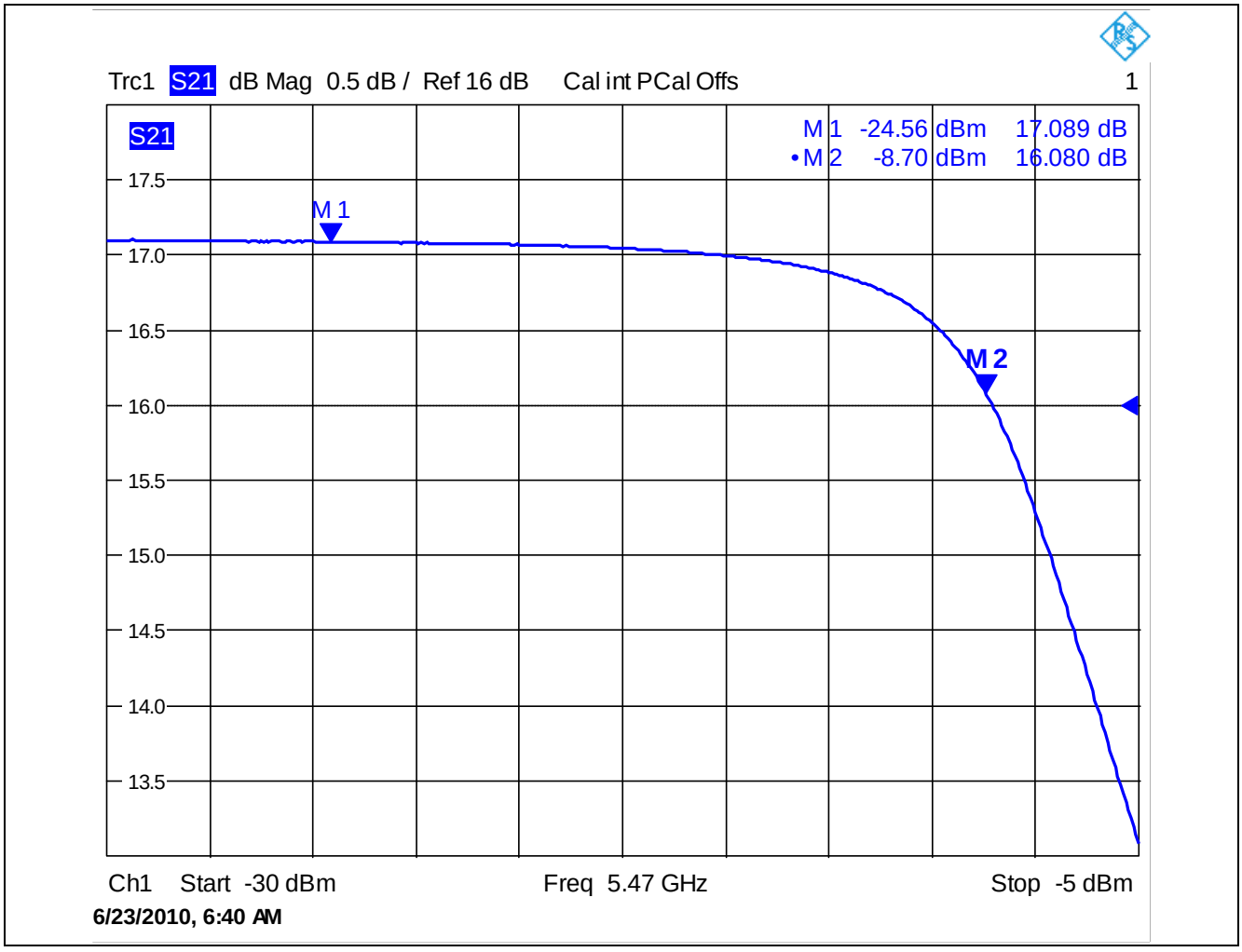



**Figure 3 Input 1 dB Compression Point**

## 5.3 Gain

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

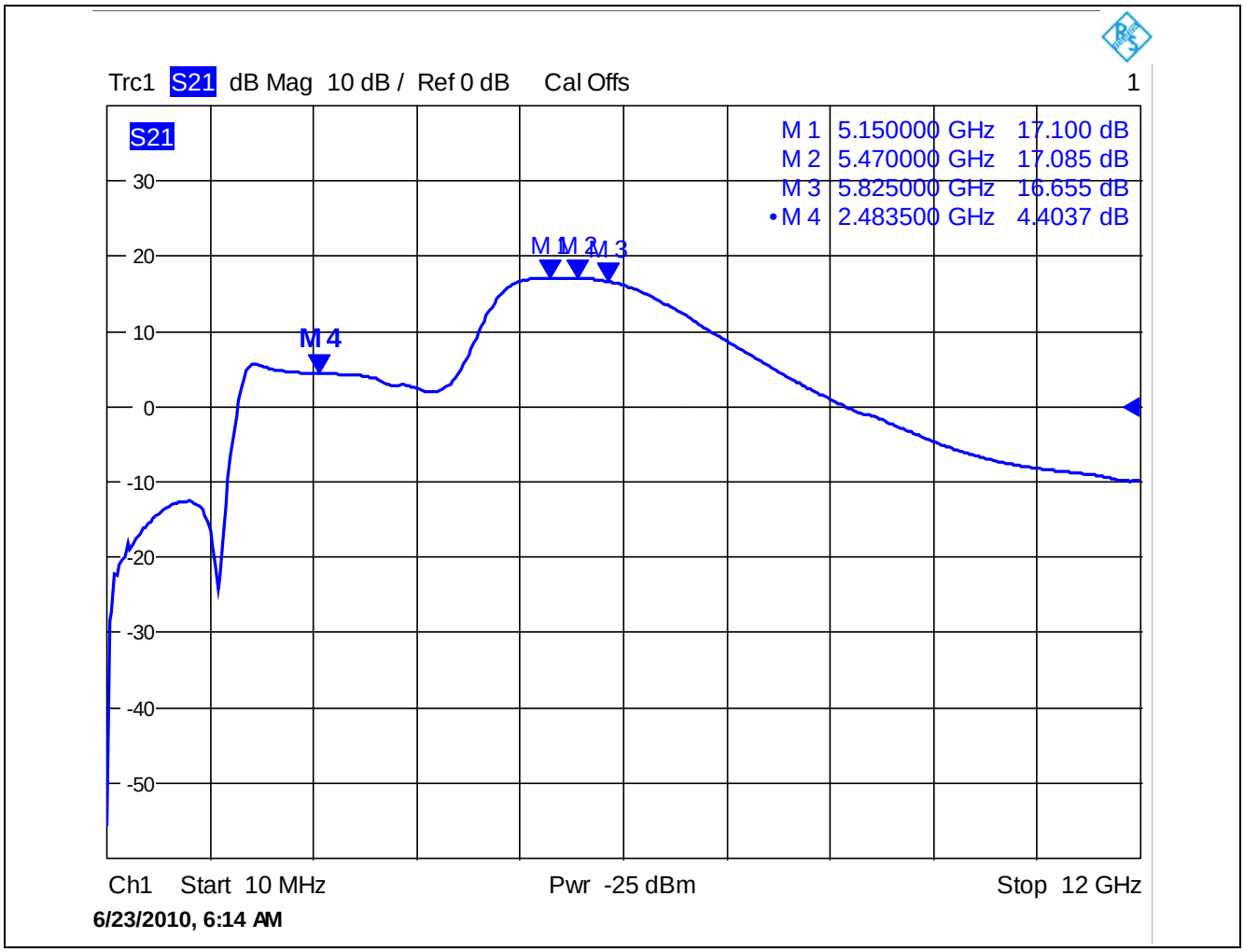



**Figure 4 Forward Gain**

## 5.4 Input Return Loss

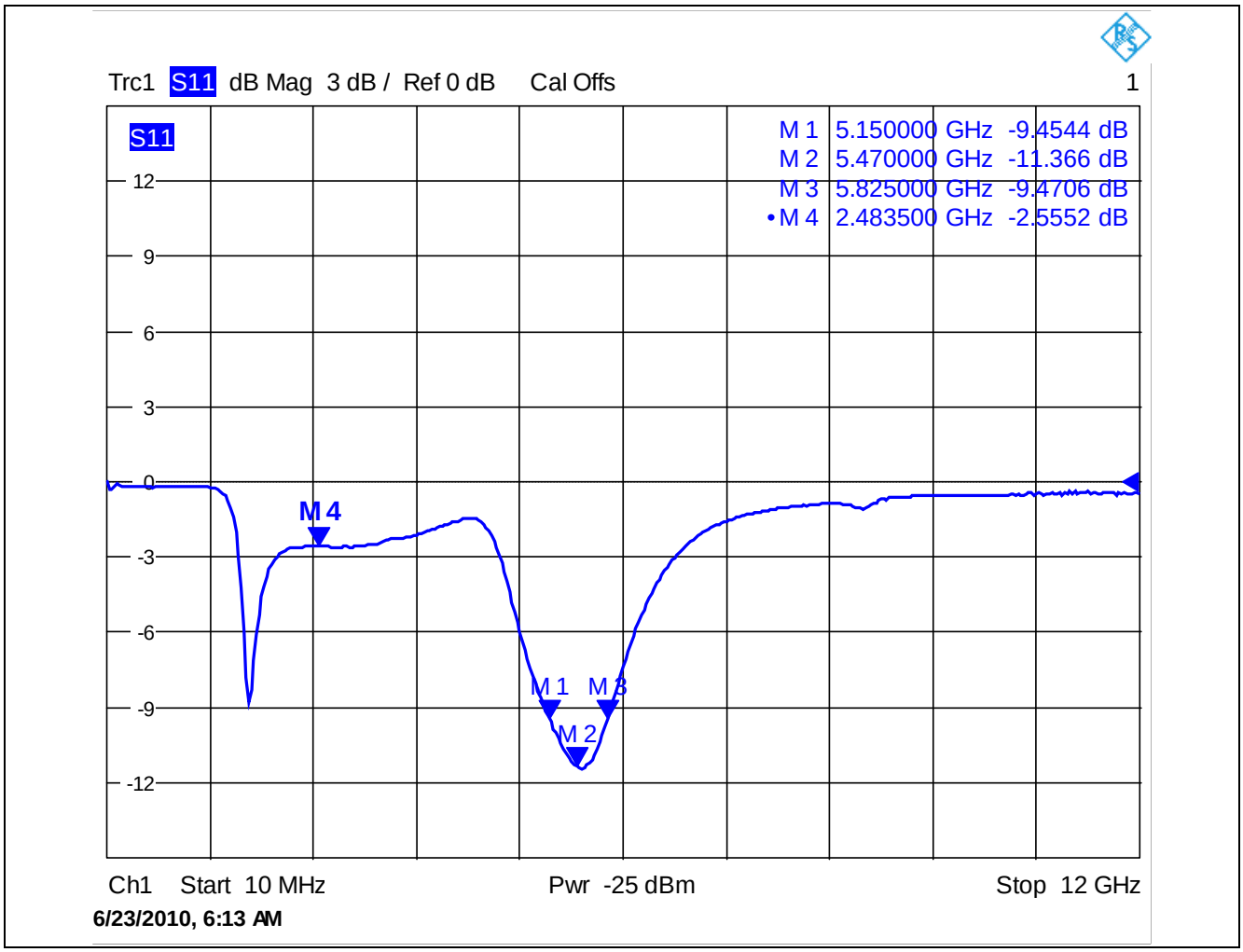



