BFP540FESD

BFP540FESD ESD-Hardened RF Transistor with 1kV HBM ESD Rating in Low Gain 2.4 GHz LNA Application with short Turn-On Turn-Off Time

For BlueTooth and other 2.4 GHz Applications requiring low to moderate gain and fast switching speed

Application Note AN180

Revision: Rev. 1.2
2011-05-31

RF and Protection Devices

Edition 2011-05-31

Published by
Infineon Technologies AG
81726 Munich, Germany

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1 Overview

Infineon Technologies BFP540FESD is an ESD-hardened, high gain, low noise Silicon RF Transistor suitable for a wide range of Low Noise Amplifier (LNA) applications. The BFP540FESD is rated to survive up to 1000 V ESD events between any pair of terminals, per the Human Body Model (HBM). Refer to Reference [1], BFP540FESD datasheet, and refer to Refernce [2] for details on how the BFP540FESD sand similar Infineon RF transistors achieve improved ESD-robustness.

The circuit shown is targeted for higher sensitivity or longer range BlueTooth and similar applications. Commercially available fully integrated CMOS BlueTooth transceiver chips may claim receiver sensitivity numbers which are far higher than real-world implementations permit. Losses in the bandpass filter (see block diagram below) are often higher than claimed due to non-ideal effects. Therefore, to improve receiver sensitivity, some (external) gain is required just after the antenna. However, too much external LNA gain compromises the large-signal handling capability of the BlueTooth receiver. We want just enough gain to dominate the overall system noise figure, no more. The LNA shown in this applications note is an attempt to achieve such a balance, with a gain of between 8 dB and 9 dB. LNAs for this application must be able to switch on / off within about 1 µs (1000 ns). The 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 (IP3) performance. Inductive emitter degeneration is used to improve amplifier low-frequency stability and impedance matching. Refer to Reference [3] for a general overview of charge storage and inductive emitter degeneration.

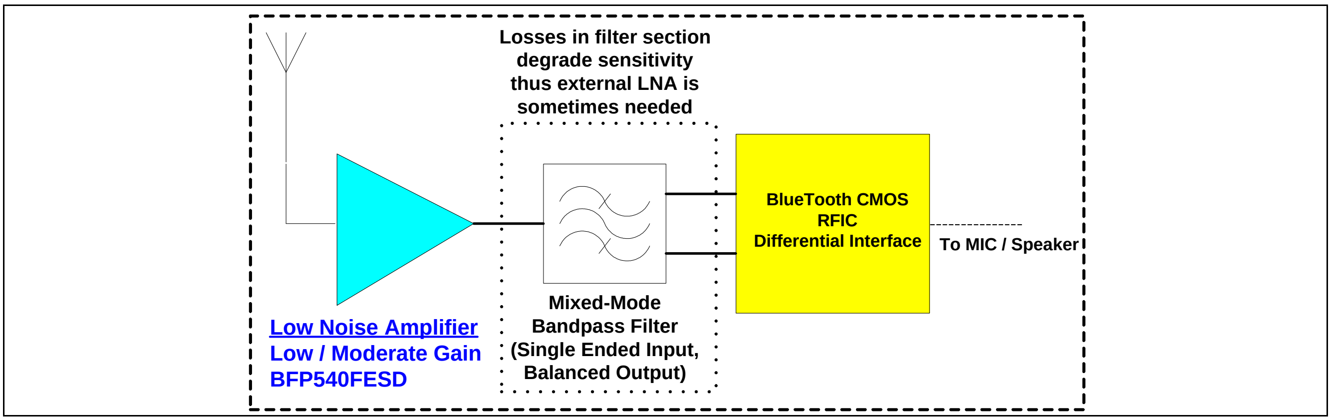


Figure 1 Block diagram of an example Bluetooth receiver system

1.1 Summary of Performance Data

Table 1 Summary of performance data
T=25 °C, network analyzer source power = -25 dBm, V_{CC} = 2.8 V, V_{CE} = 2.5 V, I_C=5.0 mA

Frequency (MHz)	dB[s11]²	dB[s21]²	dB[s12]²	dB[s22]²	NF[1] (dB)	IIP3 (dBm)	IP1dB (dBm)
2400	-10.0	8.9	-23.9	-10.2	**1.4**		
2441	-10.3	8.7	-23.9	-10.1	**1.4**	-6.3	-13.6
2483.5	-10.5	8.5	-23.8	-10.0	**1.4**		

Amplifier is unconditionally Stable (µ1 > 1.0) from 50 MHz to 12 GHz.

External parts count (not including BFP540FESD transistor) = 14; 6 capacitors, 6 resistors, and 2 chip inductors. All passives are 0402 case size. BFP540FESD transistor package is RoHS – compliant and measures 1.4 x 1.2 x 0.55 mm^3.

[1] Does not extract PCB loss. If PCB loss (at input) were extracted, NF would be ~0.1 dB lower.

