AN12015

LTE3401H, high gain LTE LNA with bypass switch, evaluation board

Rev. 1.1 — 4 December 2017

Application note

Document information

Info	Content
Keywords	LTE3401H, LTE, LNA
Abstract	This document explains the LTE3401H LTE LNA evaluation board
Ordering info	Type: Freq. Range: Board-nmbr: 12NC: LTE3401H-0 1452 < f < 1560 MHz not available LTE3401H-1 1710 < f < 1800 MHz OM17069 9340 714 83598 LTE3401H-2 1800 < f < 2200 MHz OM17070 9340 714 84598 LTE3401H-3 2300 < f < 2690 MHz OM17071 9340 714 85598
Contact information	For more information, please visit: http://www.nxp.com

Revision history

Rev	Date	Description
1.1	20171204	Paragraph 4.1 added (Supply current)
1	20171117	First publication

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1. Introduction

NXP Semiconductors LTE3401H is a single bypass Low Noise Amplifier (LNA) for LTE applications. It is the high gain version of the LTE3301H. The high gain variants are recommended in combination with certain transceivers with reduced gain to enhance the overall receiver sensitivity.

1.1 The LTE LNA Evaluation Board (EVB)

The EVB is designed to evaluate the performance of the LNA in its typical application, using the LTE3401H, a matching inductor and a decoupling capacitor.

NXP Semiconductors LTE3401H is a low-noise amplifier with bypass switch for LTE receiver applications in an extremely small Quad Flat No-leads Package (QFN). The LTE3401H features gain of 19.5 dB and a noise figure of 0.65 dB at a current consumption of ~13 mA. The bypass switch insertion loss is 2.7 dB. Its superior linearity performance removes interference and noise from co-habitation cellular transmitters, while retaining sensitivity. The LNA components occupy a total area of approximately 4 mm^2.

In this document, the application diagram, board layout, bill of materials, and typical performance are given, as well as some explanations on LTE related RF-parameters like input third-order intercept point IIP3, gain compression and noise.

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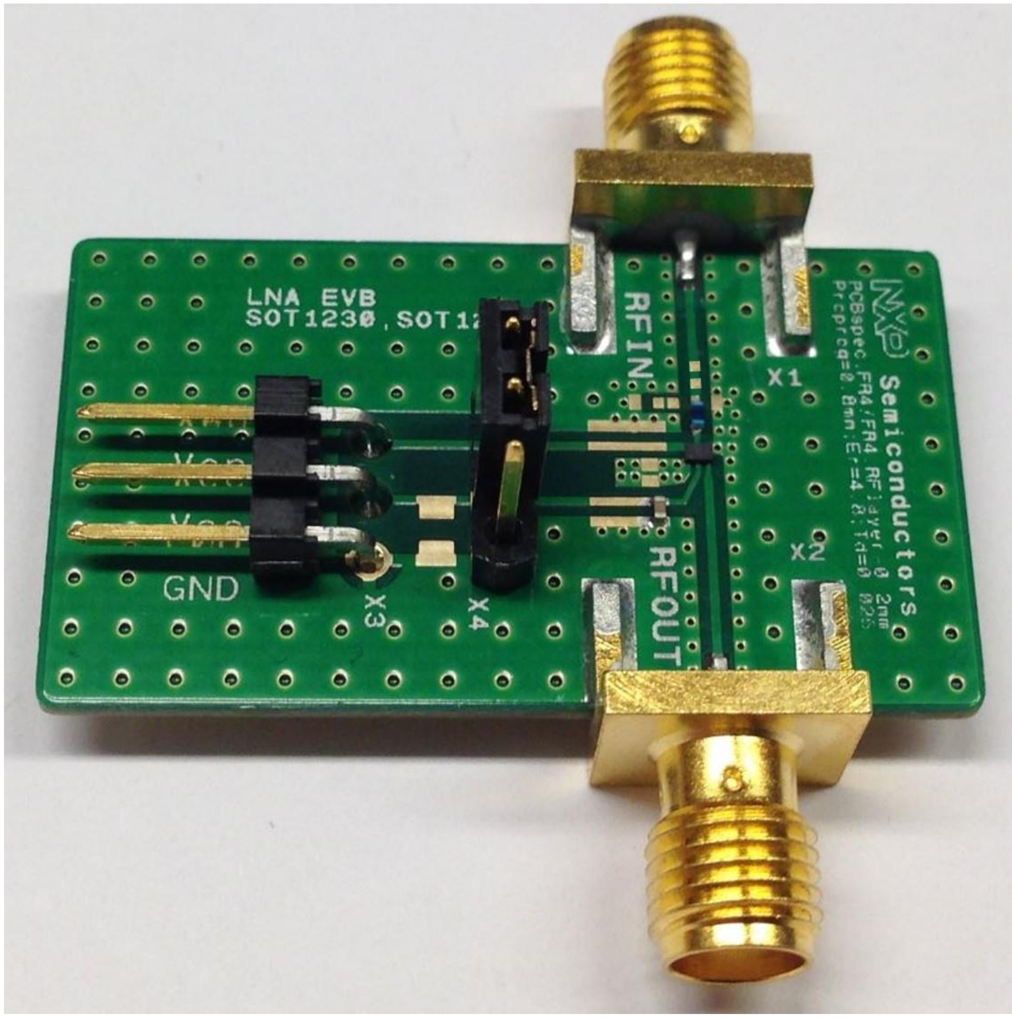

Fig 1. LTE3x01x LNA evaluation board (used for LTE3301x and LTE3401x)

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2. General description of application & product

Modern mobile applications have multiple radio systems serving different frequency bands and systems. In those applications co-habitation issues are quite common. Since the LTE diversity antenna needs to be placed far from the main antenna to ensure the efficiency of the channel, a low noise amplifier close to the antenna is used to compensate the transmission line losses (and SAW-filter losses when applicable). An LTE receiver implemented in a mobile application requires a low current consumption and low noise figure. In smart phones and tablets different transmit signals can be active simultaneously, demanding high linear devices in the RX chain(s) to avoid intermodulation products.

2.1 LTE3401H: Advantage of integrated By-pass function

The major advantage of having a bypass-switch option is the very low current consumption (< 1 µA) when LTE LNA is not needed in the receive chain (at high RSSI/CQI level, 3~5 dB higher than the Sensitivity level). Fig 2 gives a graphical explanation for this.

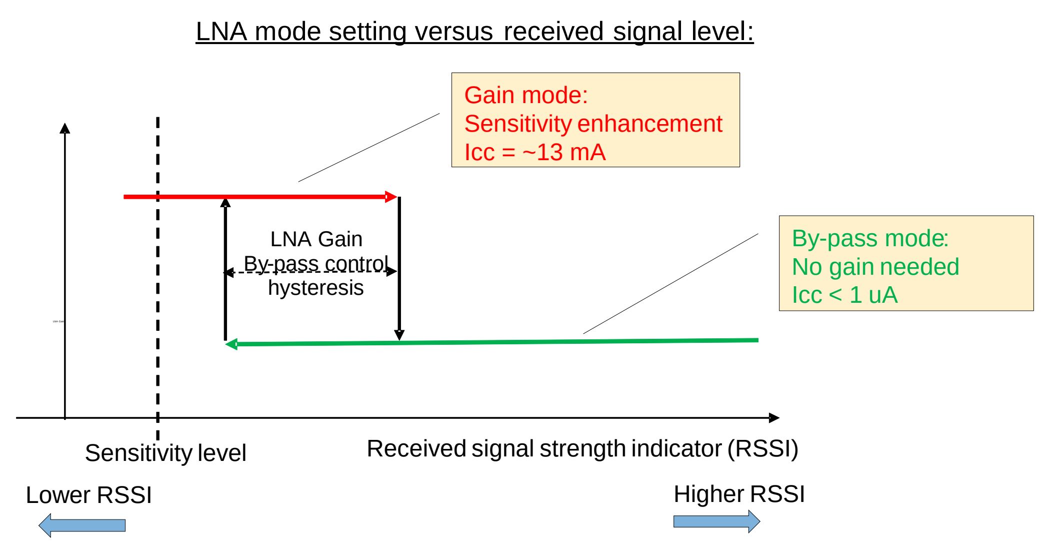

Fig 2. LNA mode setting versus received signal level

To avoid frequently switching between Gain- and bypass-mode around chosen Receiver Signal Strength Indicator (RSSI) switching level, one should take a hysteresis loop into consideration in the switching logic of the control chip (transceiver or baseband chip), see Fig 2.

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3. LTE3401H LTE LNA evaluation board

The LTE3401H LNA evaluation board simplifies the RF evaluation of the LTE3401H LTE LNA applied in an LTE front-end, often used in mobile cell phones. The evaluation board enables isolated testing of the device RF performance and requires no additional support circuitry. The board is fully assembled with the LTE3401H, the input series inductor and a Vcc decoupling capacitor. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The LTE3401H can operate from a 1.5 V to 3.1 V single supply and consumes typical ~13 mA.

3.1 Application Circuit

The circuit diagram of the evaluation board is shown in Fig 3. With jumper JU1 the control input can be connected either to Vcc (Gain-mode) or GND (Bypass mode).

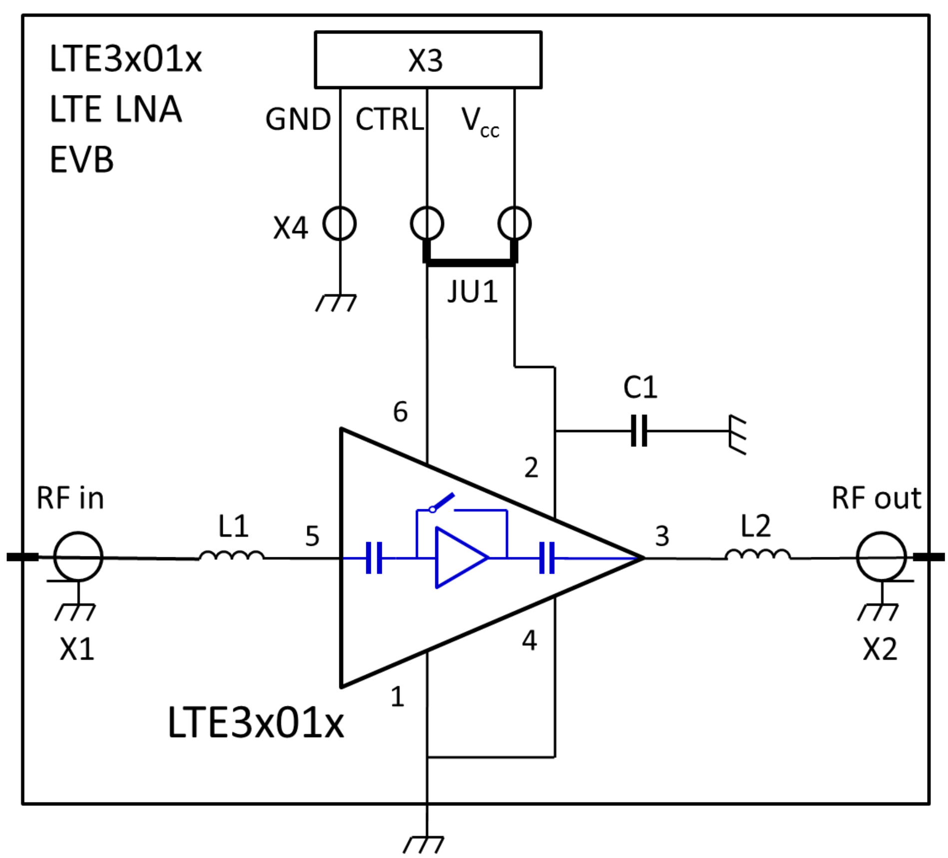

Fig 3. Circuit diagram of the LTE3x01x LNA evaluation board (used for LTE3301x and LTE3401x)