**Figure 5 Input Return Loss in dB**

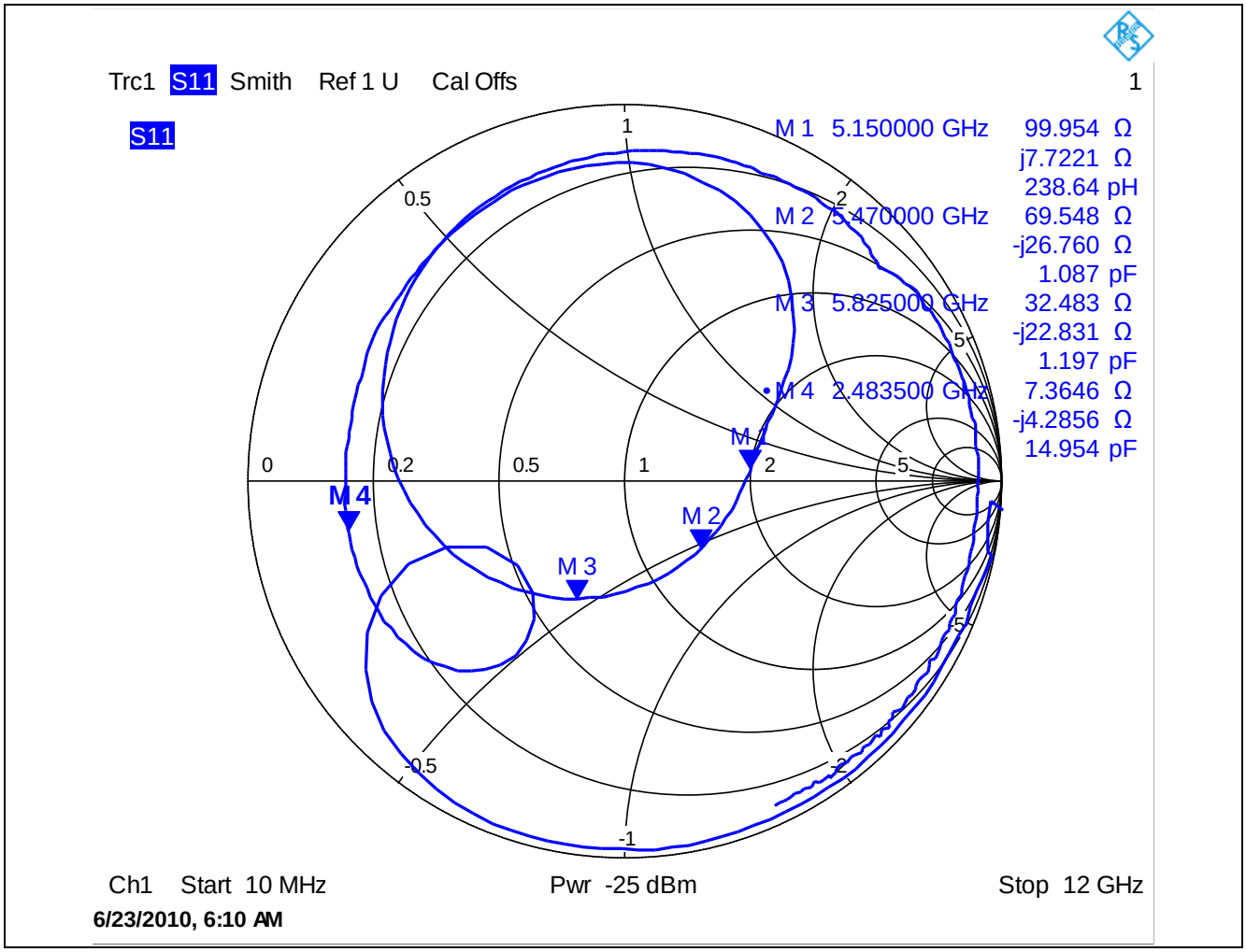



**Figure 6 Input Return Loss, Smith Chart**

## 5.5 Output Return Loss

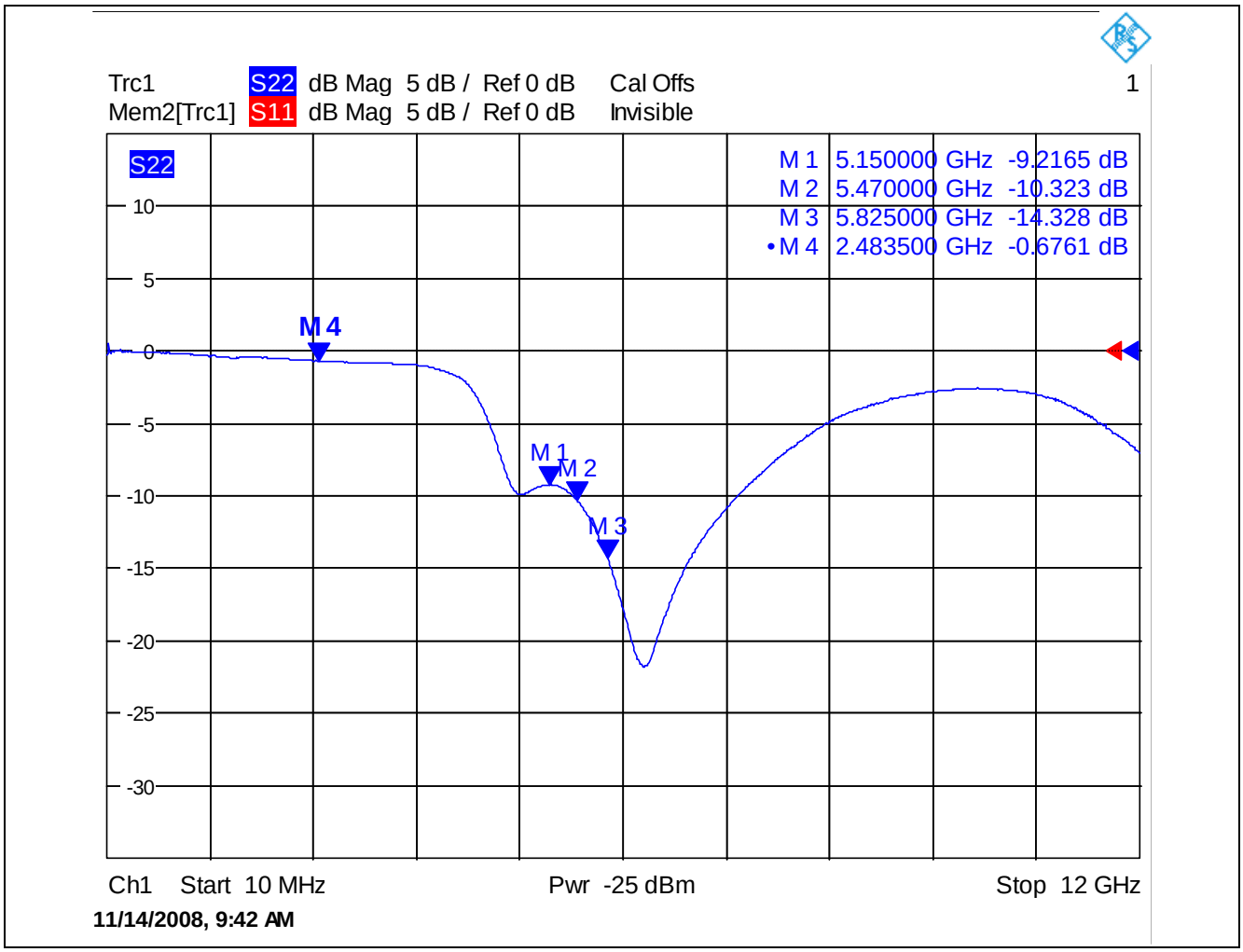



**Figure 7 Output Return Loss in dB**

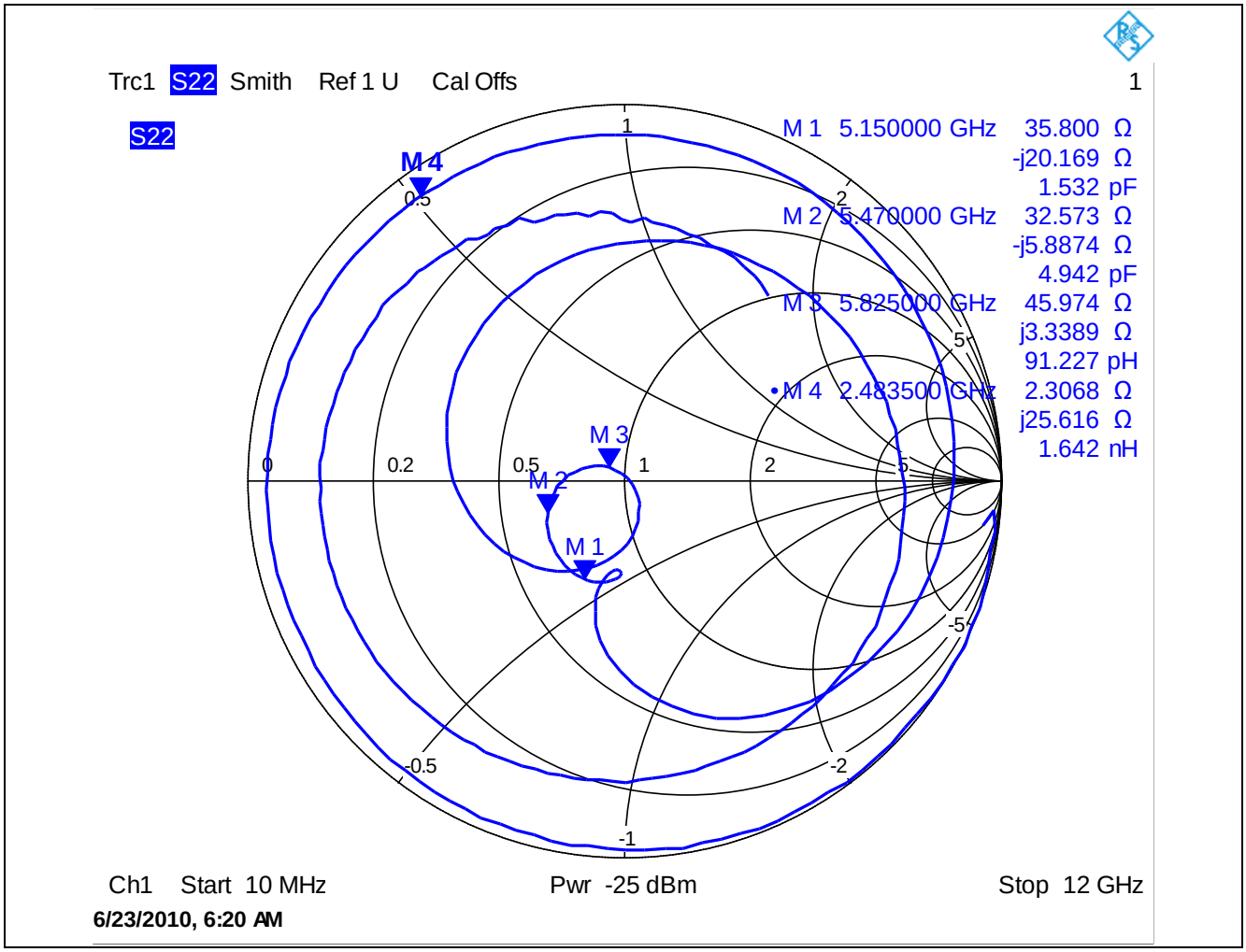



**Figure 8 Output Return Loss, Smith Chart**

## 5.6 Reverse Isolation

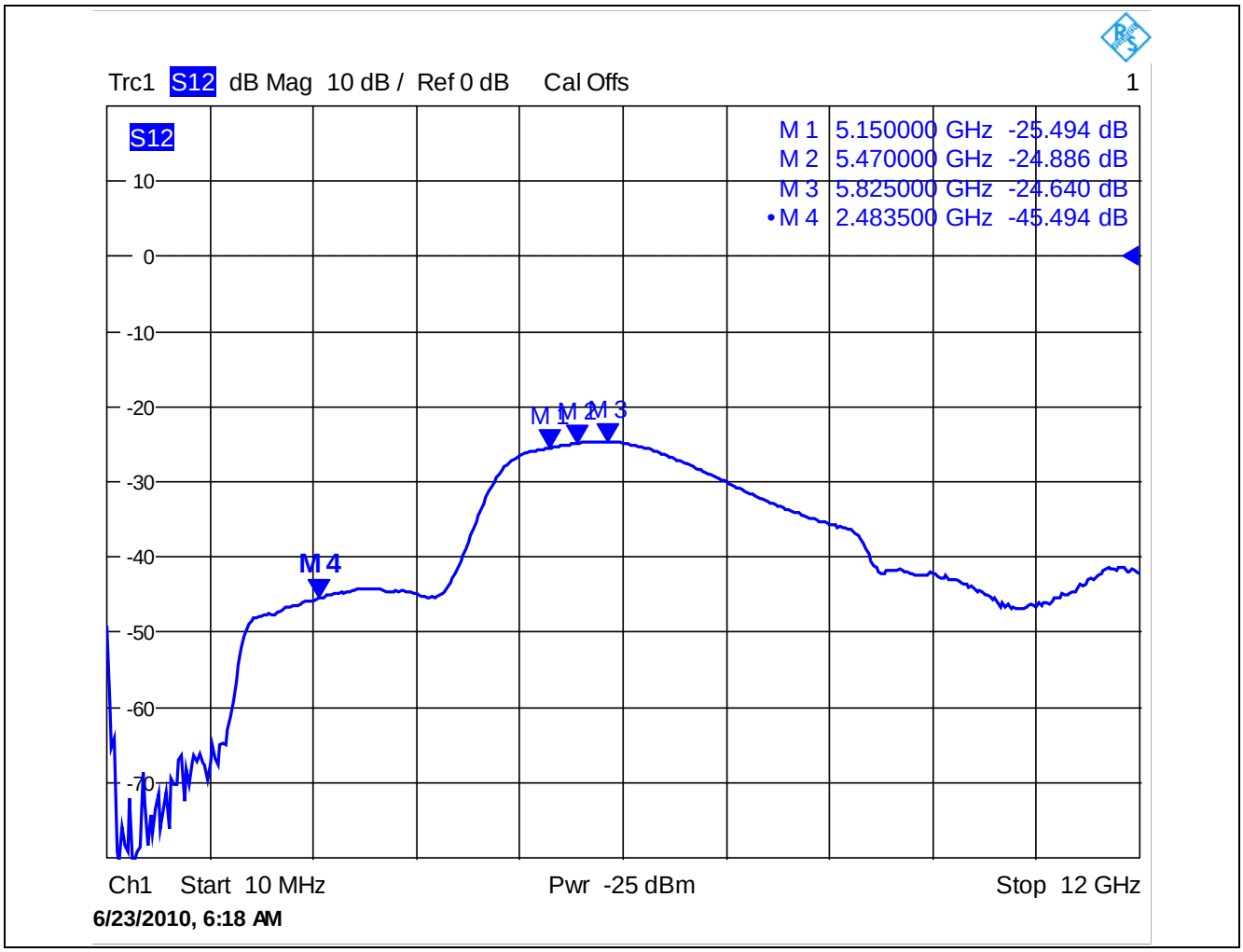