2 Schematic Diagram and Bill of Material

2.1 Schematic Diagram

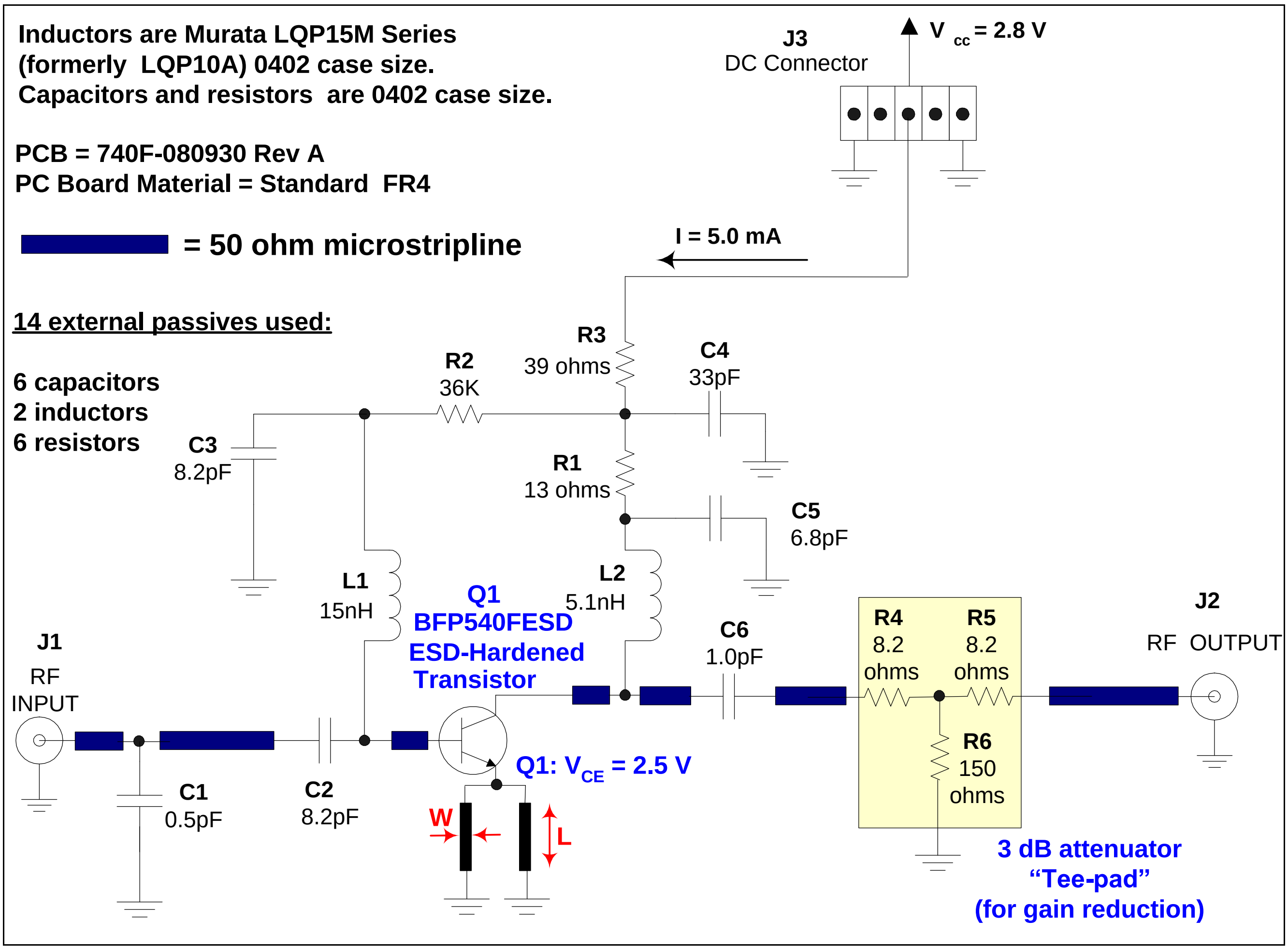


Figure 2 Schematic diagram

Inductive emitter degeneration is used for low frequency stability improvement and impedance matching. One identical microstrip track from each of the two emitters leads to a separate ground via hole is used. Ground hole via diameter is 0.012 inch (0.3 mm).

Microstrip dimensions are: W = 0.010 inch (0.25 mm); L = 0.023 inch (0.584 mm).

Height between top layer RF traces and internal ground plane is 0.012 inch (0.3 mm). 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), for example 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.

2.2 Bill of Material

Table 2 Bill-of-Material

Symbol	Value	Unit	Size	Manufacturer	Comment
C1	0.5	pF	0402	Various	Impedance matching, input
C2	8.2	pF	0402	Various	RF decoupling / blocking cap
C3	8.2	pF	0402	Various	RF decoupling / blocking cap
C4	33	pF	0402	Various	RF decoupling / blocking cap
C5	16.8	pF	0402	Various	RF decoupling / blocking cap; also influences output match and amplifier stability margin
C6	1.0	pF	0402	Various	Output DC blocking cap; also improves input match due to nonzero s21 of transistor
L1	15	nH	0402	Murata LQP	RF choke at LNA input (for DC bias to base)
L2	5.1	nH	0402	Murata LQP	RF choke at LNA output, for DC bias to collector. Also influences matching and stability
R1	13	Ω	0402	Various	RF stability improvement
R2	36	kΩ	0402	Various	DC biasing (base current)
R3	39	Ω	0402	Various	DC biasing; provides DC negative feedback to stabilize DC operating point over temperature vartiation, transistor h_{FE} variation, etc.
R4	8.2	Ω	0402	Various	For 3 dB “Tee” attenuator
R5	8.2	Ω	0402	Various	For 3 dB “Tee” attenuator
R6	150	Ω	0402	Various	For 3 dB “Tee” attenuator
Q1	**BFP540FESD**		TSPF-4	Infineon Technologies	LNA active device

3 Measurement Data

3.1 Noise Figure

Rohde & Schwarz FSEK3

02 Apr 2009

Noise Figure Measurement

EUT Name:	BFP540FESD, Low Gain, Fast Switching / Fast Turn ON-OFF Time
Manufacturer:	Infineon Technologies
Operating Conditions:	T=25 C, V = 2.8V, Vce = 2.5V, I = 5.0mA
Operator Name:	Gerard Wevers
Test Specification:	BlueTooth LNA
Comment:	PCB = 740F-080930 Rev A ; Preamp = MITEQ SMC-02 2 April 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

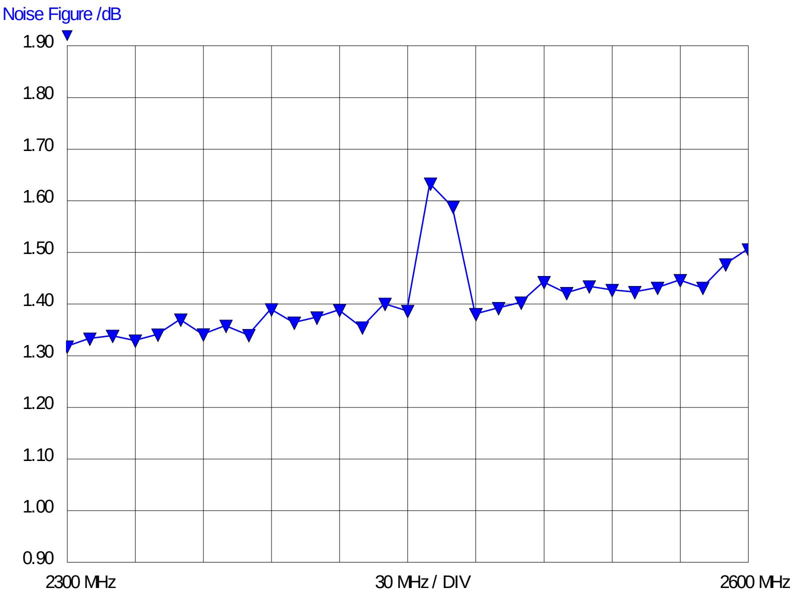


Figure 3 Noise figure plot

Table 3 Noise figure, tabular data

Frequency	NF	Noise temperature
2300 MHz	1.32 dB	102.7 K
2310 MHz	1.33 dB	104 K
2320 MHz	1.34 dB	104.6 K
2330 MHz	1.33 dB	103.7 K
2340 MHz	1.34 dB	104.8 K
2350 MHz	1.37 dB	107.4 K
2360 MHz	1.34 dB	104.8 K
2370 MHz	1.36 dB	106.4 K
2380 MHz	1.34 dB	104.7 K
2390 MHz	1.39 dB	109.2 K
2400 MHz	1.36 dB	106.9 K
2410 MHz	1.37 dB	107.8 K
2420 MHz	1.39 dB	109.1 K
2430 MHz	1.35 dB	106.1 K
2440 MHz	1.40 dB	110.2 K
2450 MHz	1.39 dB	108.9 K
2460 MHz	1.63 dB	132.3 K
2470 MHz	1.59 dB	127.9 K
2480 MHz	1.38 dB	108.4 K
2490 MHz	1.39 dB	109.5 K
2500 MHz	1.40 dB	110.4 K
2510 MHz	1.44 dB	114.2 K
2520 MHz	1.42 dB	112.1 K
2530 MHz	1.43 dB	113.4 K
2540 MHz	1.43 dB	112.7 K
2550 MHz	1.42 dB	112.3 K
2560 MHz	1.43 dB	113.1 K
2570 MHz	1.44 dB	114.5 K
2580 MHz	1.43 dB	113.1 K
2590 MHz	1.48 dB	117.3 K
2600 MHz	1.50 dB	120.1 K

3.2 Amplifier Compression Point Measurement

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. X-axis of VNA screen-shot below shows input power to LNA swept from –25 dBm to –5 dBm.