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3.2 PCB Layout

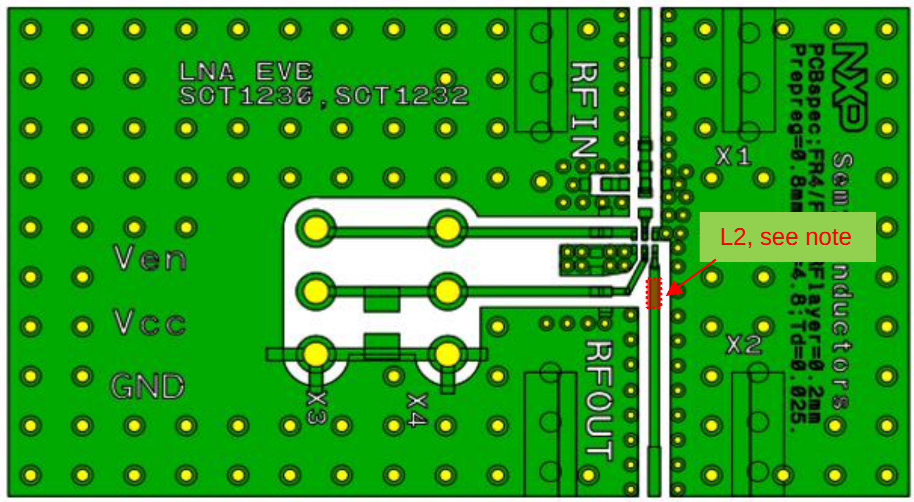

Fig 4. Printed-Circuit Board layout of the LTE3x01x LNA evaluation board (used for LTE3301x and LTE3401x).

Note: The position for L2 is not by default present in the layout and can be created by removing part of the solder resist en cupper of the output track in the top-layer.

A good PCB layout is an essential part of an RF circuit design. The LTE3401H LNA evaluation board can serve as a guideline for laying out a board using the LTE3401H.

- Use controlled impedance lines for all high frequency inputs and outputs.
- Bypass Vcc with decoupling capacitors, preferably located as close as possible (less than 15 mm) to the device.
- Proper grounding of the GND pins is also essential for good RF performance.
- Either connect the GND pins directly to the ground plane or through vias, or do both, which is recommended.

The material that has been used for the evaluation board is FR4 using the stack shown in Fig 5.

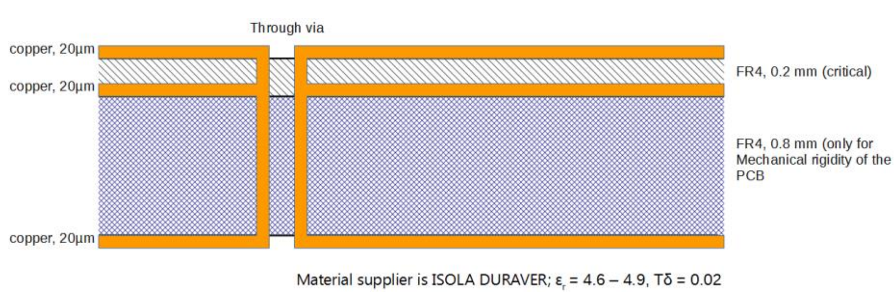

Fig 5. Stack of the PCB material

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3.3 Bill of materials

Table 1. BOM of the LTE3401H LTE LNA evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
-	LTE3401H	1.1 mm x 0.7 mm x 0.37 mm, 6 terminals, no leads, SOT1232		NXP	
PCB		20 x 35 mm		LTE3401H LTE LNA EV Kit	
C1	Capacitor	0402	1 µF	Murata GRM1555	Decoupling
L1	Inductor	0402	8.2 nH 5.6 nH 4.3 nH 2.2 nH	Murata LQW15 (wire wound) Murata LQW15 Murata LQW15 Murata LQW15	1452 - 1560 MHz 1710– 1800 MHz 1800 – 2200 MHz 2300 – 2690 MHz
L2	Inductor	0402	4.7 nH n.a. n.a. n.a.	Murata LQG15 (multilayer) n.a. n.a. n.a.	1452 - 1560 MHz 1710– 1800 MHz 1800 – 2200 MHz 2300 – 2690 MHz
X1, X2	SMA RD connector	-	-	Johnson, End launch SMA 142-0701-841	RF input/ RF output
X3	DC header	-	-	Molex, PCB header, Right Angle, 1 row, 3 way 90121-0763	Bias connector
X4	JUMPER Stage	-	-	Molex, PCB header, Vertical, 1 row, 3 way 90120-0763	Connect Ven to Vcc or separate Ven voltage
JU1	JUMPER				

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3.4 LTE3401H

NXP Semiconductors LTE3401H LTE low noise amplifier is designed for the LTE mid- and high-bands. The integrated biasing circuit is temperature stabilized, which keeps the bias current constant over temperature. It also enables the superior linearity performance of the LTE3401H. The LTE3401H is also equipped with an enable function that allows it to be controlled via a logic signal. In disabled mode it consumes less than 1 μA.

The output of the LTE3401H is internally matched to 50 ohms between 1710 MHz and 2690 MHz whereas only one series inductor at the input is needed to achieve the best RF performance. The LTE3401H can also be used between 1452 MHz and 1560 MHz if additional to the input series inductor also an output series inductor is used. The output is AC coupled via an integrated capacitor.

The LTE3401H requires only two (or 3 for lowest frequency range) external components to build a LTE bypass LNA having the following advantages:

- Low noise
- System optimized gain
- High linearity under jamming
- 1.1 mm x 0.7 mm x 0.37 mm, 6 terminals, no leads, SOT1232
- Low current consumption
- Short power settling time

3.5 Series inductor

The evaluation board is supplied with Murata LQW15 series input matching inductor (L1) which value is chosen for the desired frequency band. This is a wire wound type of inductor with high quality factor (Q) and low series resistance (Rs) like the Murata LQW15A series (see Table 2). This type of inductor is recommended in order to achieve the best noise performance. High Q inductors from other suppliers can be used. If it is decided to use other low cost inductors with lower Q and higher Rs the noise performance will degrade. For the output series coil (L2), a Murata LQG series can be used because this coil is less critical for the noise figure performance.

Table 2. Series Inductor options

Type	Murata	Size 0201	Size 0402	Size 0603	Comment
Multilayer Non-Magnetic Core	LQG		15H NF↑↑	18H NF↑	
Film	LQP	03T NF↑↑	15M NF↑		
Wirewound Non-Magnetic Core	LQW		15A **Default**	18A NF↓	Lowest NF

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4. Typical LNA evaluation board results LTE3401H-0 (1452– 1560 MHz)

4.1 Supply current

The typical relation between the supply current Icc with supply voltage Vcc and temperature Tamb is shown in Fig 6. For low input power levels (Pin ≤ -30dBm), this relation of supply current versus Vcc and temperature is independent on input matching coil values so valid for all matching versions described in this application note.

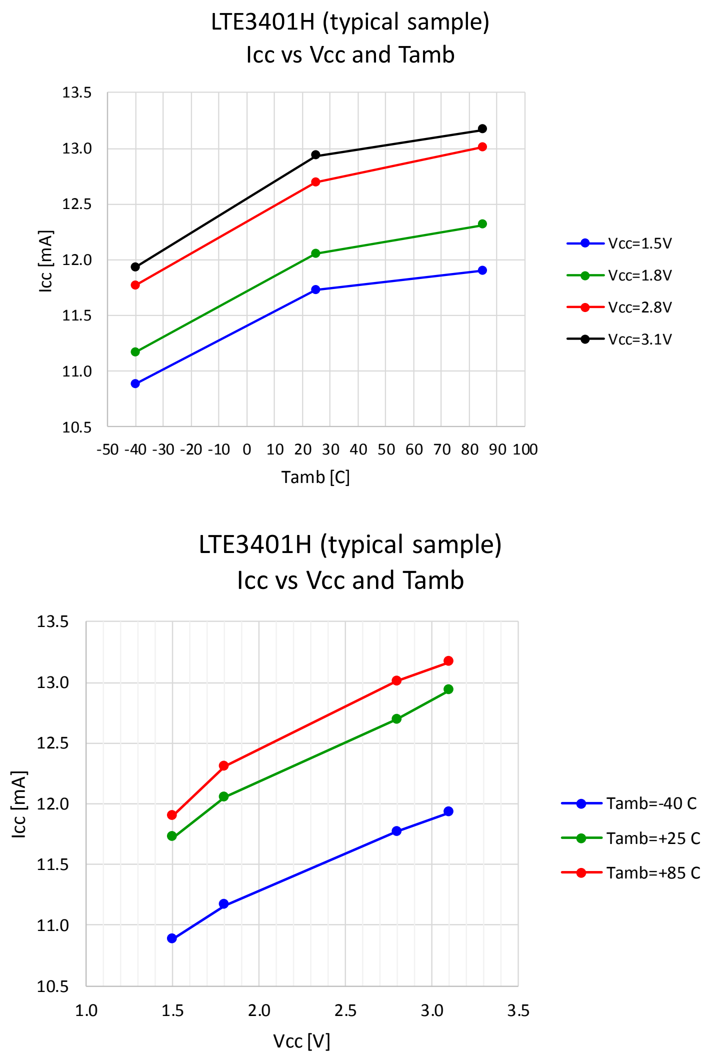

Fig 6. LTE3401H relation between the supply current Icc with Supply voltage Vcc and Temperature, Tamb), Pin=-30 dBm. Gain mode.