**Figure 9 Reverse Isolation**

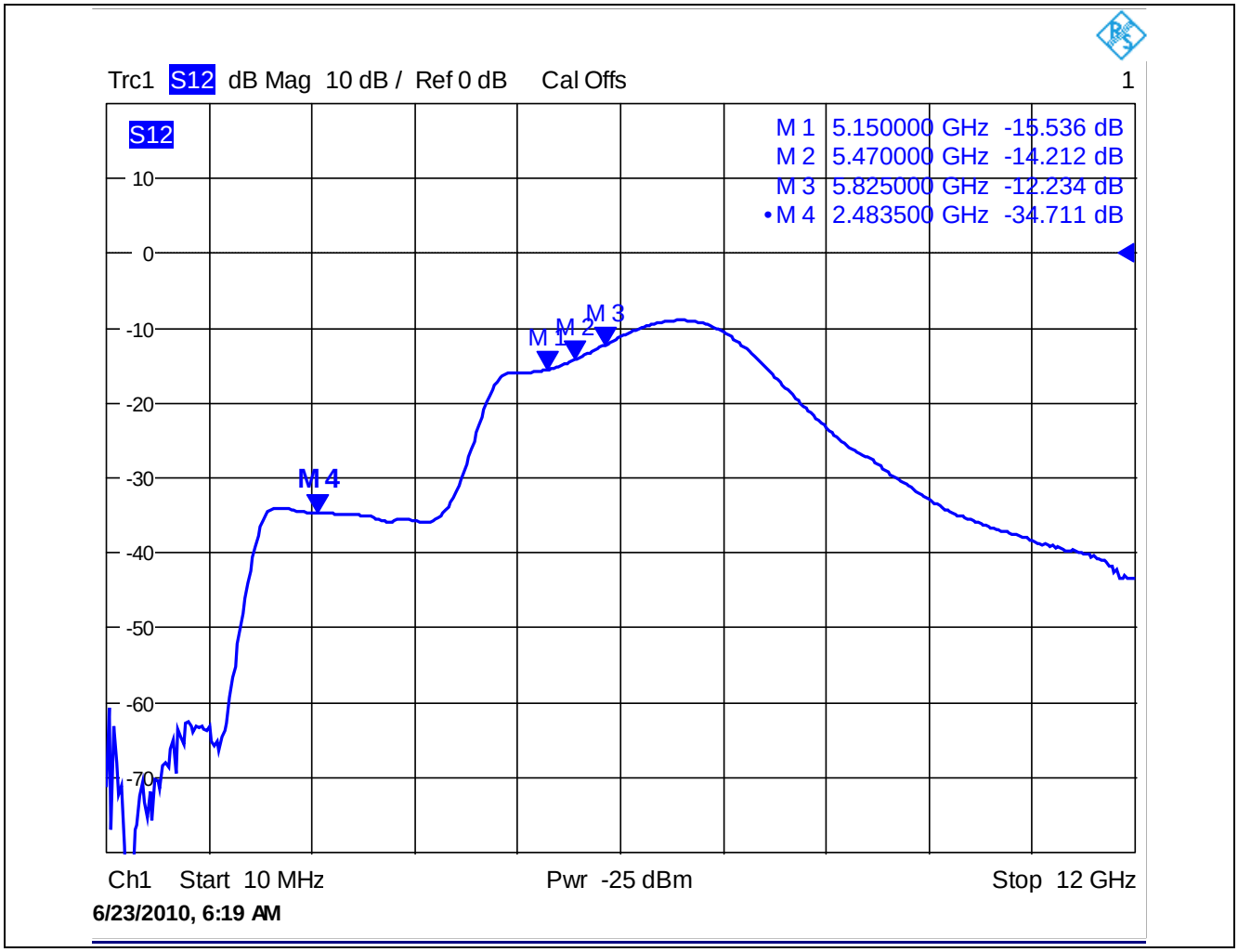



**Figure 10 Reverse Isolation, Amplifier DC Power turned off**

## 5.7 Amplifier Stability

Rohde and Schwarz ZVB Network Analyzer calculates and plots stability factor "µ1" of the BFP740FESD amplifier in real time. Stability Factor µ1 is defined as follows[1]:

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

**Figure 11 Definition of Stability Factor µ1**

The necessary and sufficient condition for Unconditional Stability is µ1 > 1.0. In the plot, µ1 > 1.0 over 10 MHz – 12 GHz; amplifier is Unconditionally Stable over 10 MHz – 12 GHz frequency range.