Input 1 dB compression point = **-13.6 dBm**

Output 1 dB compression point = -13.6 dBm + (Gain – 1dB) = -13.6 dBm +8.5 dB = **-5.1 dBm**

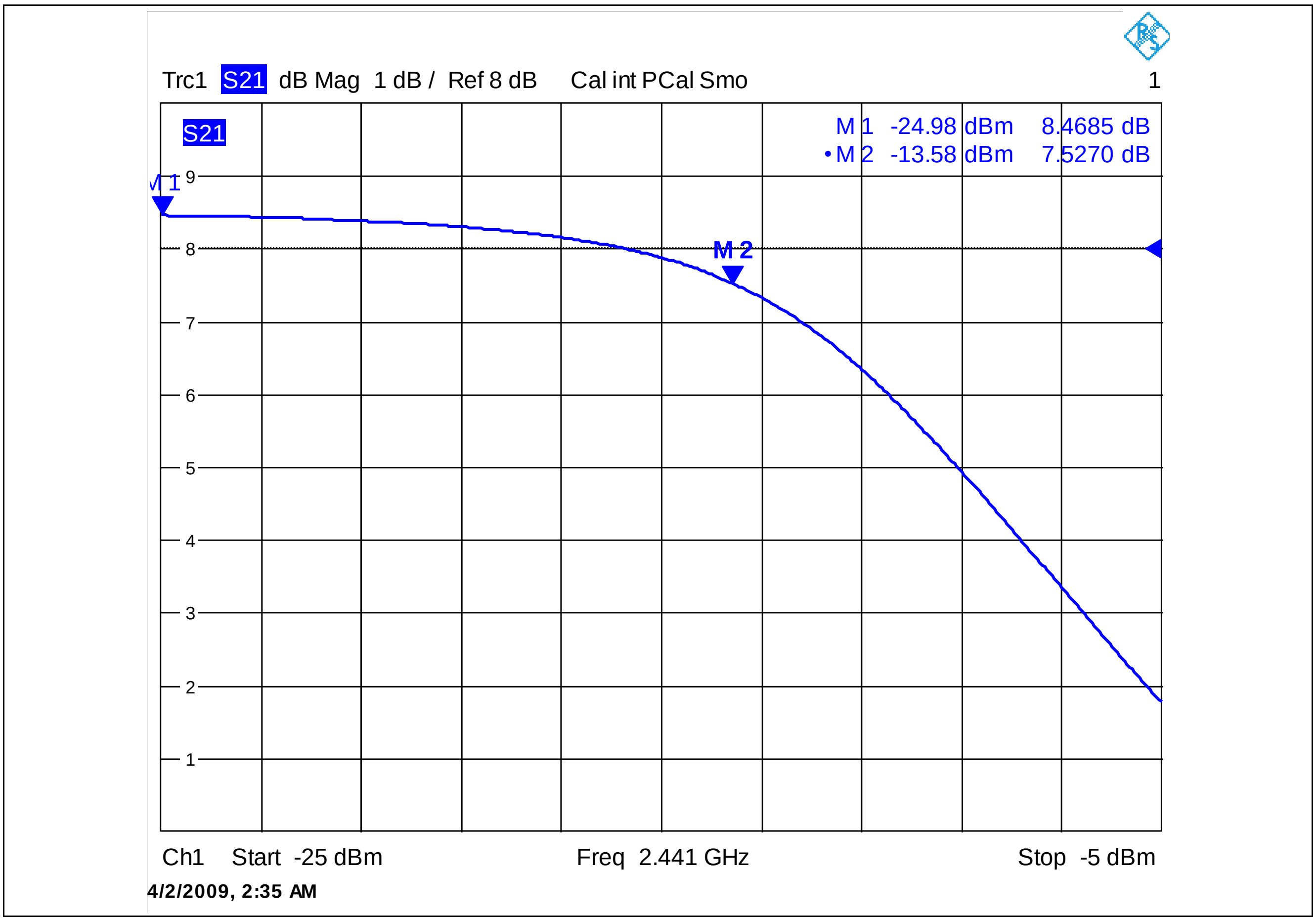


Figure 4 Gain compression at 2441 MHz, V_{CC} = +2.8 V, I = 5.0 mA, V_{CE} = 2.5 V, T = 25 °C

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

3.3.1 Stability

Rohde and Schwarz ZVB Network Analyzer Calculates and plots stability factor “µ1” of the BFP540FESD amplifier in real time. Stability Factor µ1 is defined as follows:

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

The necessary and sufficient condition for Unconditional Stability is µ1 > 1. In the plot, µ1 > 1 over 10 MHz to 12 GHz; amplifier is Unconditionally Stable over 10 MHz to 12 GHz frequency range.

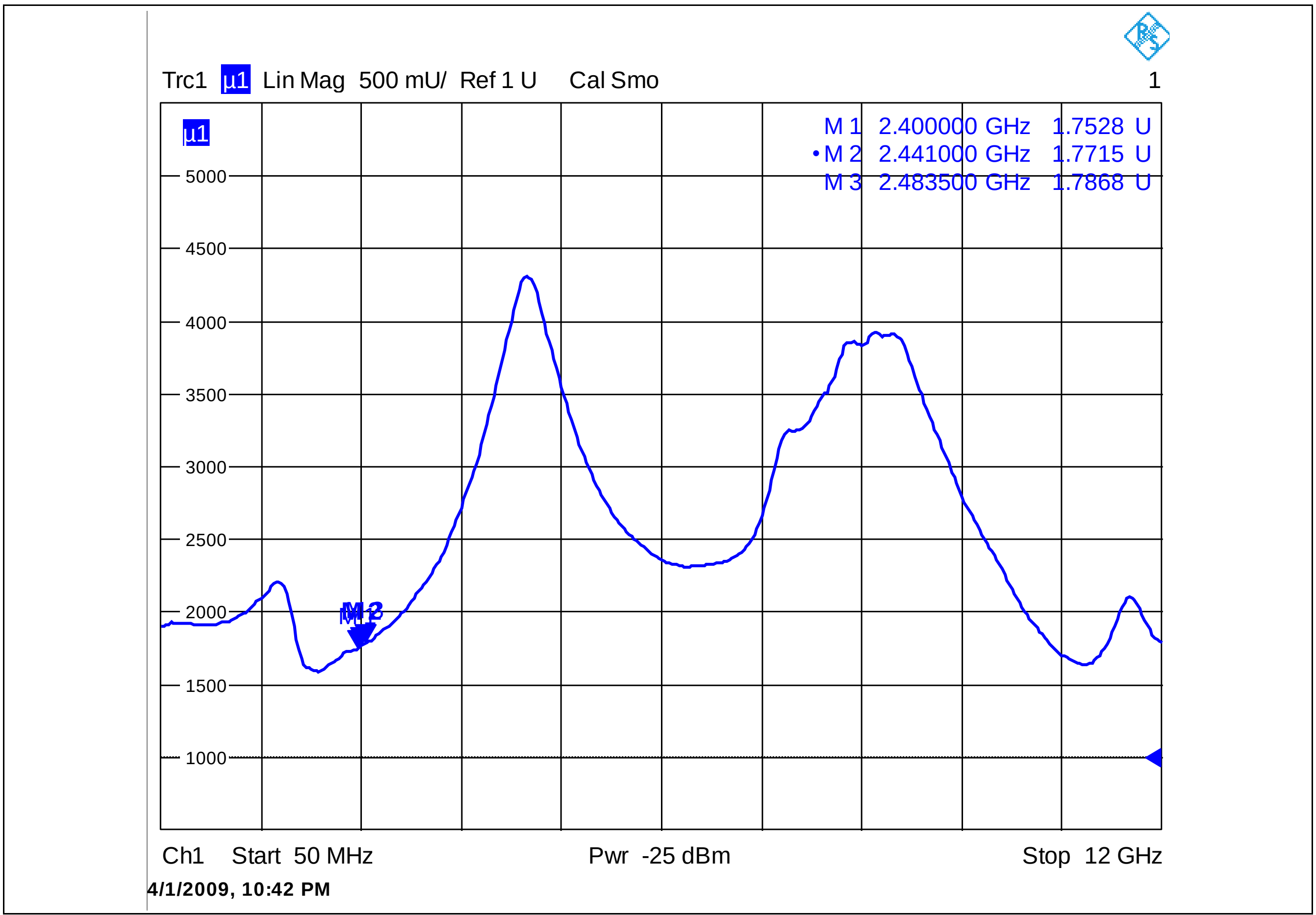


Figure 5 Amplifier stability: Plot of Stability Factor µ1

3.3.2 Input Return Loss

Reference plane is input SMA connector on PC board.