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4.2 S-Parameters

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

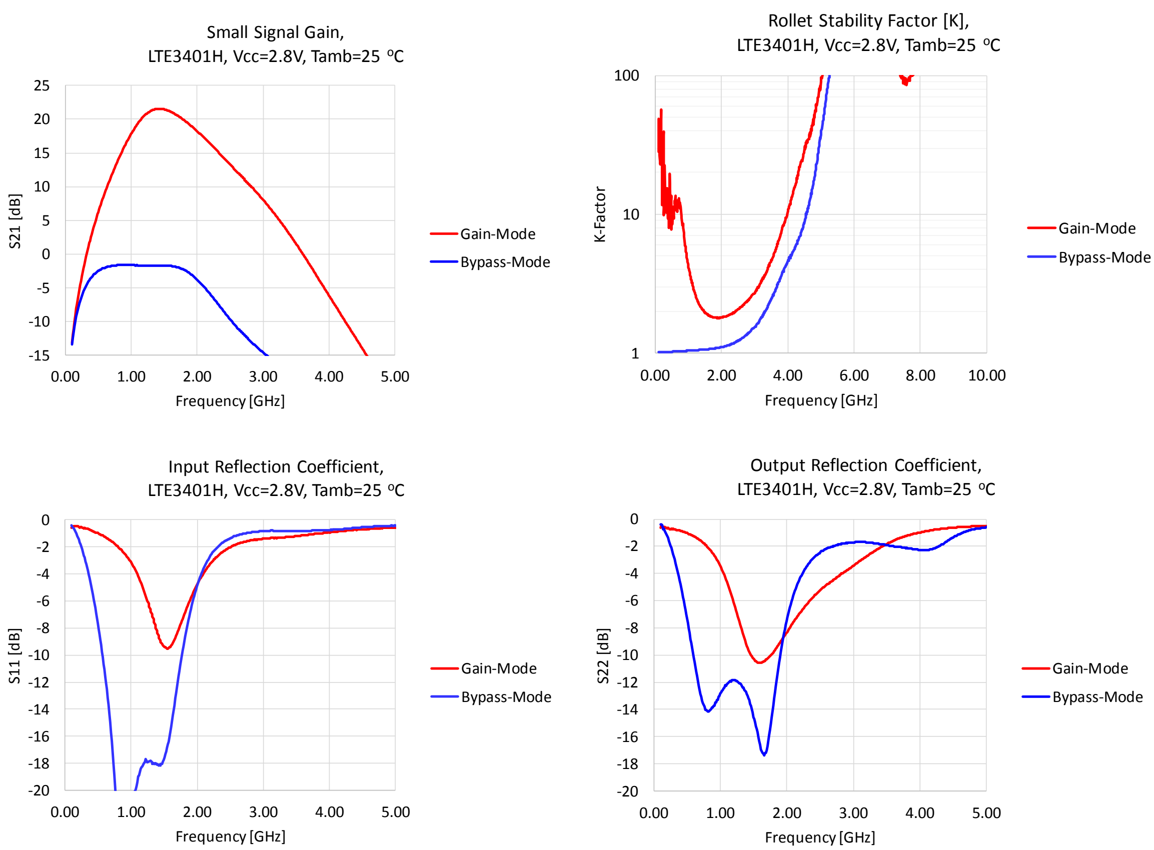

Fig 7. LTE3401H S-Parameters (typical values). L1=8.2 nH and L2 = 4.7 nH, Vcc=2.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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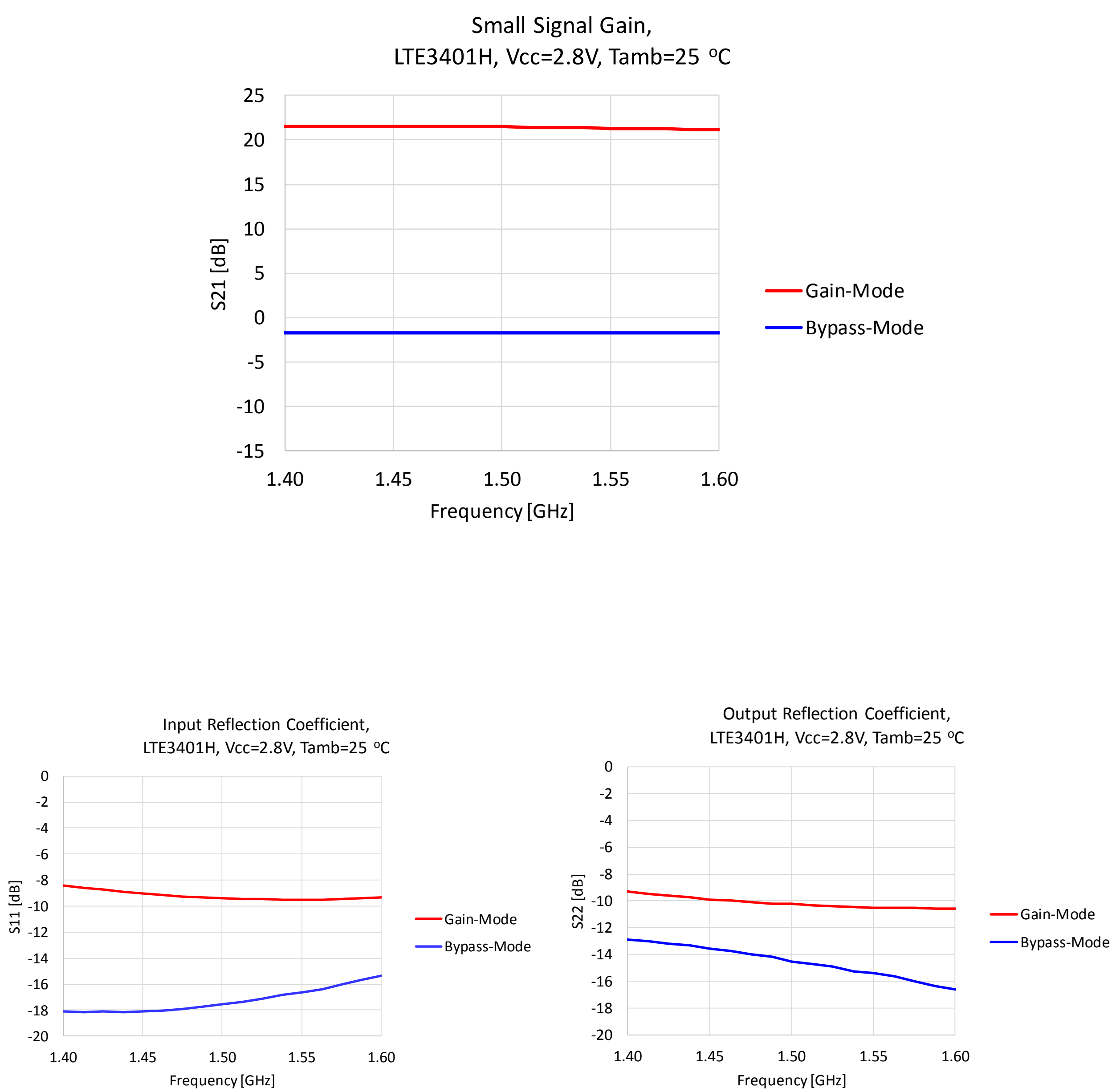

Fig 8. LTE3401H S-Parameters (typical values). L1=8.2 nH and L2 = 4.7 nH, Vcc=2.8 V, Pin=-30 dBm, Gain mode (frequency range zoomed in).

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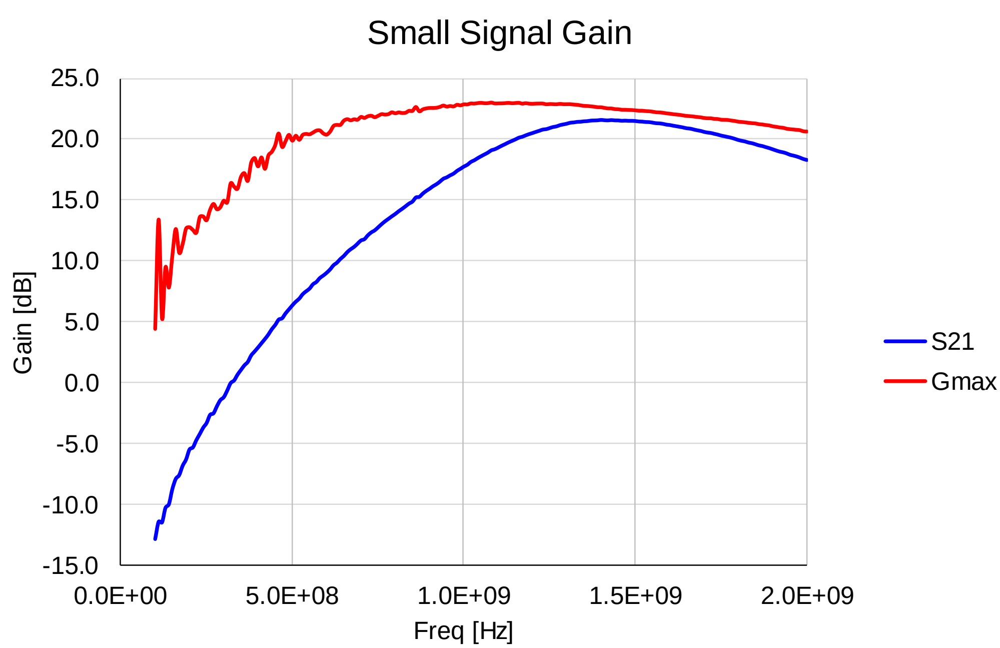
4.3 Improving the Gain by optimized matching

The design of the LTE3401H is optimized for best RF-performance using only one input series matching coil. In some cases, the Gain can be increased with a better in- and output matching circuit at the expense of using more components. Fig 9 gives the theoretical maximum gain (Gmax) using (ideal) optimized in- and output matching circuits, and S21 (typical measured performance) of an LTE3401H EVB.



freq [MHz]	Gmax(dB)	S21 (dB)	S11 (dB)	S22 (dB)	S12(dB)
1.30E+09	22.8	21.3	-6.5	-7.9	-37.1
1.40E+09	22.6	21.6	-8.4	-9.4	-35.4
1.50E+09	22.3	21.5	-9.4	-10.3	-34.3
1.60E+09	22.1	21.2	-9.2	-10.5	-33.5
1.70E+09	21.7	20.6	-8.2	-10.3	-33.1

Fig 9. S21 and Maximum achievable gain (Gmax) typ. values (L1=8.2 nH and L2 = 4.7 nH, Vcc=2.8V, Pin=-30 dBm, Gain mode)

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4.4 Noise Figure

The measured results for Noise Figure (NF) of the LTE3401H evaluation board can be seen in Fig 10 below. The measurements have been carried out using the setup as shown in Fig 36.

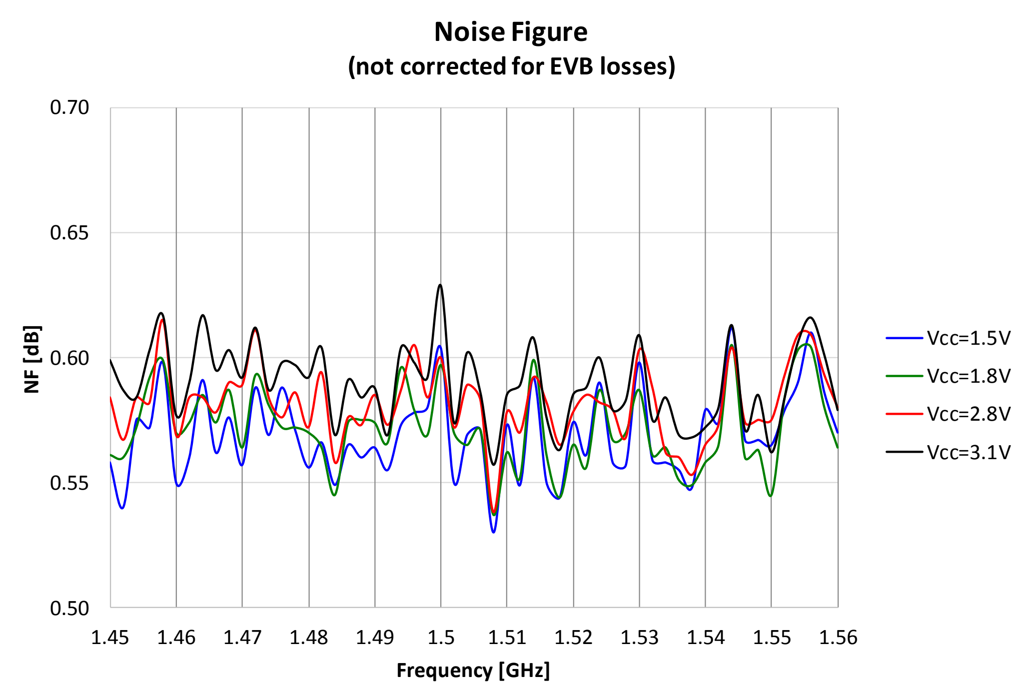

Fig 10. Typical Noise Figure (NF) in Gain mode, Temperature = 25 ºC.