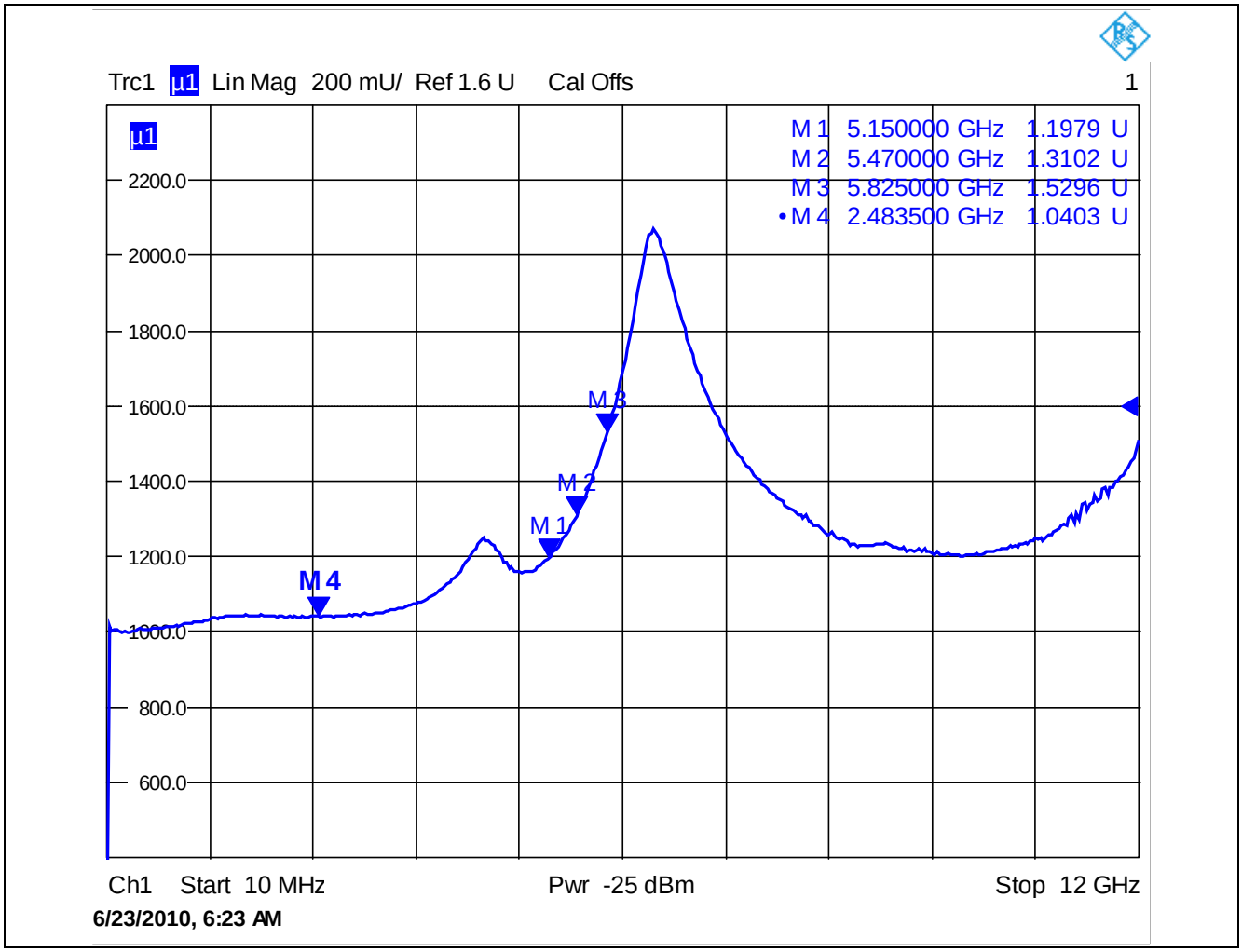



**Figure 12 Stability Factor**

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

## 5.8 Third Order Intercept Point

In-Band Third Order Intercept (IIP3) Test.

Input Stimulus: f1=5470 MHz, f2=5471 MHz, -23 dBm each tone.

Input IP3 = -23 + (47.5 / 2) = +0.8 dBm. Output IP3 = +0.8 dBm + 17.1 dB gain = +17.9 dBm.

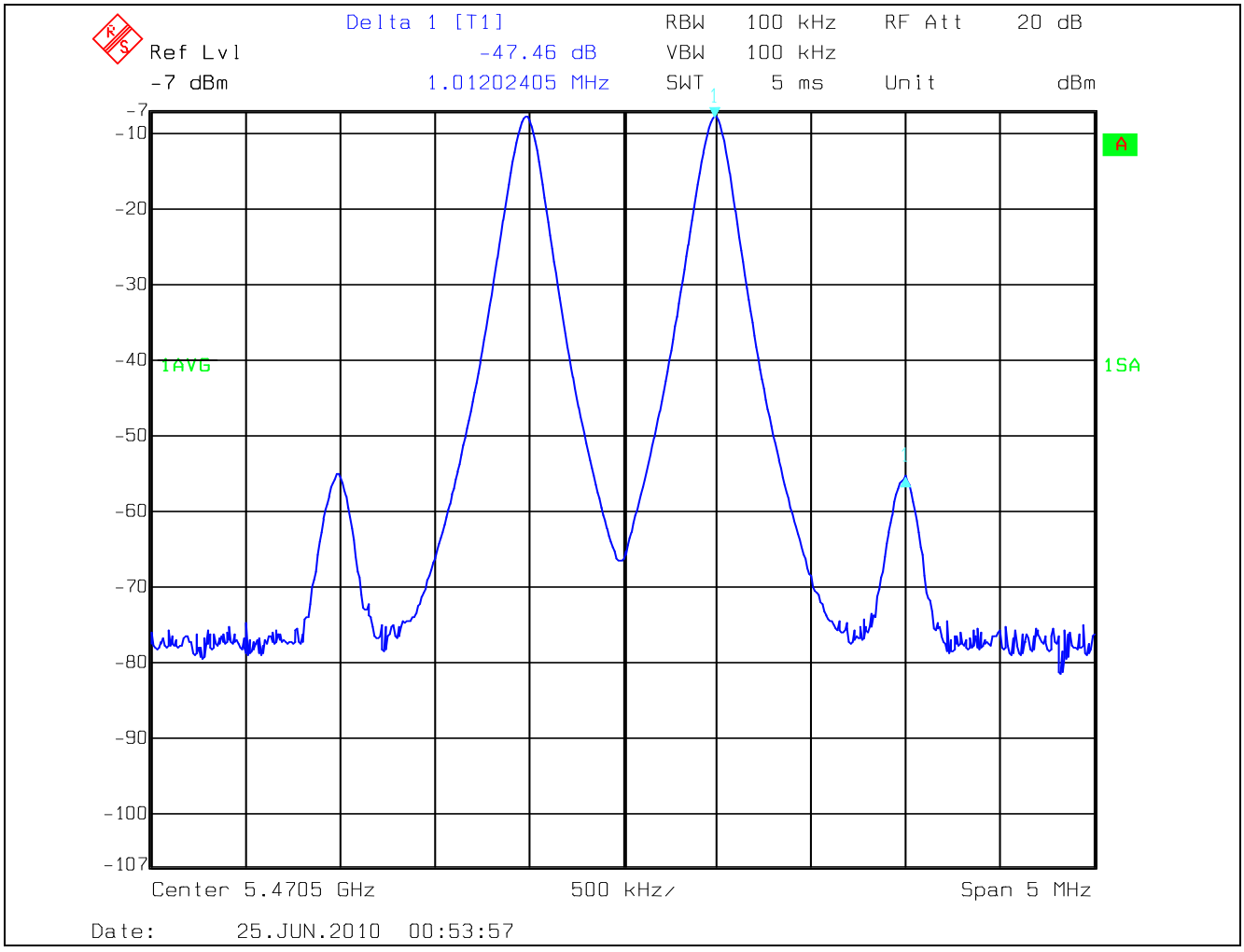
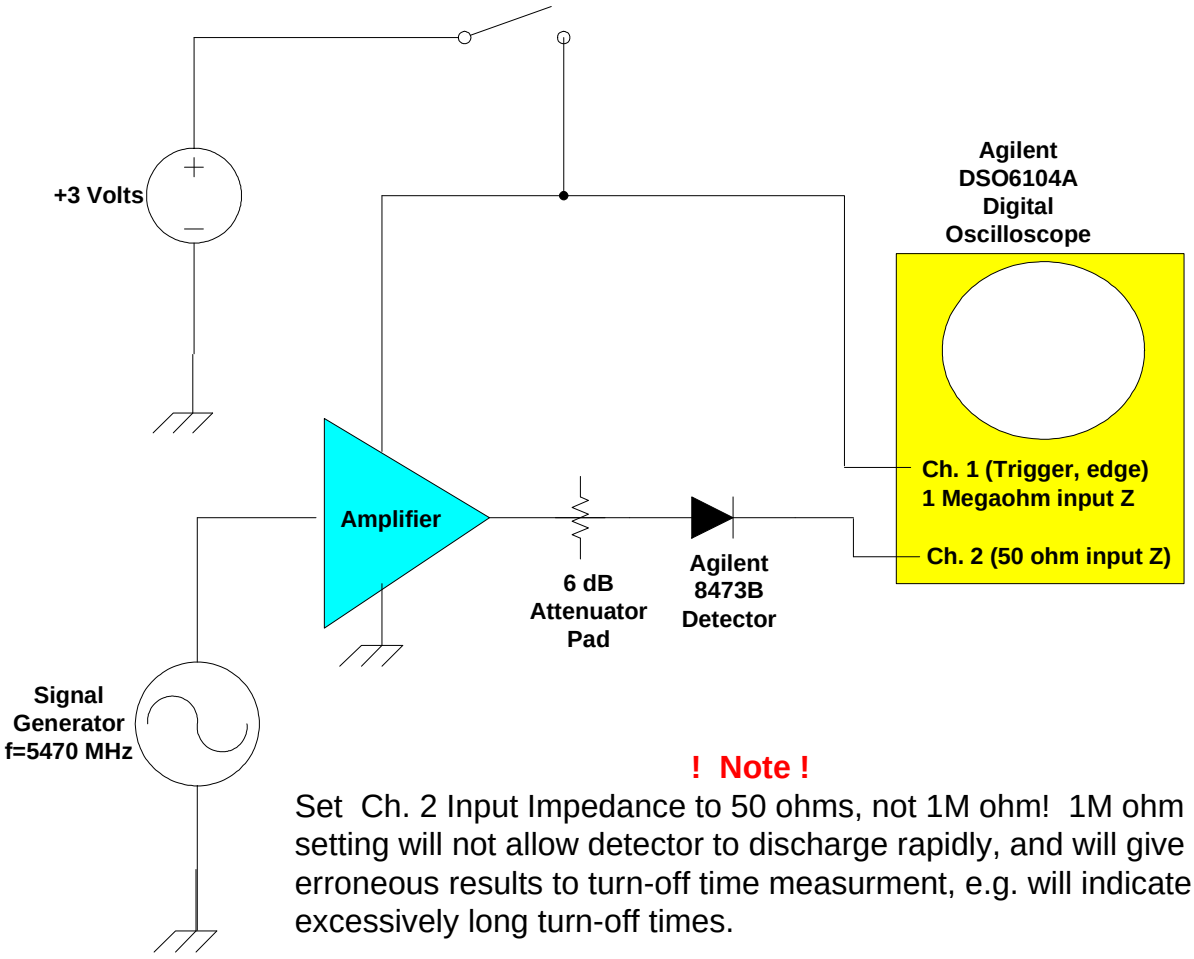