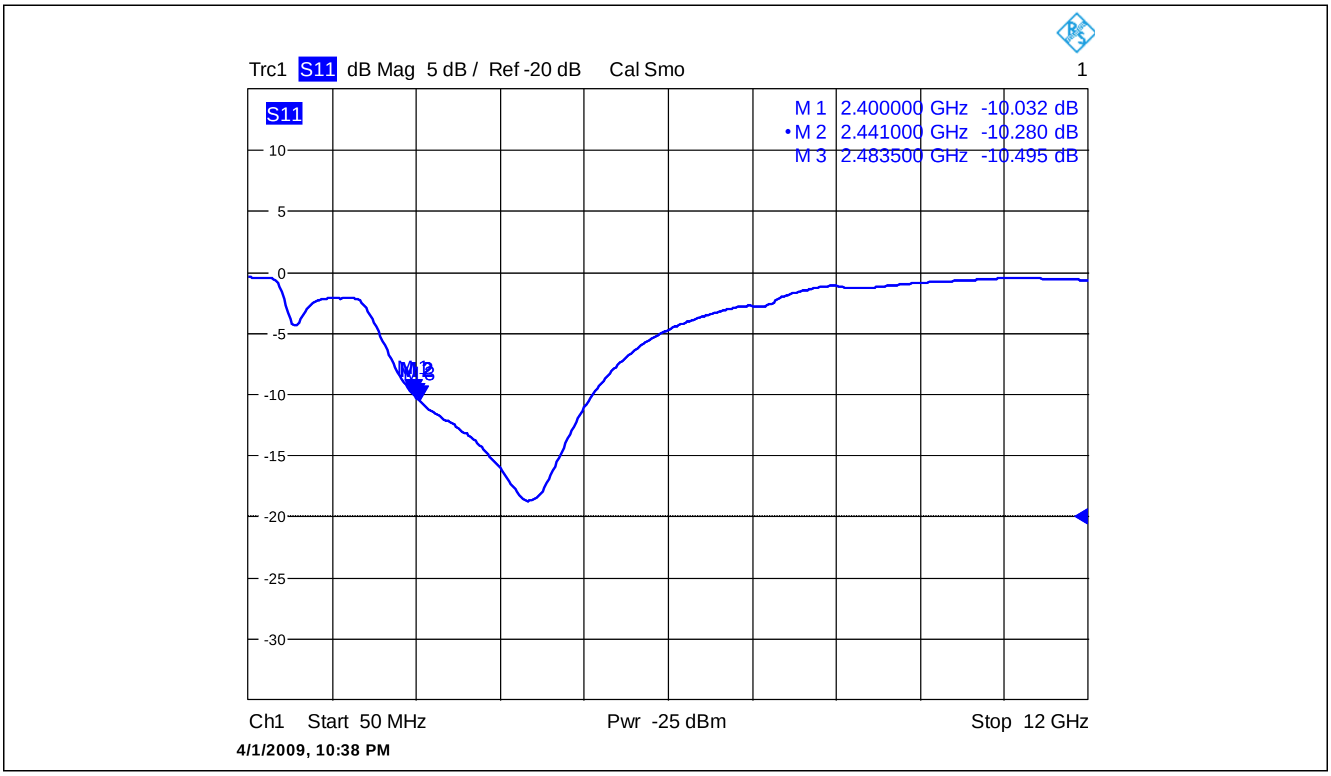


Figure 6 Input return loss / dB

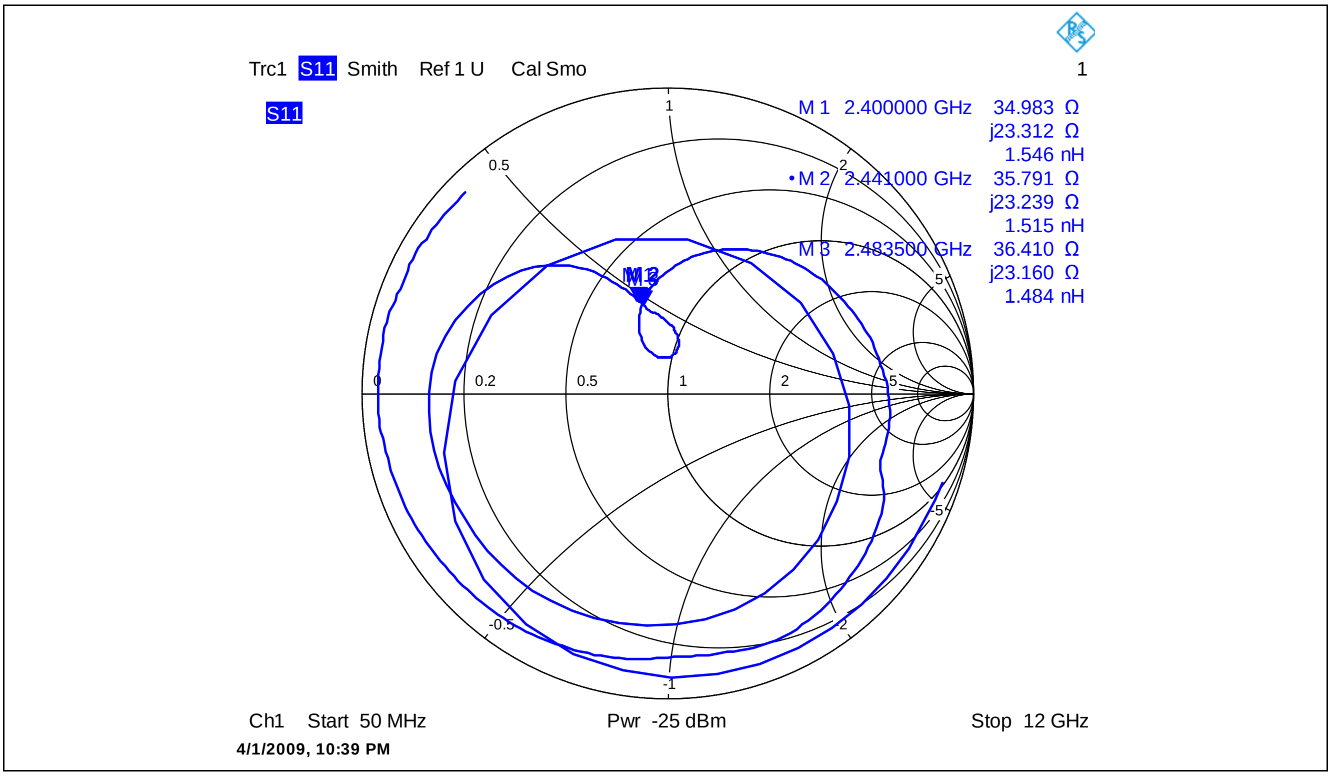


Figure 7 Input return loss (Smith chart)