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4.5 1dB gain compression

Strong in-band cell phone TX jammers can cause linearity problems and result in third-order intermodulation products in the LTE frequency band. In this chapter the effects of these strong signals is shown. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the LTE center frequencies. The figures below show the gain compression curves at LNA-board.

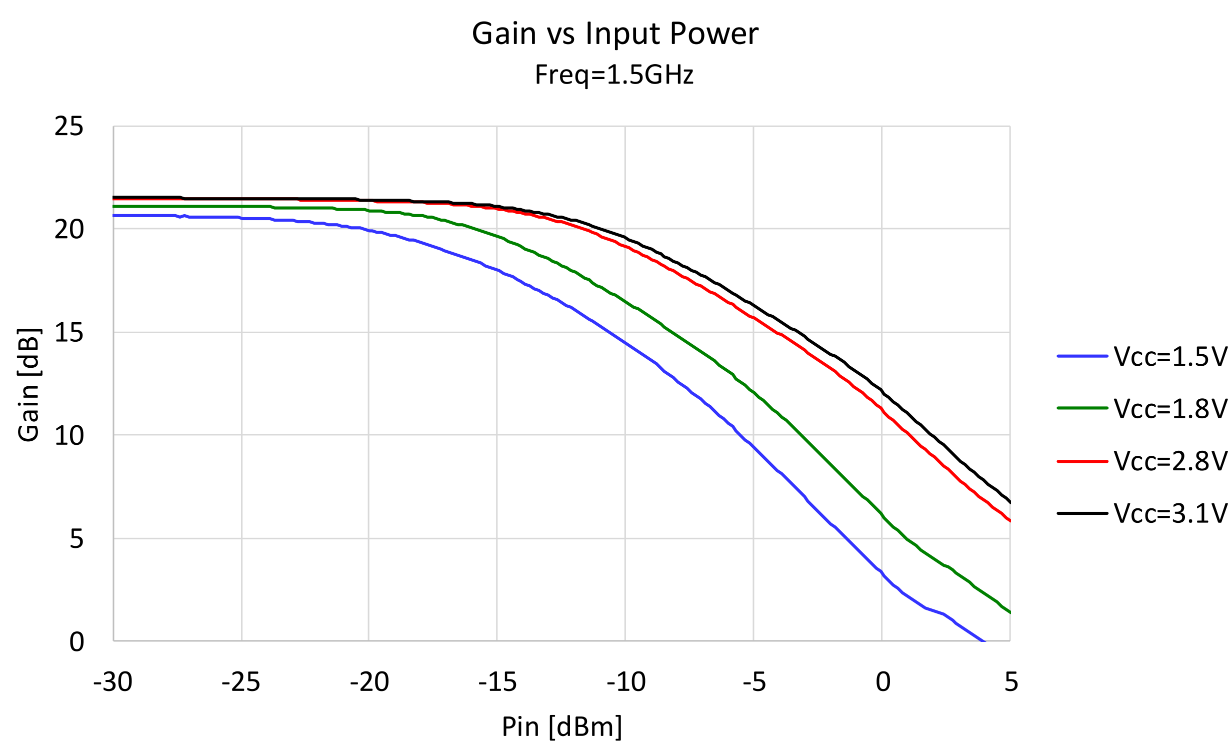

Fig 11. Gain versus input power, f=1.5 GHz, Temperature = 25 ºC.

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4.6 IIP3 2-Tone Test

The figure below show measured input-IP3-results of the DUT measured with a 2-Tone test at the 1500MHz. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

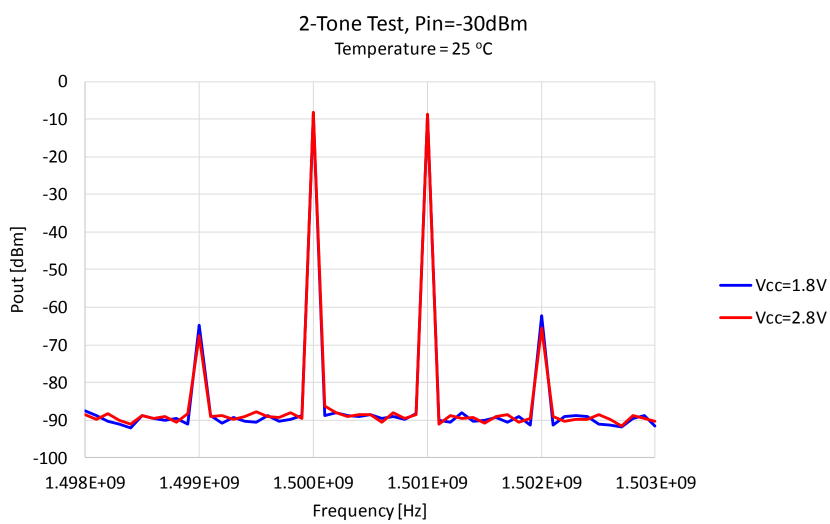

Fig 12. 2 Tone test: Pout=F(Vcc), Pin=-30 dBm

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5. Typical LNA evaluation board results LTE3401H-1 (1710 – 1800 MHz)