**Figure 13 Carrier and Intermodulation Products at LNA's Output**

## 5.9 Turn-On / Turn-Off Time

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**

**Figure 14 Test setup for Turn-On / Turn-Off measurements**

### 5.9.1 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 35 ns, or 0.035 ms. 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 Figure 1).

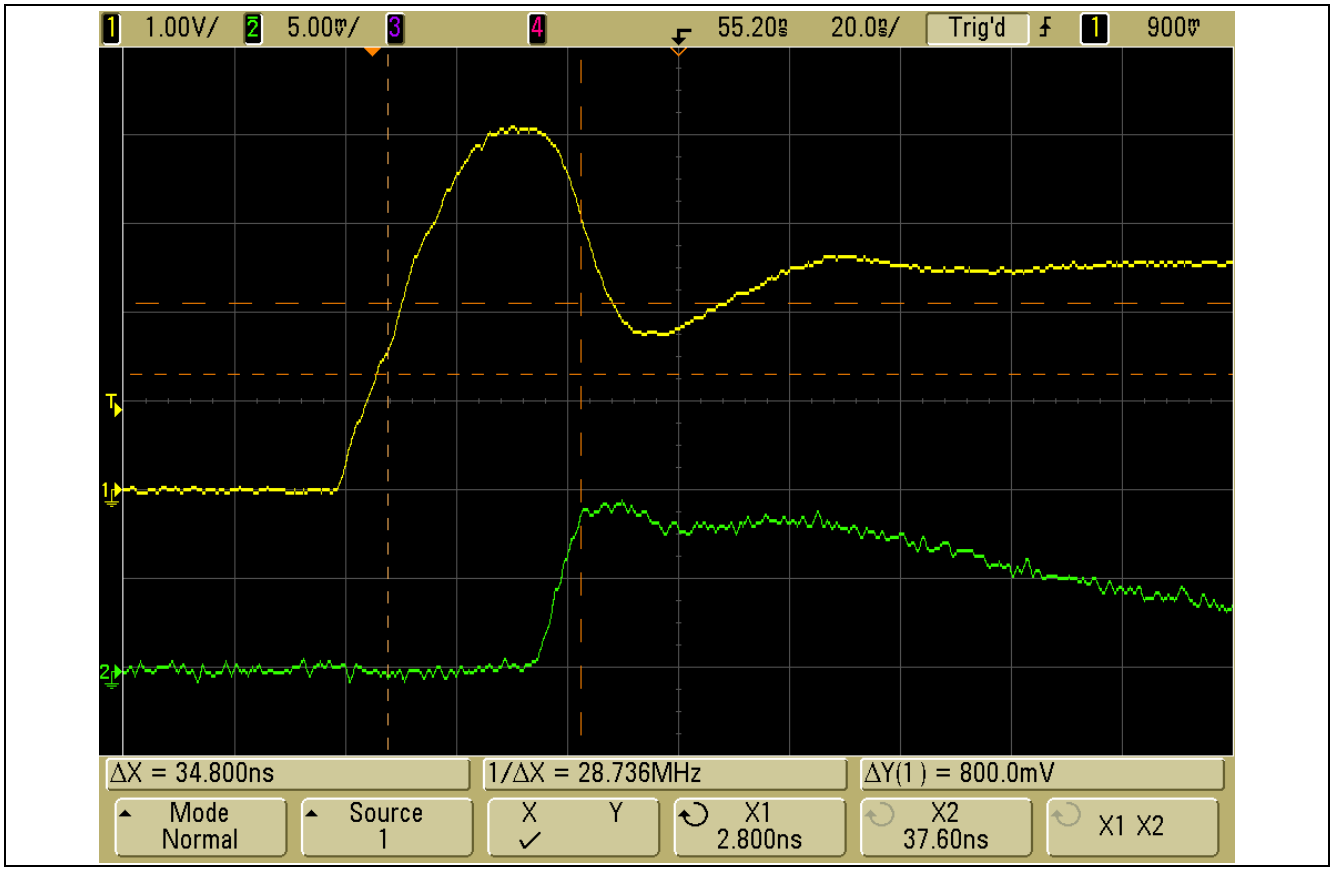



**Figure 15 Turn On Time**

### 5.9.2 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 ~ 25 ns or ~ 0.025 ms 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 Ω, rather than 1 MΩ, to permit RF Detector Diode to rapidly discharge after Amplifier is turned off.