3.3.3 Forward Gain and Reverse Isolation

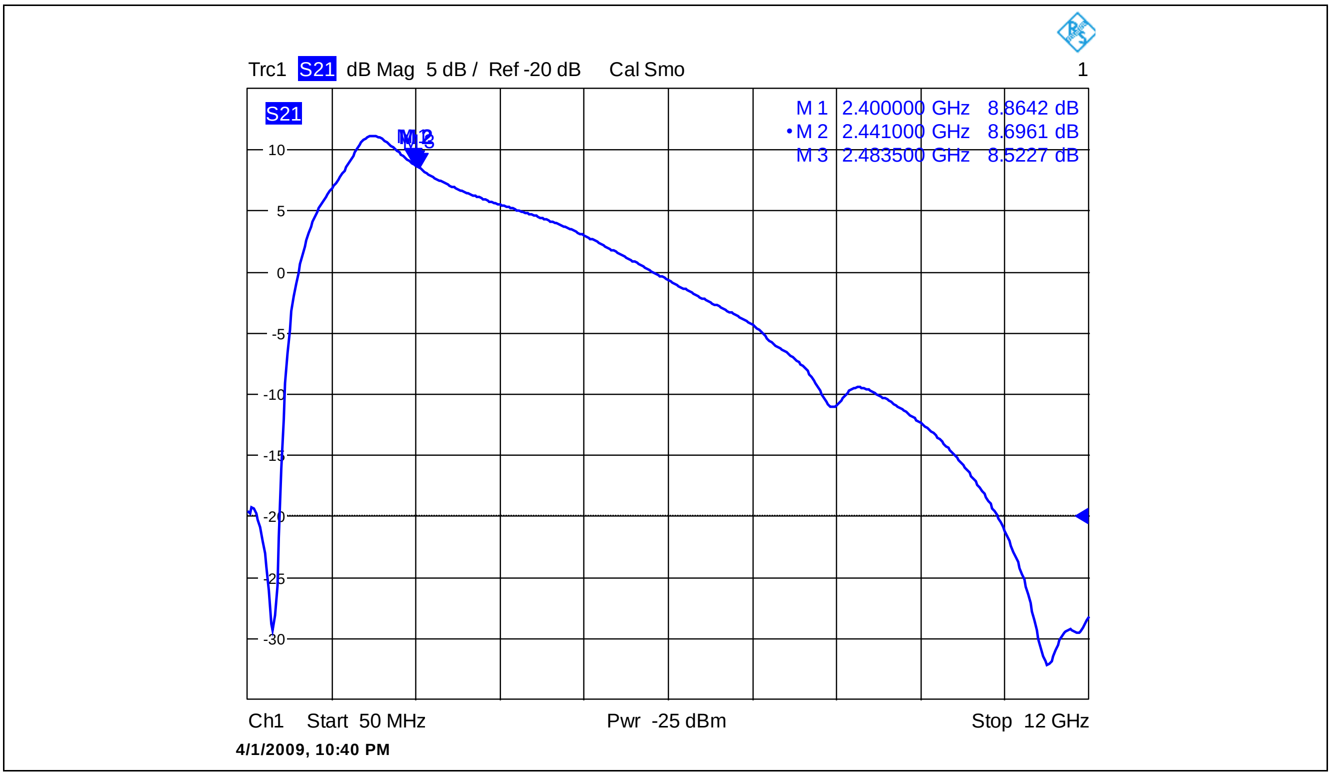


Figure 8 Forward Gain / dB

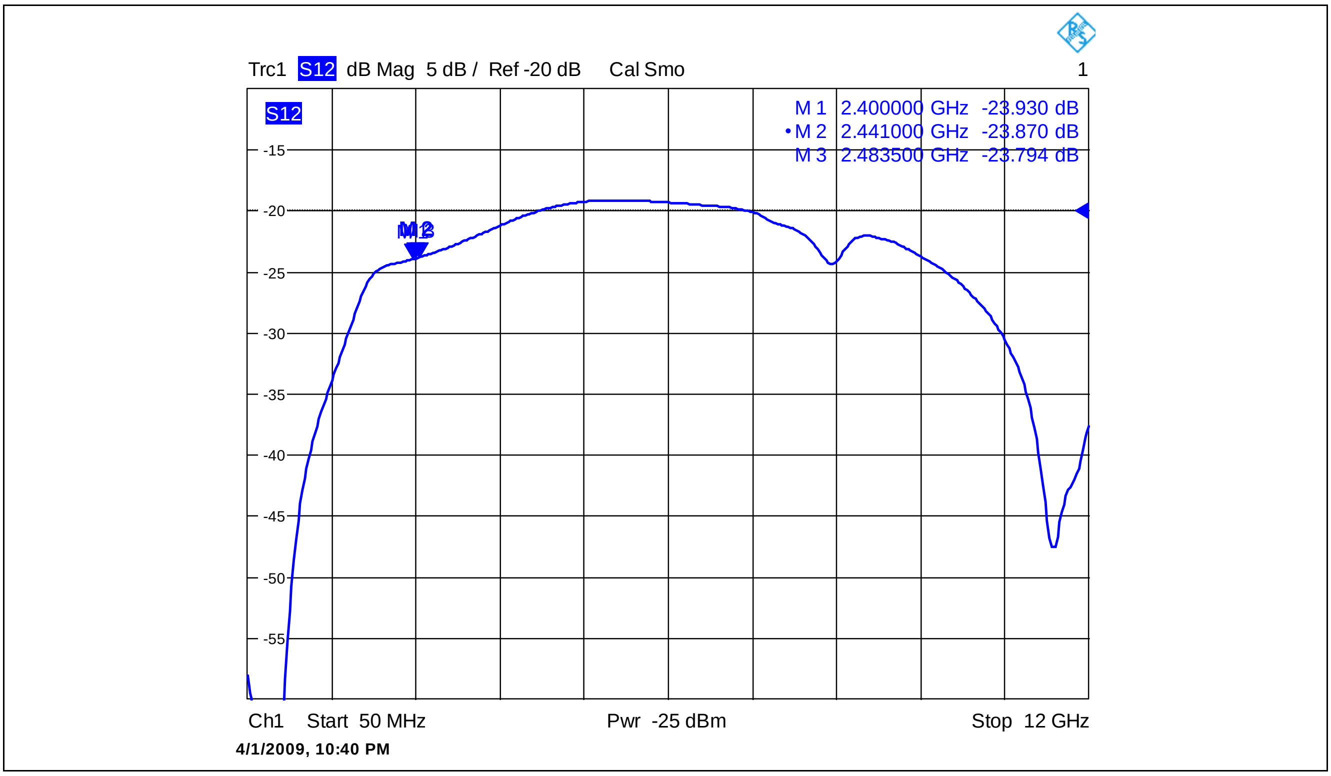


Figure 9 Reverse Isolation / dB

3.3.4 Output Return Loss

Reference plane is output SMA connector on PC board.