5.1 S-Parameters

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

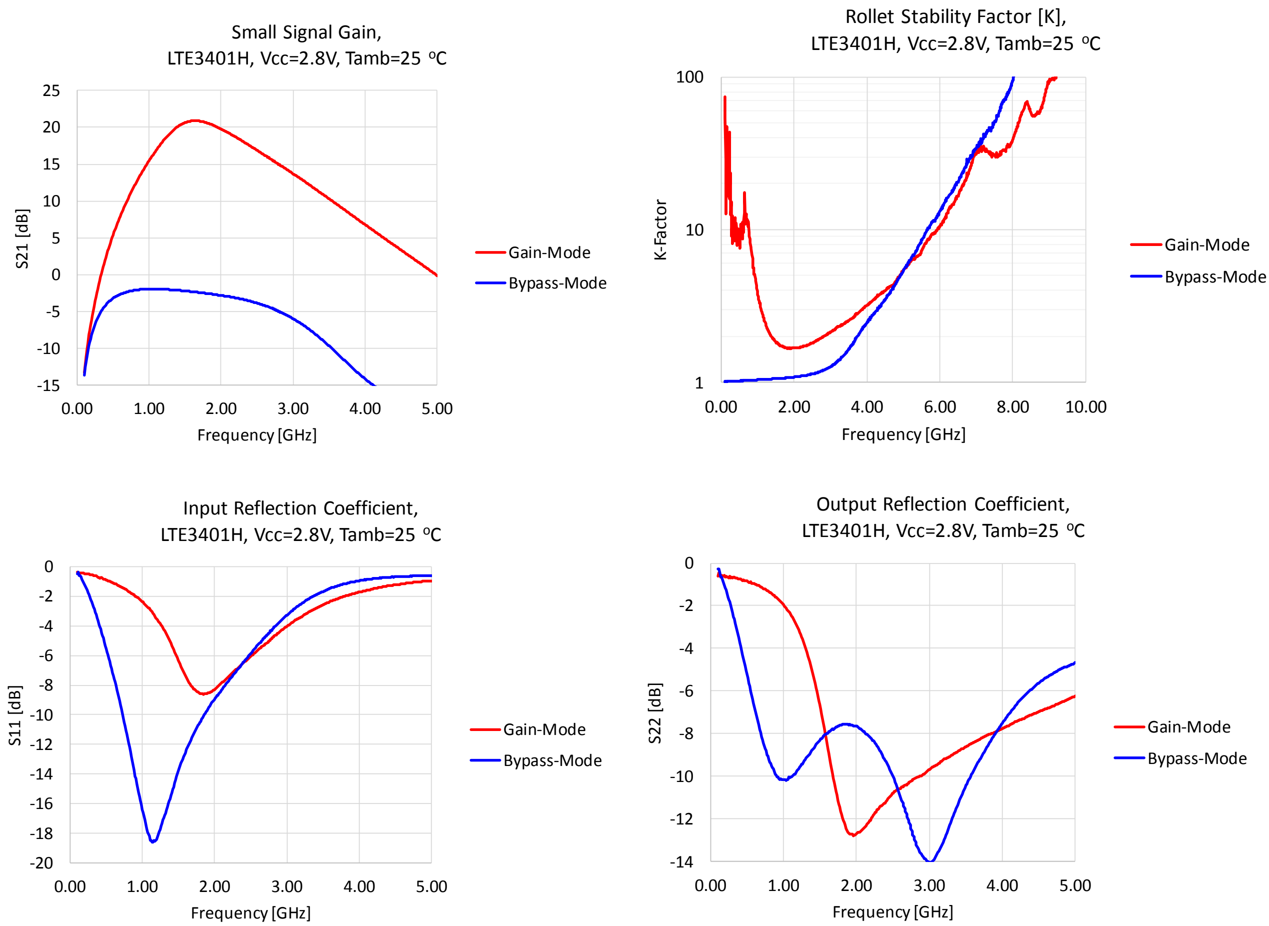

Fig 13. LTE3401H S-Parameters (typical values). L1=5.6 nH, Vcc=2.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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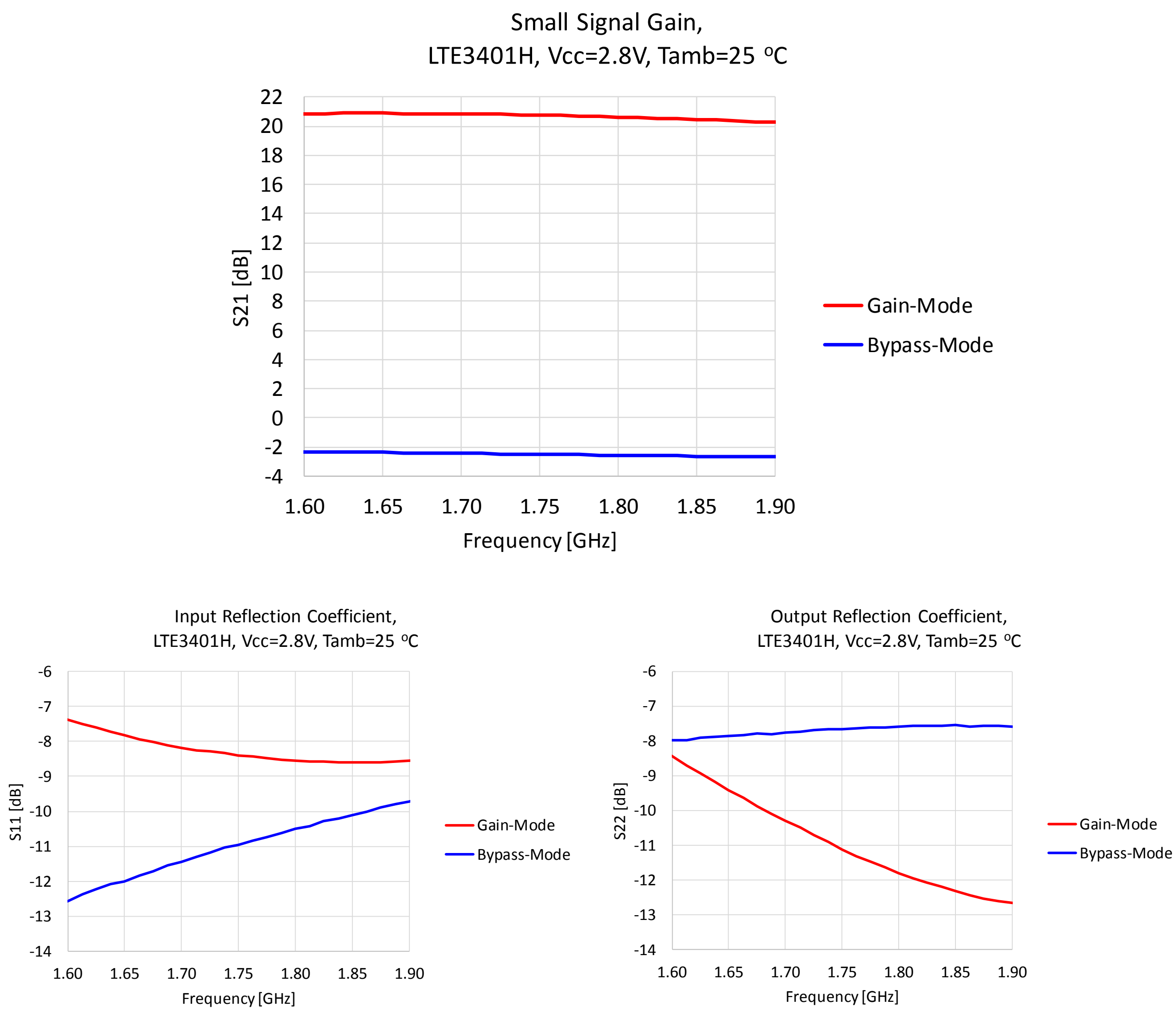

Fig 14. LTE3401H S-Parameters (typical values). L1=5.6 nH, Vcc=2.8 V, Pin=-30 dBm, Gain mode (frequency range zoomed in).

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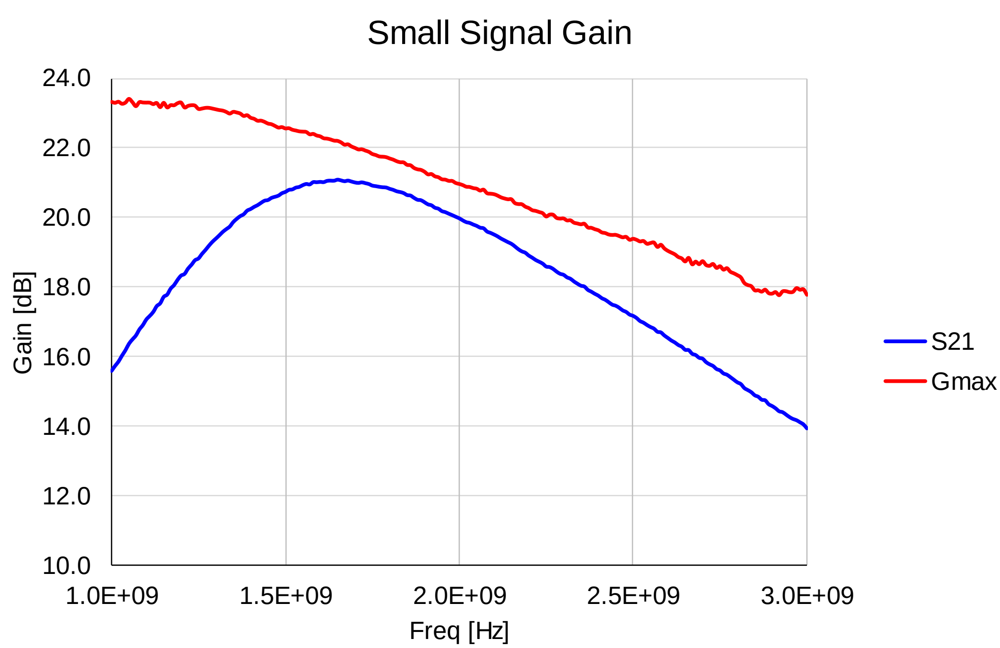
5.2 Improving the Gain by optimized matching

The design of the LTE3401H is optimized for best RF-performance using only one input series matching coil. In some cases, the Gain can be increased with a better in- and output matching circuit at the expense of using more components. Fig 15 gives the theoretical maximum gain (Gmax) using (ideal) optimized in- and output matching circuits, and S21 (typical measured performance) of an LTE3401H EVB.



freq [MHz]	Gmax(dB)	S21 (dB)	S11 (dB)	S22 (dB)	S12(dB)
1.60E+09	22.3	21.0	-7.0	-8.5	-33.2
1.70E+09	22.0	21.0	-7.8	-10.3	-32.3
1.80E+09	21.7	20.8	-8.2	-11.9	-31.6
1.90E+09	21.3	20.5	-8.2	-12.6	-31.2
2.00E+09	21.0	20.0	-7.9	-12.8	-31.0

Fig 15. S21 and Maximum achievable gain (Gmax) typ. values (L1=5.6 nH, Vcc=2.8V, Pin=-30 dBm, Gain mode)

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5.3 Noise Figure

The measured results for Noise Figure (NF) of the LTE3401H evaluation board can be seen in Fig 10 below. The measurements have been carried out using the setup as shown in Fig 36.

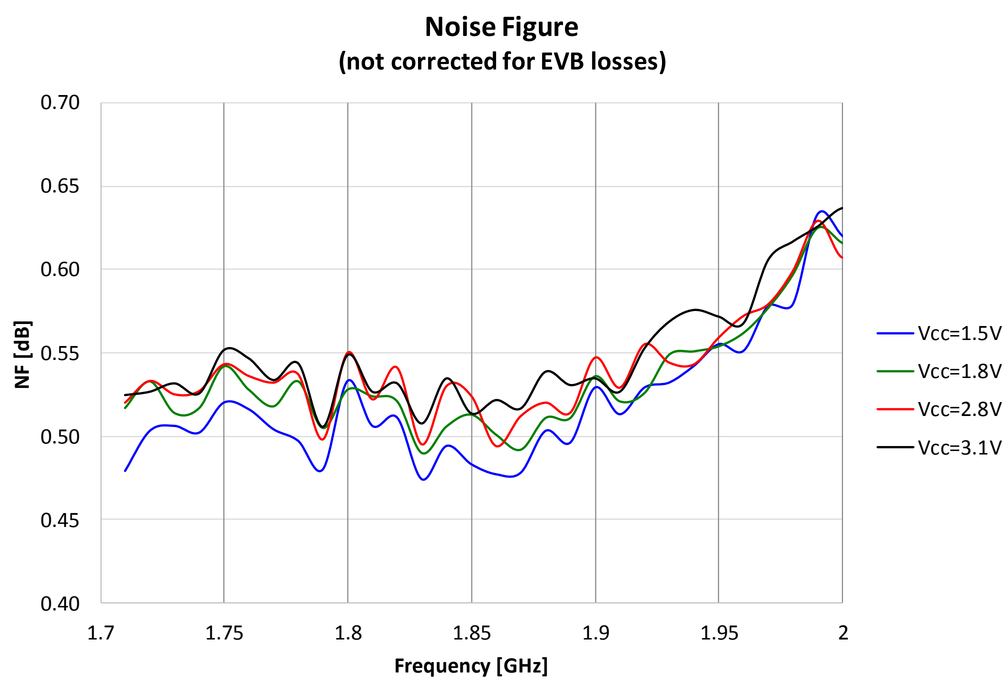

Fig 16. Typical Noise Figure (NF) in Gain mode, Temperature = 25 ºC.

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5.4 1dB gain compression

Strong in-band cell phone TX jammers can cause linearity problems and result in third-order intermodulation products in the LTE frequency band. In this chapter the effects of these strong signals is shown. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the LTE center frequencies. The figures below show the gain compression curves at LNA-board.

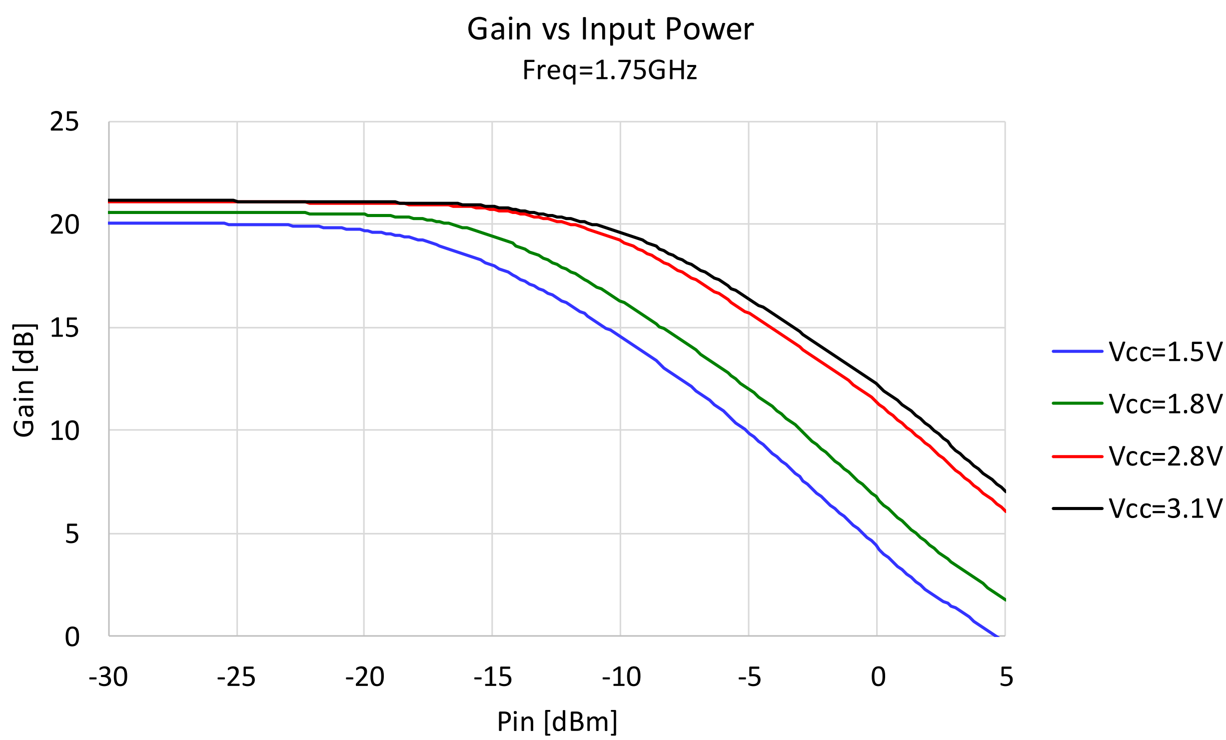

Fig 17. Gain versus input power, f=1.75 GHz, Temperature = 25 ºC.