If input impedance of oscilloscope is set to 1 MΩ, the RF Detector will have to discharge through this 1 MΩ impedance, giving excessively long results for the turn-off time measurement.

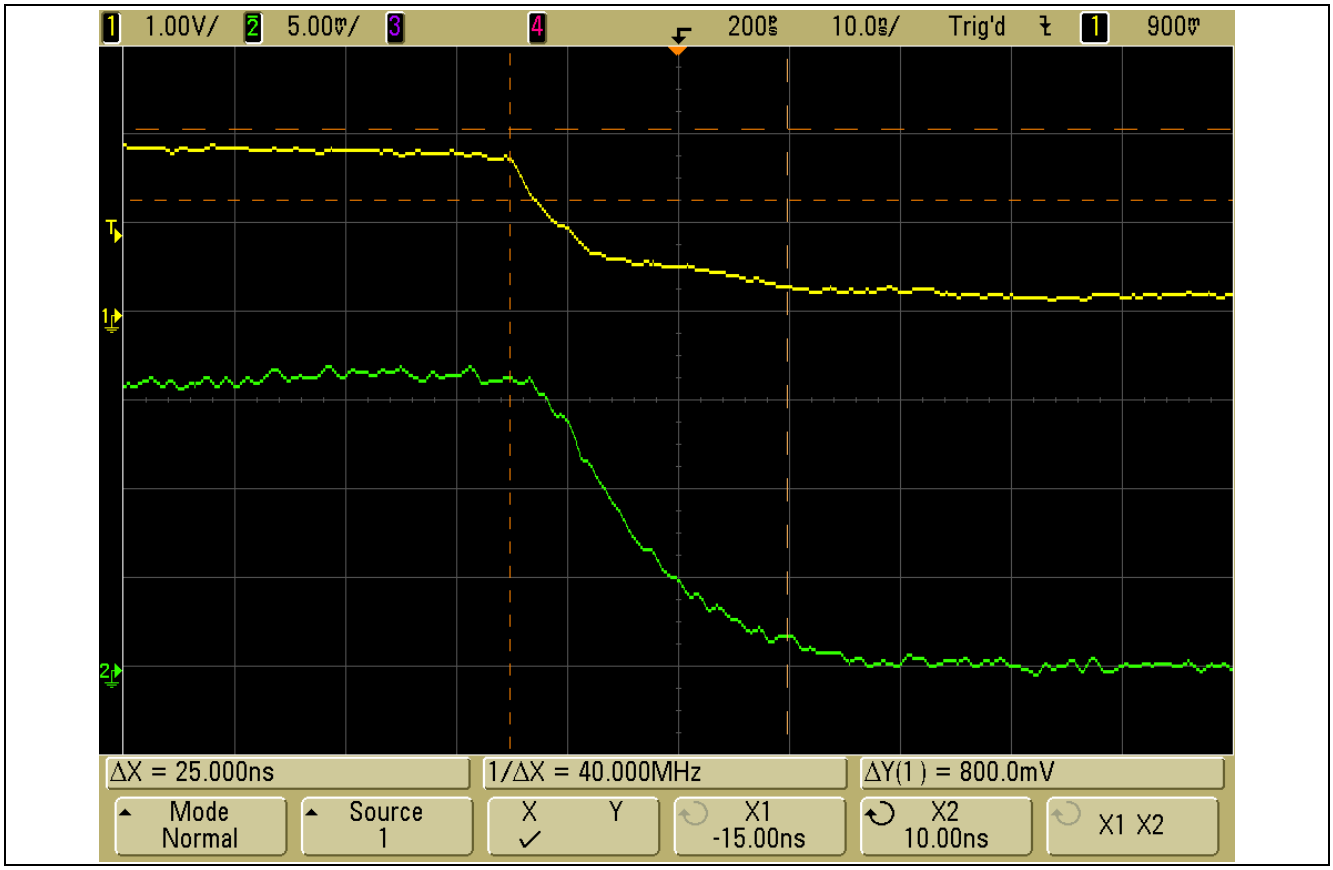



**Figure 16 Turn Off time**

# 6 Details of PC Board Construction

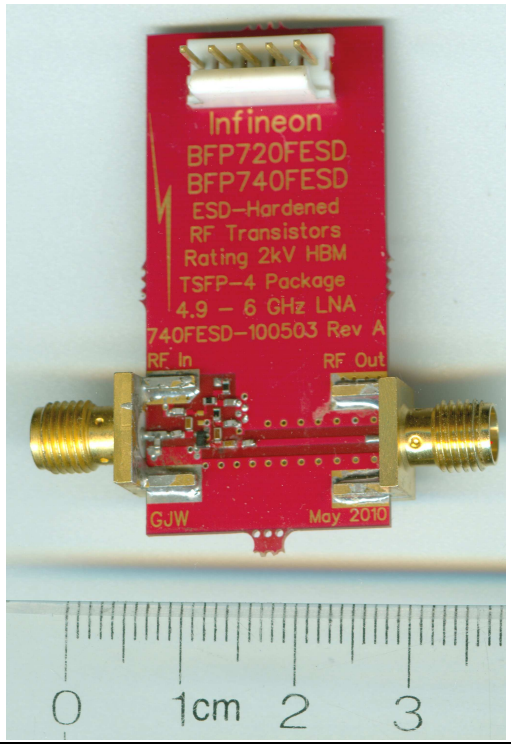



**Figure 17 View of entire PC Board, Top / Component Side**

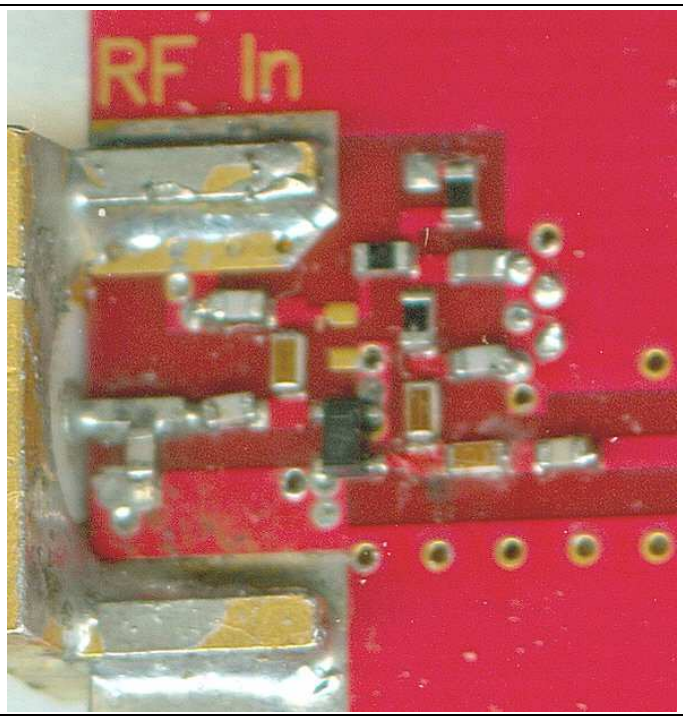



**Figure 18 Close-In View of LNA Section**

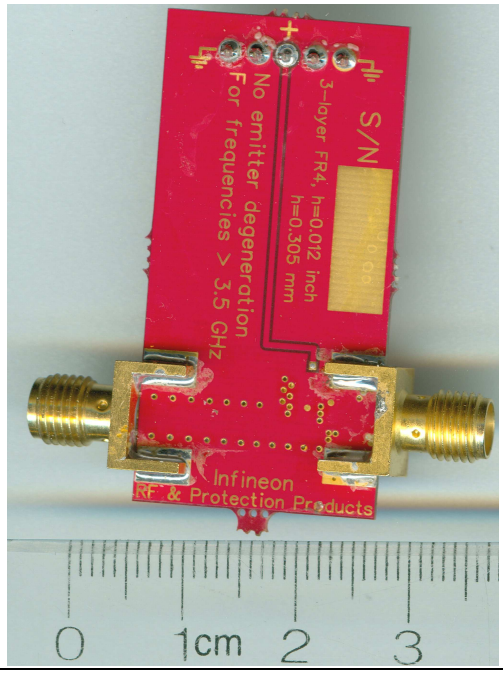



**Figure 19 Backside of PCB**

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

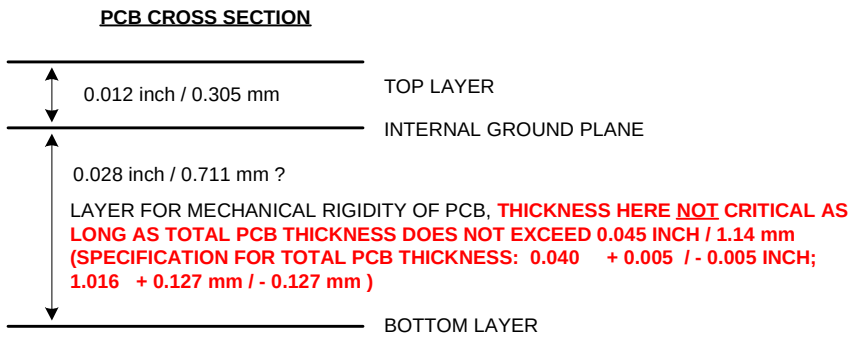



**Figure 20 PCB Layer Information**

# 7 TSFP-4 Package Outline and Footprint

Dinensions in millimeters. Note maximum package height is 0.59 mm / 0.023 inch

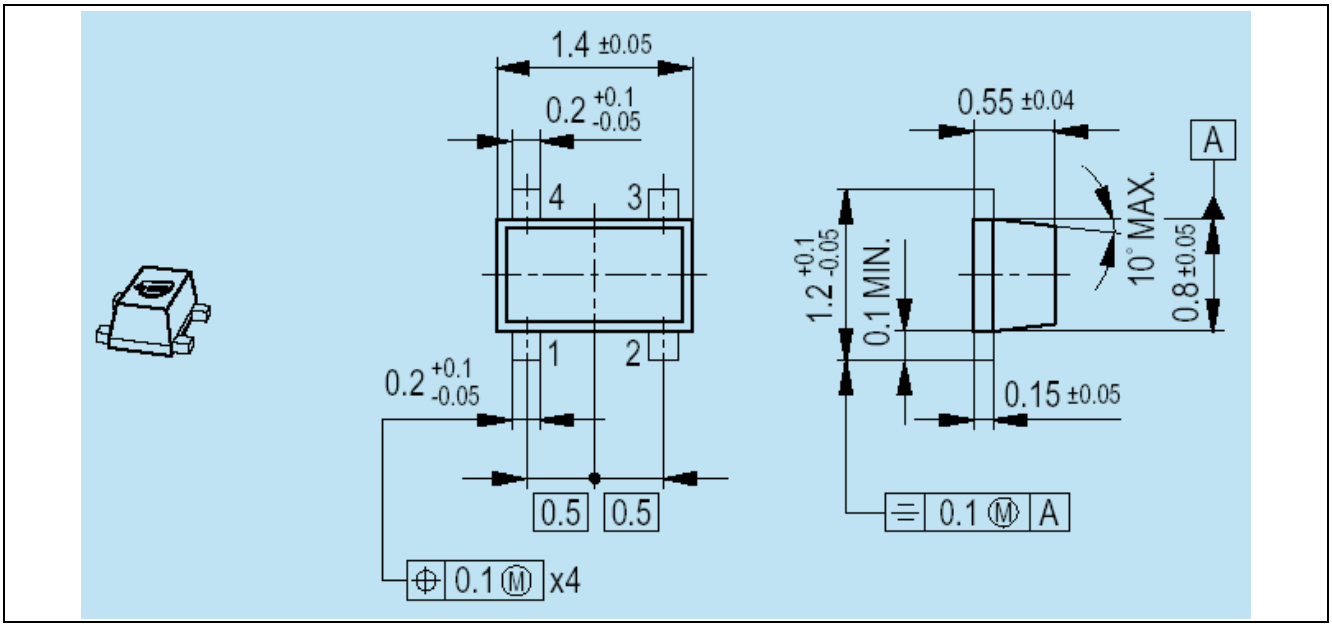



**Figure 21 TSFP-4 package outline**

Recommended Soldering Footprint for TSFP-4 (dimensions in millimeters). Device package is to be oriented as shown in above drawing (e.g. orient long package dimension horizontally on this footprint).

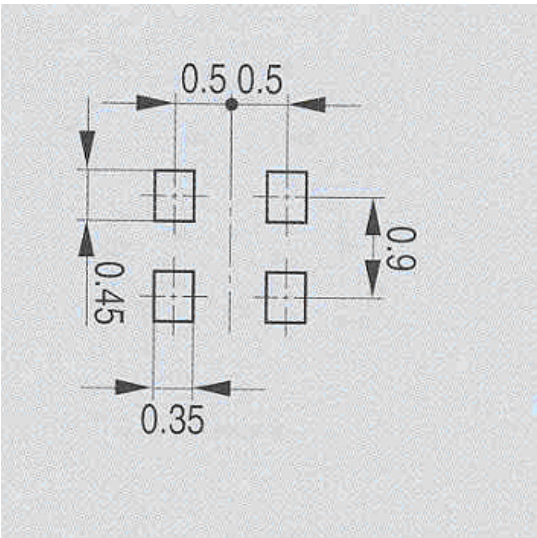



**Figure 22 Recommended Soldering Footprint**

# 8 ESD Protection

Electrostatic discharge (ESD) plays an important role when ESD sensitive devices are connected to exposed interfaces or antennas that can be touched by humans. This is usually applicable to low noise amplifiers (LNAs) and therefore LNAs must be properly protected against ESD in order to avoid irreversible damage of the LNA.

For mobile applications low voltage supply and low current consumption is a major issue that requires new technologies with smaller transistor structures. However, the smaller the transistor structure the more sensitive the transistor is to ESD events. Therefore, RF-LNAs based on new front-end technologies have already ESD protection