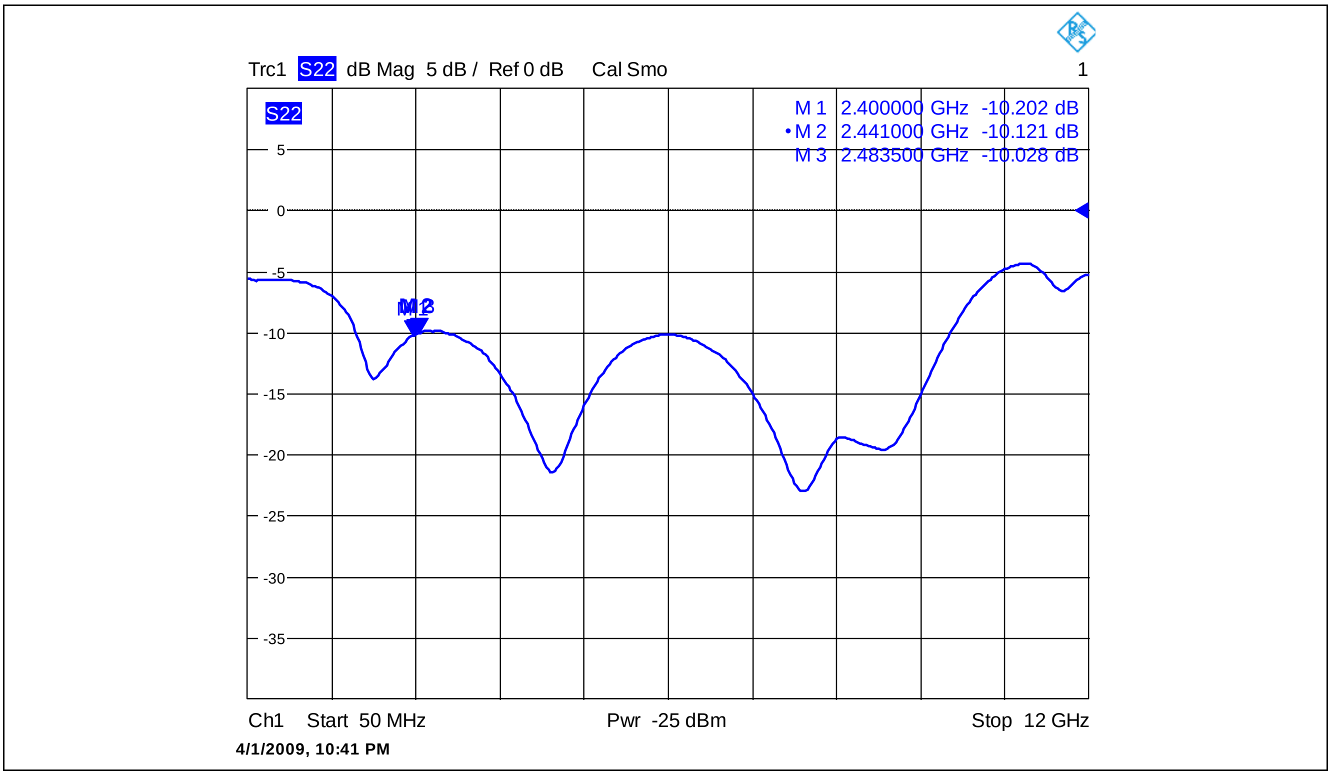


Figure 10 Output return loss / dB

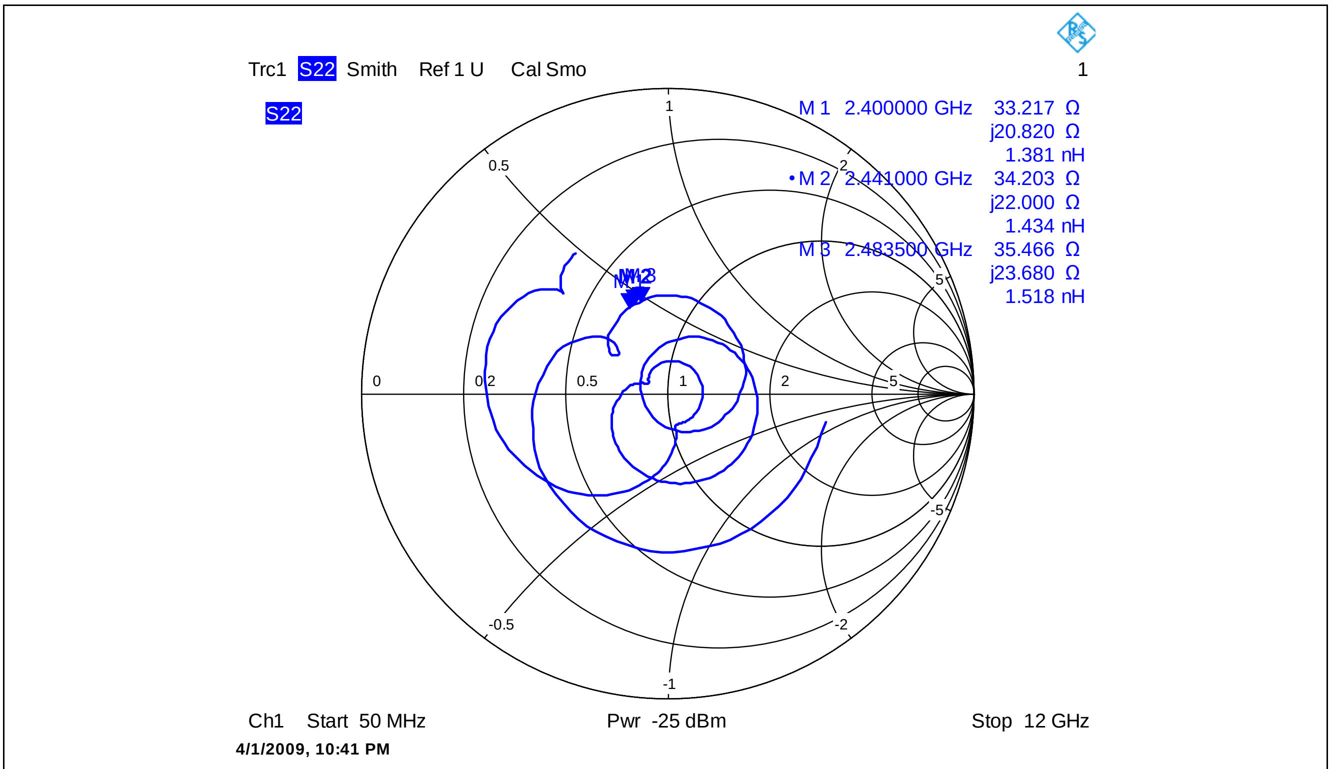


Figure 11 Output return loss (Smith chart)

3.4 Amplifier Third Order Intercept (TOI) Measurement

In-band third order intercept point (IIP_3) test:

Input Stimulus: f_2 = 2440 MHz, f_2 = 2442 MHz, -28 dBm each tone.

Input IP_3 =-28 + (43.4/2) = **-6.3dBm**. **Output IP_3** = -6.3 dBm + 8.7 dB gain = **+2.4 dBm**