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5.5 IIP3 2-Tone Test

The figure below show measured input-IP3-results of the DUT measured with a 2-Tone test at the 1500MHz. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

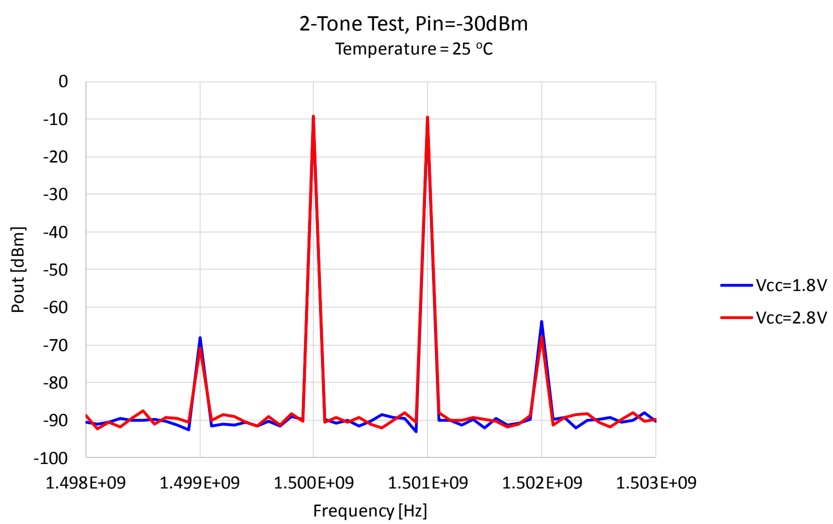

Fig 18. 2 Tone test: Pout=F(Vcc), Pin=-30 dBm

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6. Typical LNA evaluation board results LTE3401H-2 (1800 – 2200 MHz)

6.1 S-Parameters

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

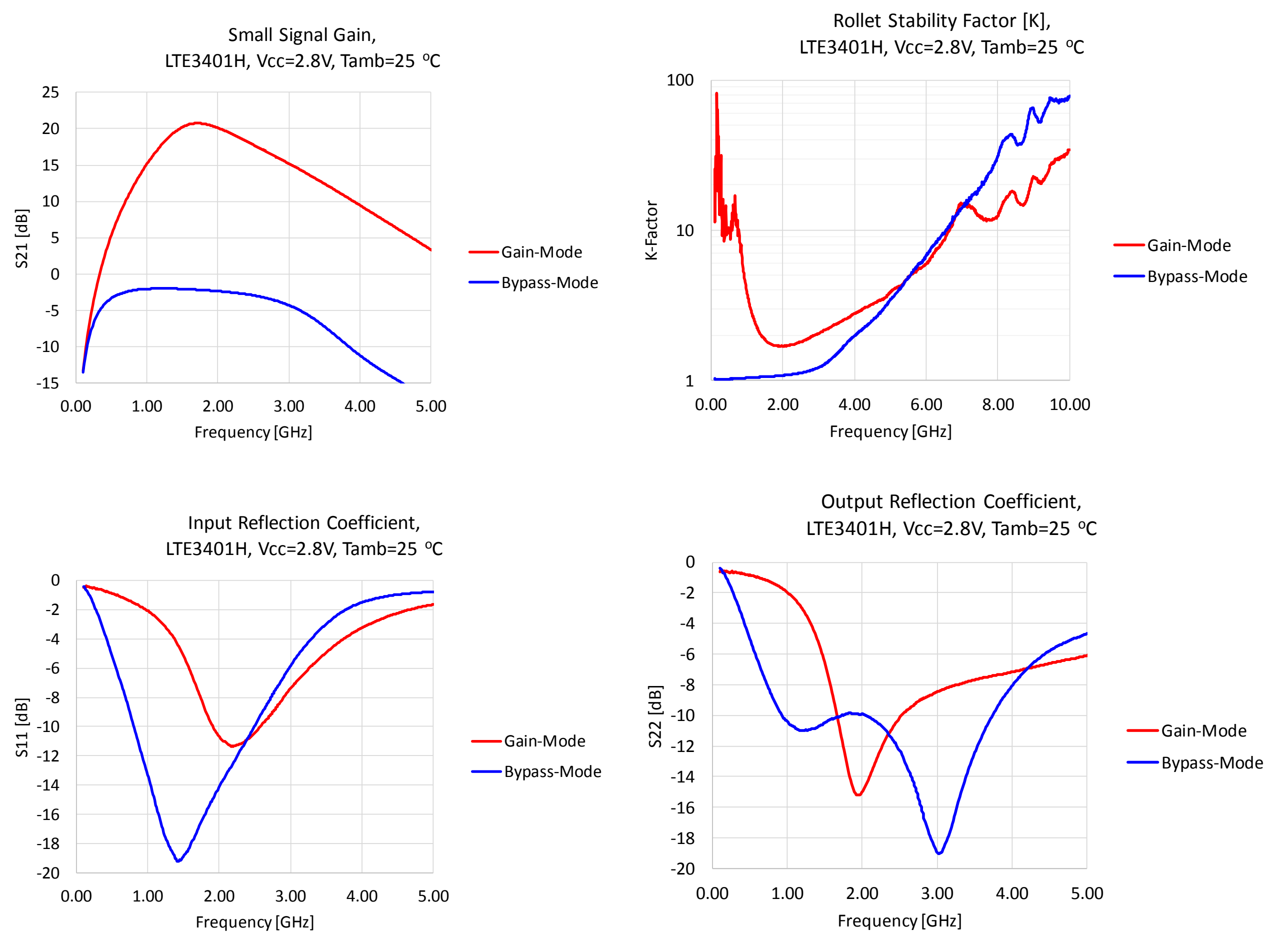

Fig 19. LTE3401H S-Parameters (typical values). L1=4.3 nH, Vcc=2.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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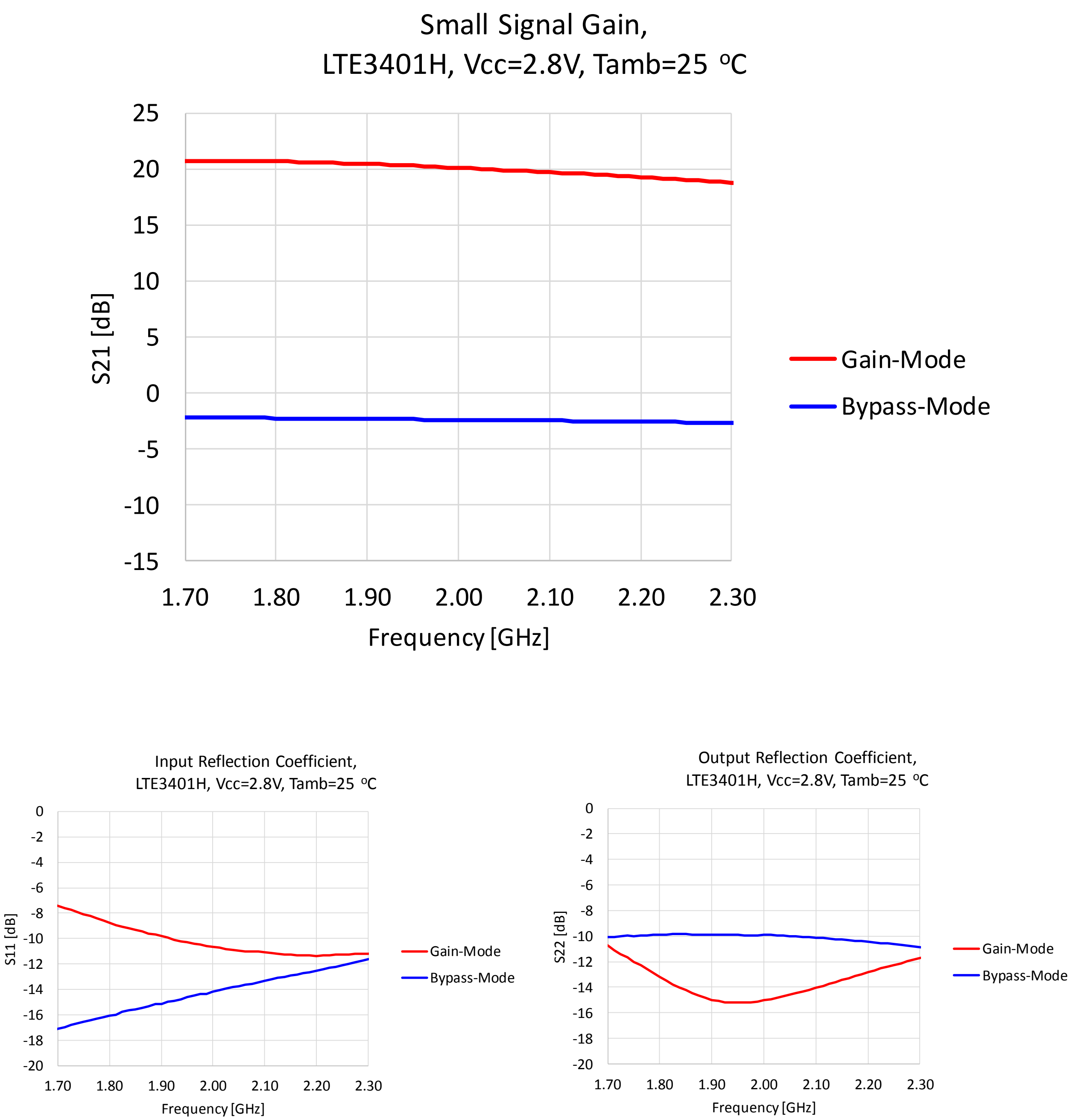

Fig 20. LTE3401H S-Parameters (typical values). L1=4.3 nH, Vcc=2.8 V, Pin=-30 dBm, Gain mode (frequency range zoomed in).

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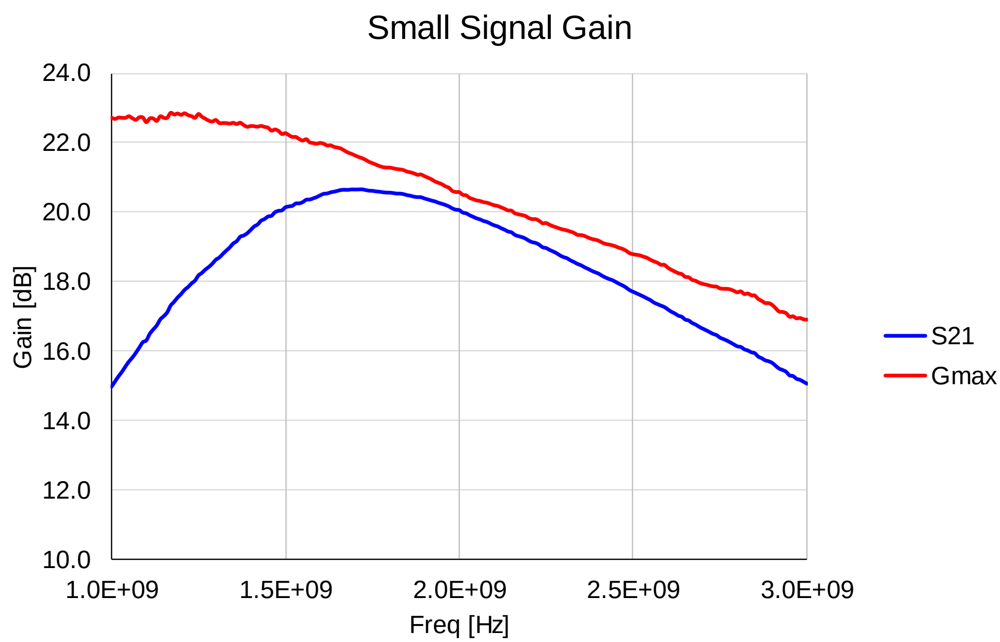
6.2 Improving the Gain by optimized matching