elements integrated on-chip, e.g. BFP740FESD, BFP640FESD, BFP540FESD. These on-chip ESD protection techniques are always a compromise between good ESD protection and RF performance. Integrated RF ESD concepts hardly ever achieve an ESD protection above ±2 kV according HBM. An on-chip ESD protection of ±1 kV HBM (component level ESD test JEDEC JESD 22-A115) is quite sufficient to protect the chip from ESD events in the manufacturing environment where stringent measures are taken to prevent electrostatic buildup. However in the field, exposed antennas, for example, always require higher ESD protection levels of at least ±8kV up to ±15kV. Additional the more stringent system level test according to IEC61000-4-2 is applied. Therefore a special ESD protection becomes mandatory to handle the majority of the ESD current. An ESD protection based on silicon TVS diodes fits perfect to keep the residual ESD stress for the subsequent device as small as possible.

For high frequency applications (2.4GHz and 5GHz WLAN) ESD protection diodes with ultra low line capacitances are required. Infineon offers ultra low clamping voltage and ultra low capacitance, 0.2pF line capacitance, ESD protection diodes in leadless packages of EIA case 0402 (TSLP-2-17) as well as 0201 (TSSLP-2-1):

**ESD0P2RF-02LRH / -02LS**

The Infineon TVS diode ESD0P2RF has a line capacitance of only 0.2 pF and comes in either a TSLP-2-17 package (1 mm x 0.6 mm x 0.39 mm) or a super small TSSLP-2-1 package (0.62 mm x 0.32 mm x 0.31 mm).

The ESD0P2 ESD diode is a bidirectional TVS diode with a maximum working voltage of ±5.3V. It is capable of handling TX power levels of up to +20dBm without influencing the signal integrity, EVM and harmonic generation. Therefore it is well suited for WLAN 2.4GHz and for a lot of 5GHz applications as well.

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