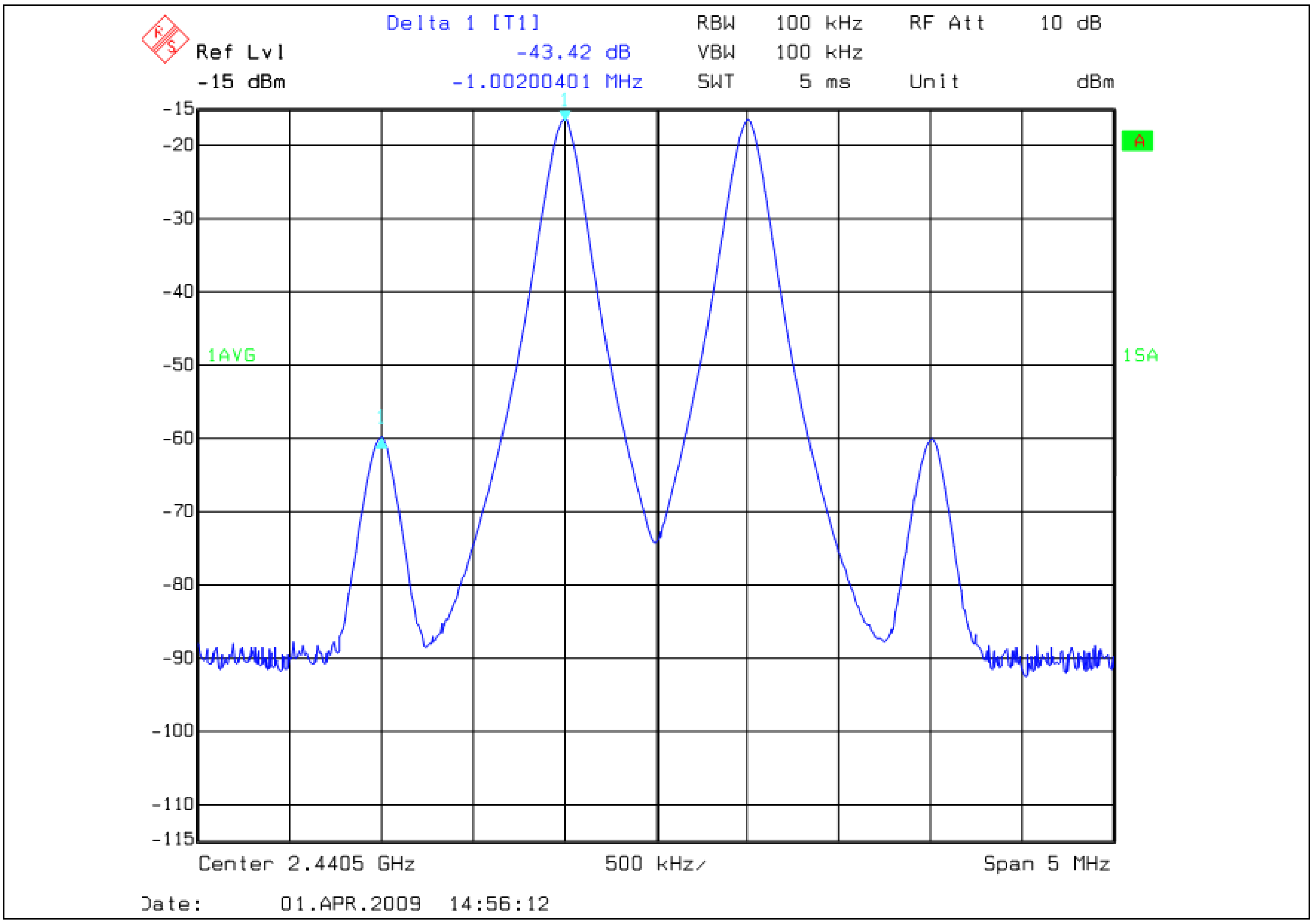
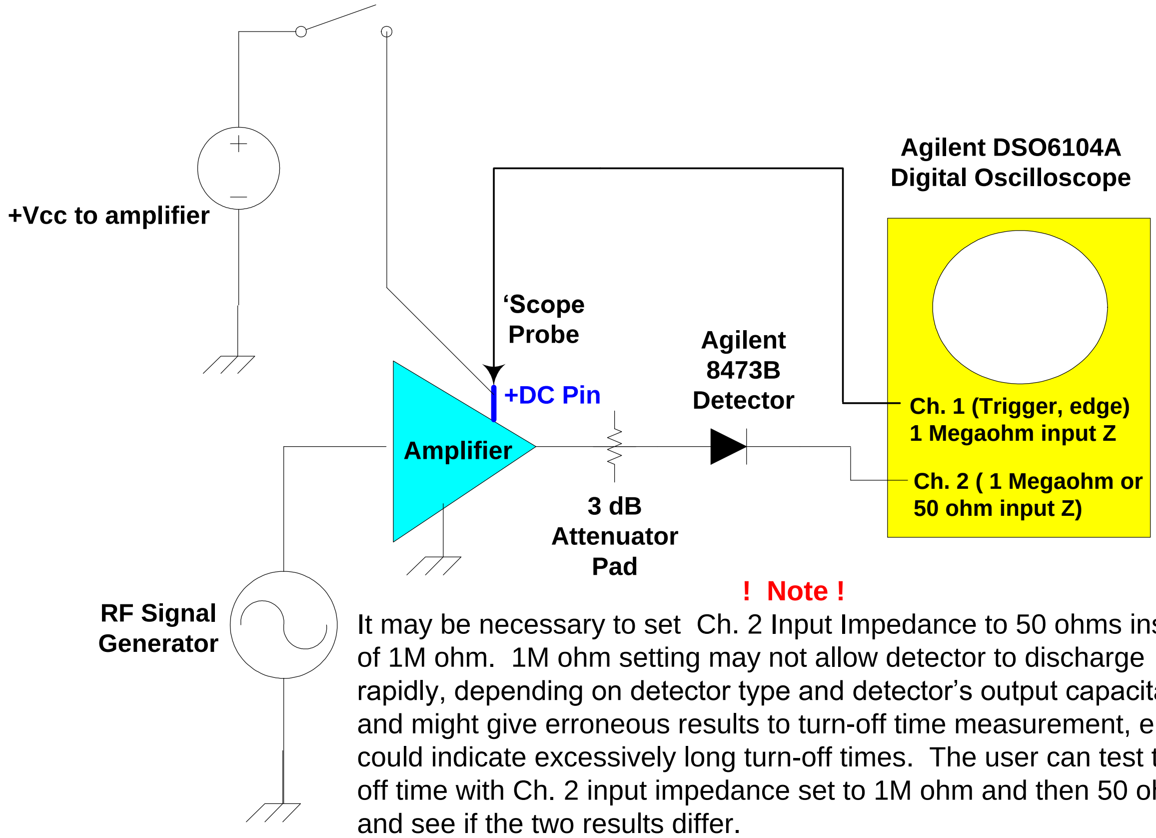


Figure 12 Output spectrum of LNA during test

3.5 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.



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.

Figure 13 Turn-on / turn-off time: Test setup

3.5.1 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 250 nanoseconds, or ~ 0.25 microseconds. Main source of time delay in the LNA turn-on event 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). Note that the input impedance of the oscilloscope for Channel 2, which senses the rectified RF output power of the amplifier, is set to 1 MΩ for this picture.

Note: Both 50 Ω and 1 MΩ input impedances were tested for turn-on time and there was no appreciable difference in results for turn-on time measurement.

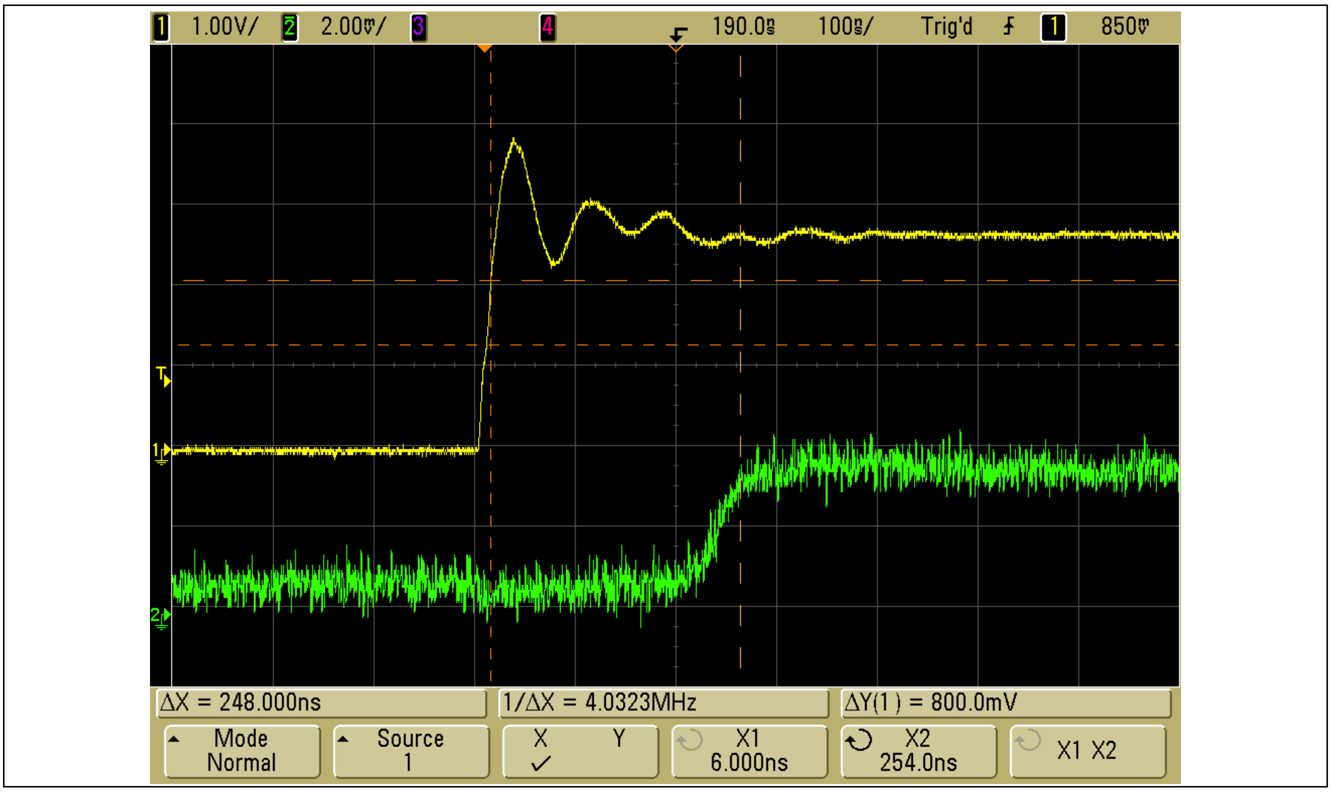


Figure 14 Screen shot: Turn on time

3.5.2 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 ~ 66 nanoseconds, or 0.066 microseconds, to settle out after power supply is disconnected.