The design of the LTE3401H is optimized for best RF-performance using only one input series matching coil. In some cases, the Gain can be increased with a better in- and output matching circuit at the expense of using more components. Fig 21 gives the theoretical maximum gain (Gmax) using (ideal) optimized in- and output matching circuits, and S21 (typical measured performance) of an LTE3401H EVB.



freq [MHz]	Gmax(dB)	S21 (dB)	S11 (dB)	S22 (dB)	S12(dB)
1.60E+09	22.0	20.5	-6.3	-8.5	-34.0
1.80E+09	21.3	20.6	-9.0	-13.2	-32.1
2.00E+09	20.6	20.1	-11.5	-15.1	-31.1
2.20E+09	19.8	19.2	-11.8	-12.9	-30.7
2.40E+09	19.2	18.2	-10.9	-10.8	-30.5

Fig 21. S21 and Maximum achievable gain (Gmax) typ. values (L1=4.3 nH, Vcc=2.8V, Pin=-30 dBm, Gain mode)

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6.3 Noise Figure

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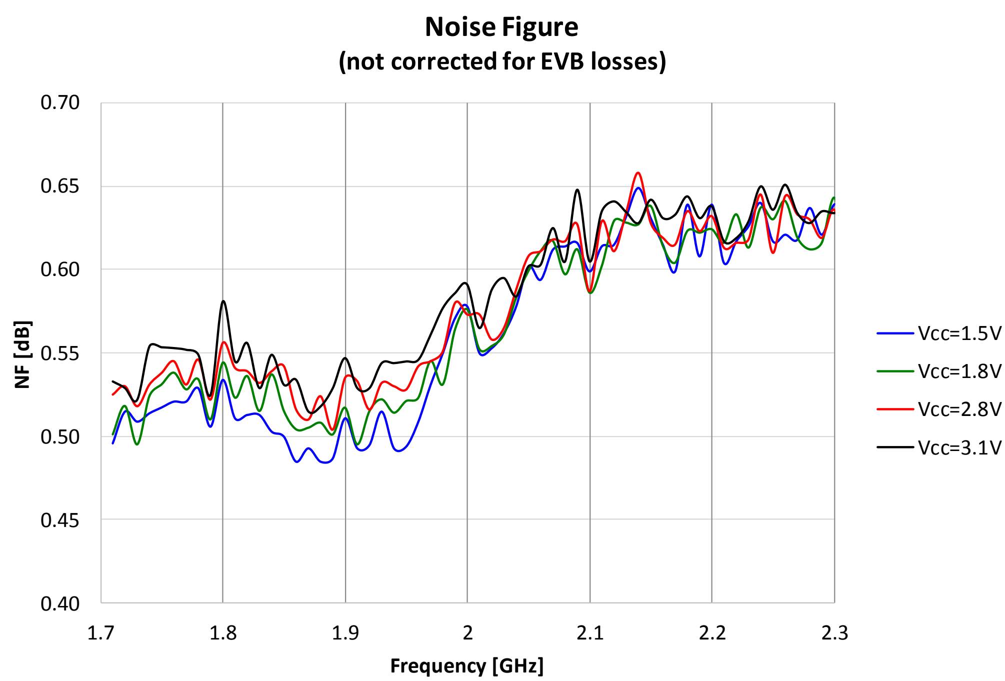

Fig 22. Typical Noise Figure (NF) in Gain mode, Temperature = 25 ºC.

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6.4 1dB gain compression

Strong in-band cell phone TX jammers can cause linearity problems and result in third-order intermodulation products in the LTE frequency band. In this chapter the effects of these strong signals is shown. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the LTE center frequencies. The figures below show the gain compression curves at LNA-board.

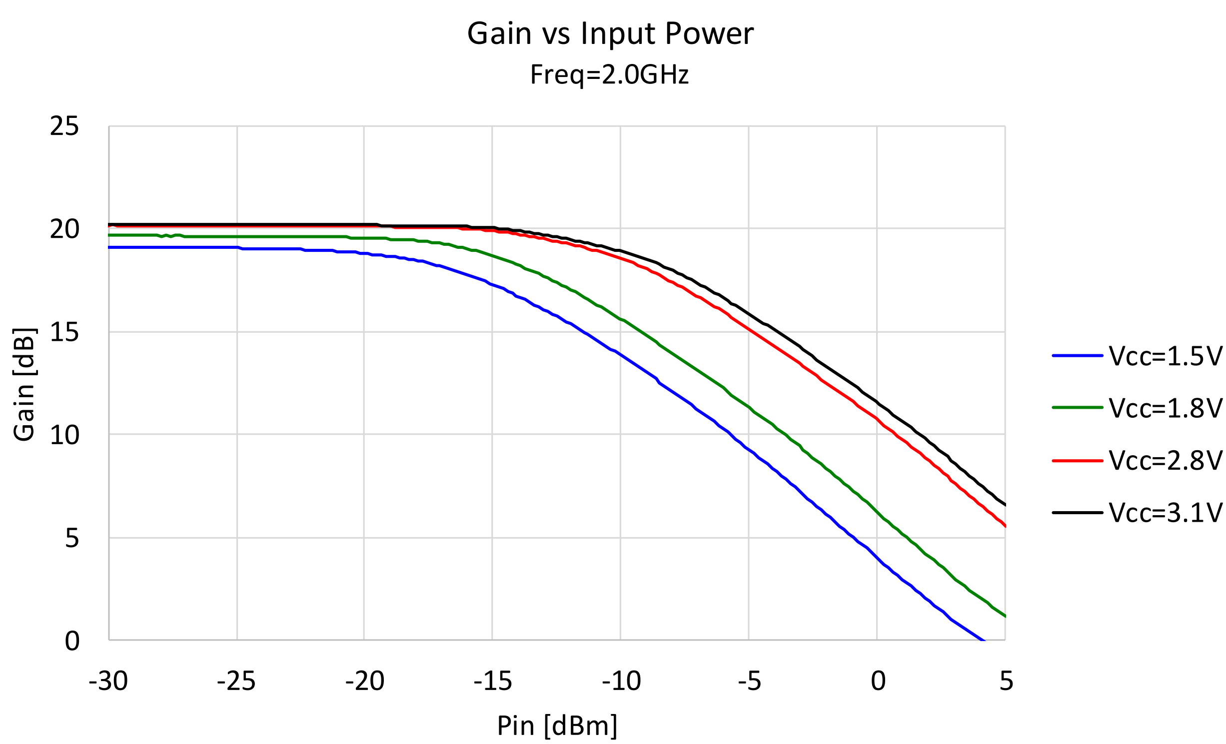

Fig 23. Gain versus input power, f=2.0 GHz, Temperature = 25 ºC.

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6.5 IIP3 2-Tone Test

The figure below show measured input-IP3-results of the DUT measured with a 2-Tone test at the 1960MHz. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

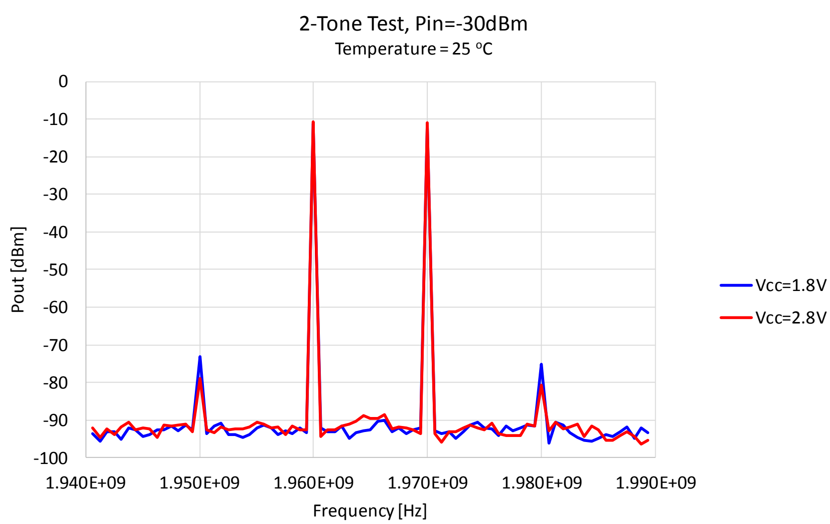

Fig 24. 2 Tone test: Pout=F(Vcc), Pin=-30 dBm

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7. Typical LNA evaluation board results LTE3401H-3 (2300 – 2690 MHz)

7.1 S-Parameters

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35.