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

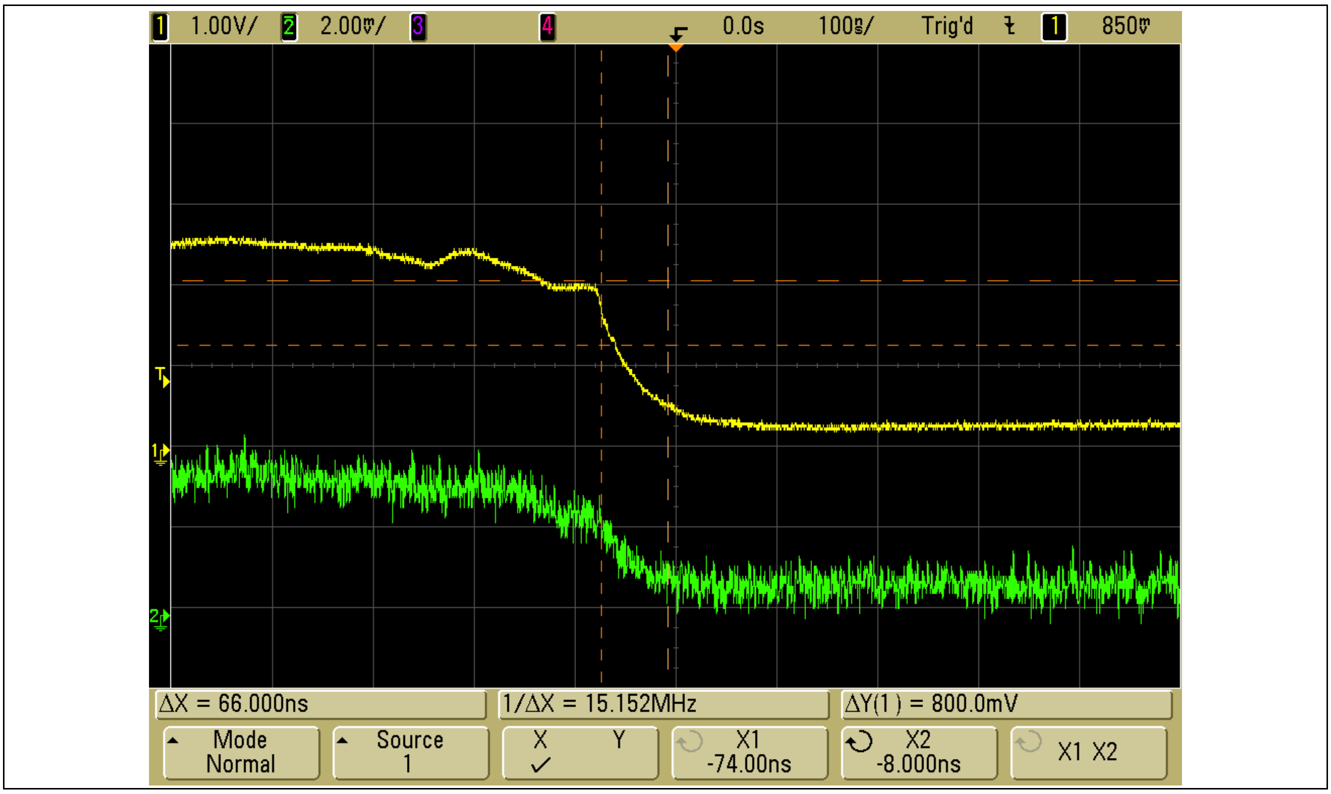


Figure 15 Screen shot: Turn on time

4 Evaluation Board

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

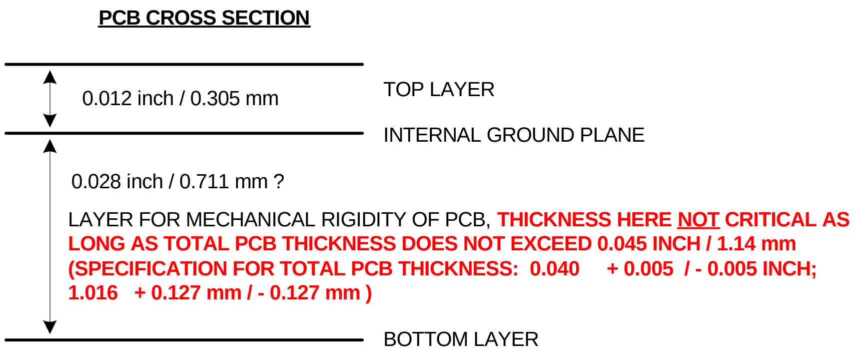


Figure 16 PCB cross section

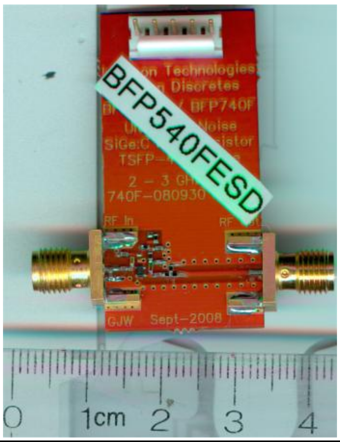


Figure 17 View of entire PC board

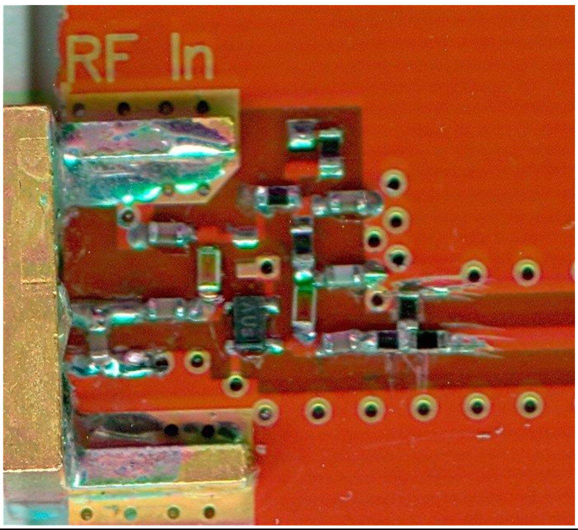


Figure 18 Close-in view of LNA section

5 References

[1] BFP540FESD Datasheet, Infineon Technologies AG

[2] "ESD-Hardened Device Fuels UHF Amplifiers". Microwaves & RF Magazine, July 2004. This article discusses one technique for improving ESD robustness in silicon bipolar RF transistors. The article describes the Infineon BFP460 device, however the basic concepts presented also apply to the BFP540FESD, which, like the BFP460, also uses a "buffer layer" to achieve increased ESD-robustness.

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

Pages 2 – 4 discuss the use of Inductive Emitter Degeneration and additional charge storage (capacitance) to stabilize and linearize LNA's using Silicon Bipolar RF Transistors like the BFP620 or BFP540FESD used in this Applications Note (AN180). Unlike the LNA shown in this reference, the LNA used in this Applications Note (AN180) had to minimize use of charge storage in order to achieve fast ON / OFF times. This resulted in compromising some Third-Order Intercept (TOI) performance.

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