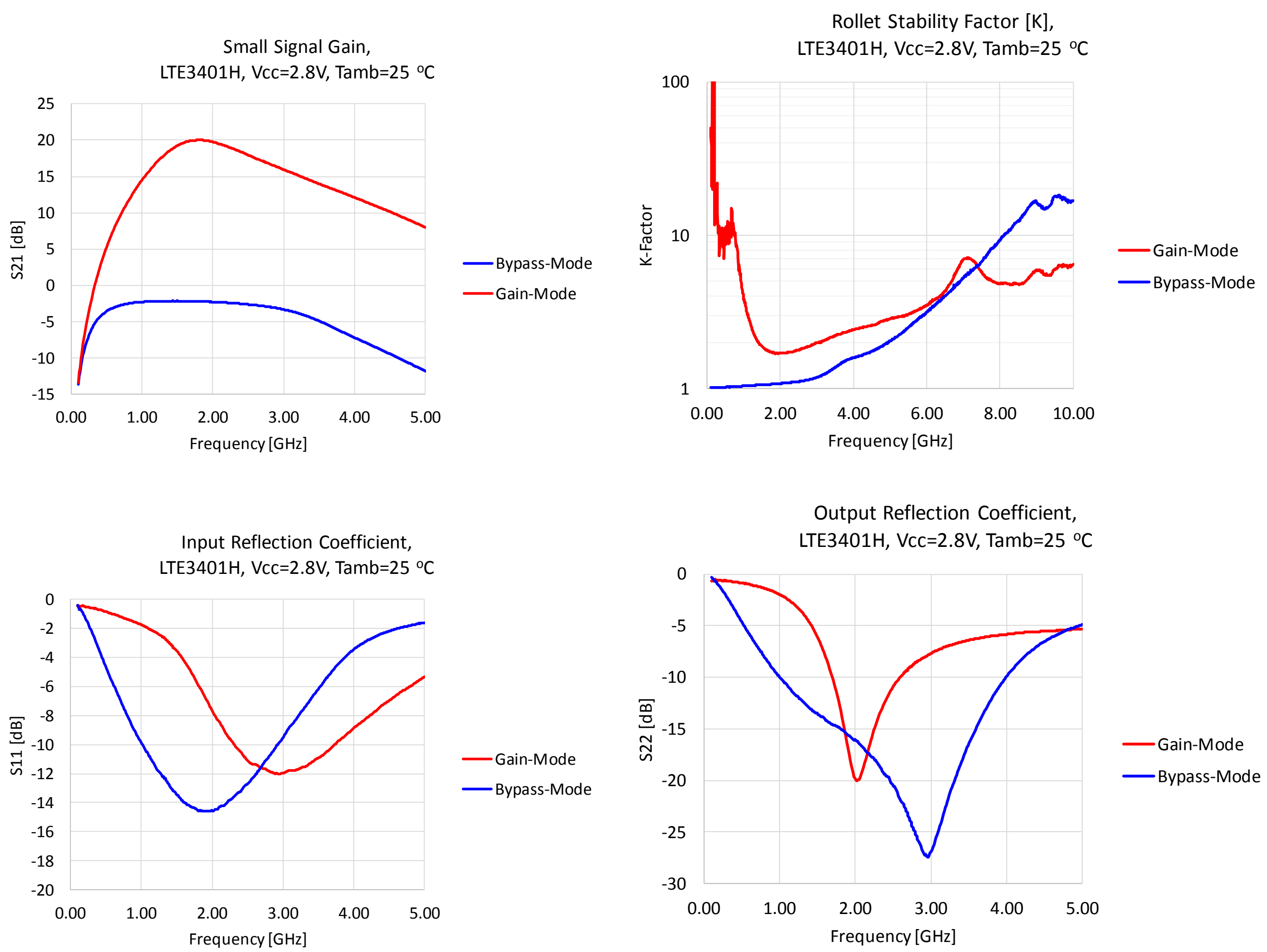

Fig 25. LTE3401H S-Parameters (typical values). L1=2.2 nH, Vcc=2.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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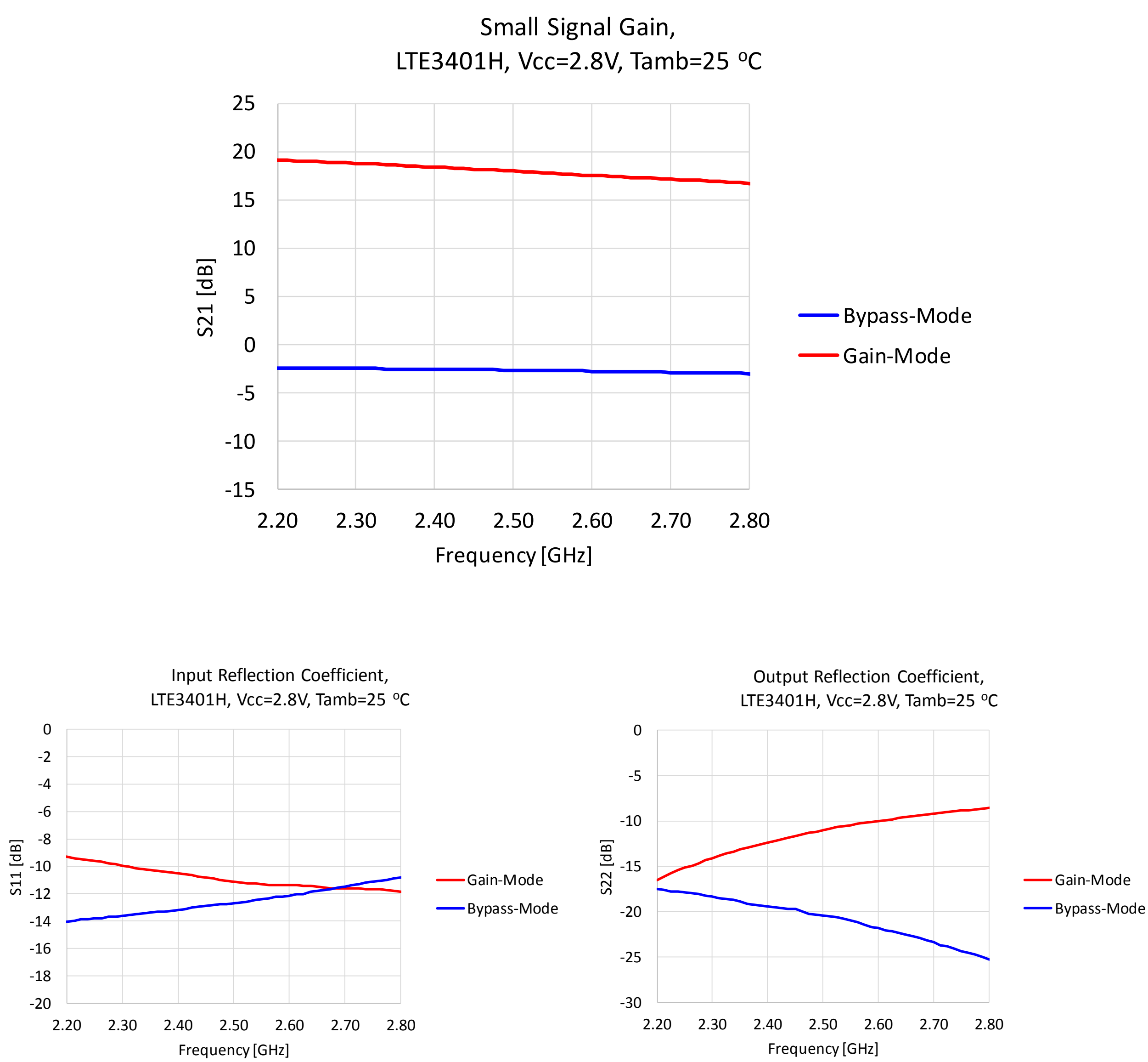

Fig 26. LTE3401H S-Parameters (typical values). L1=2.2 nH, Vcc=2.8 V, Pin=-30 dBm, Gain mode (frequency range zoomed in).

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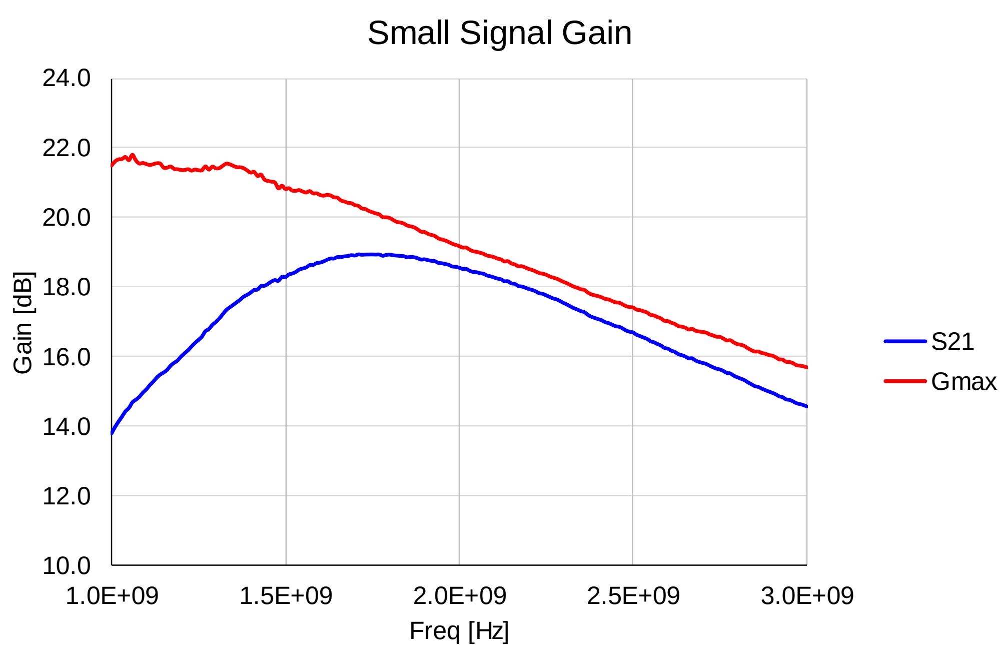
7.2 Improving the Gain by optimized matching

The design of the LTE3401H is optimized for best RF-performance using only one input series matching coil. In some cases, the Gain can be increased with a better in- and output matching circuit at the expense of using more components. Fig 27 gives the theoretical maximum gain (Gmax) using (ideal) optimized in- and output matching circuits, and S21 (typical measured performance) of an LTE3401H EVB.



freq [MHz]	Gmax(dB)	S21 (dB)	S11 (dB)	S22 (dB)	S12(dB)
2.00E+09	19.2	18.6	-9.4	-18.9	-32.3
2.20E+09	18.5	17.9	-10.9	-16.8	-31.7
2.40E+09	17.7	17.1	-12.1	-12.7	-31.3
2.60E+09	17.0	16.2	-13.2	-10.3	-31.3
2.80E+09	16.4	15.4	-13.9	-8.8	-31.2
3.00E+09	15.7	14.6	-14.1	-7.8	-31.2

Fig 27. S21 and Maximum achievable gain (Gmax) typ. values (L1=2.2 nH, Vcc=2.8V, Pin=-30 dBm, Gain mode)

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7.3 Noise Figure

The measured results for Noise Figure (NF) of the LTE3401H evaluation board can be seen in Fig 10 below. The measurements have been carried out using the setup as shown in Fig 36.

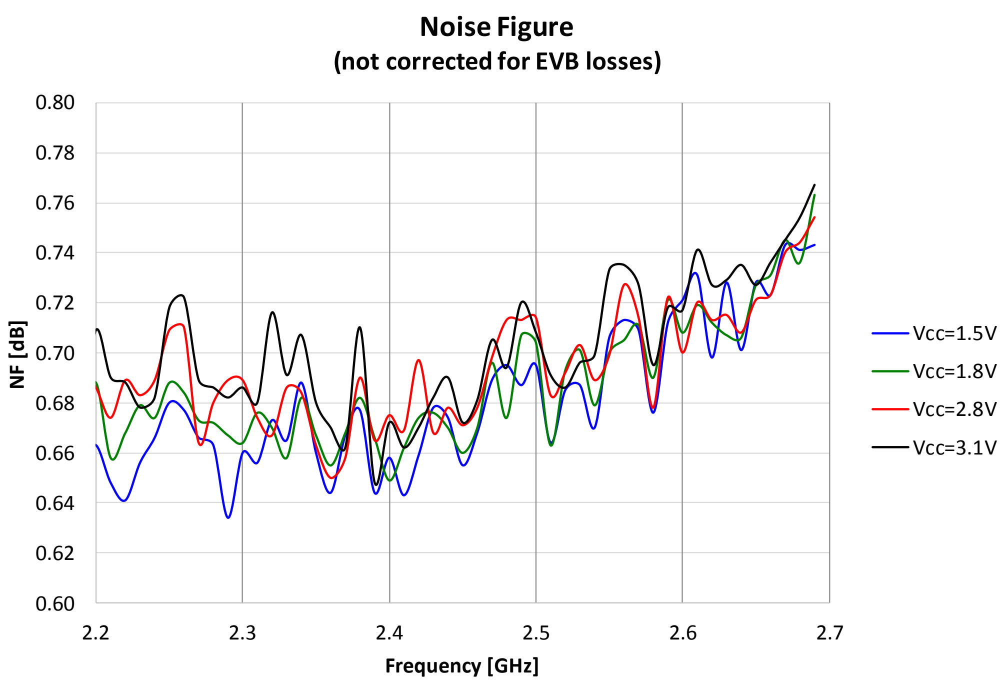

Fig 28. Typical Noise Figure (NF) in Gain mode, Temperature = 25 ºC.

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7.4 1dB gain compression

Strong in-band cell phone TX jammers can cause linearity problems and result in third-order intermodulation products in the LTE frequency band. In this chapter the effects of these strong signals is shown. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the LTE center frequencies. The figures below show the gain compression curves at LNA-board.

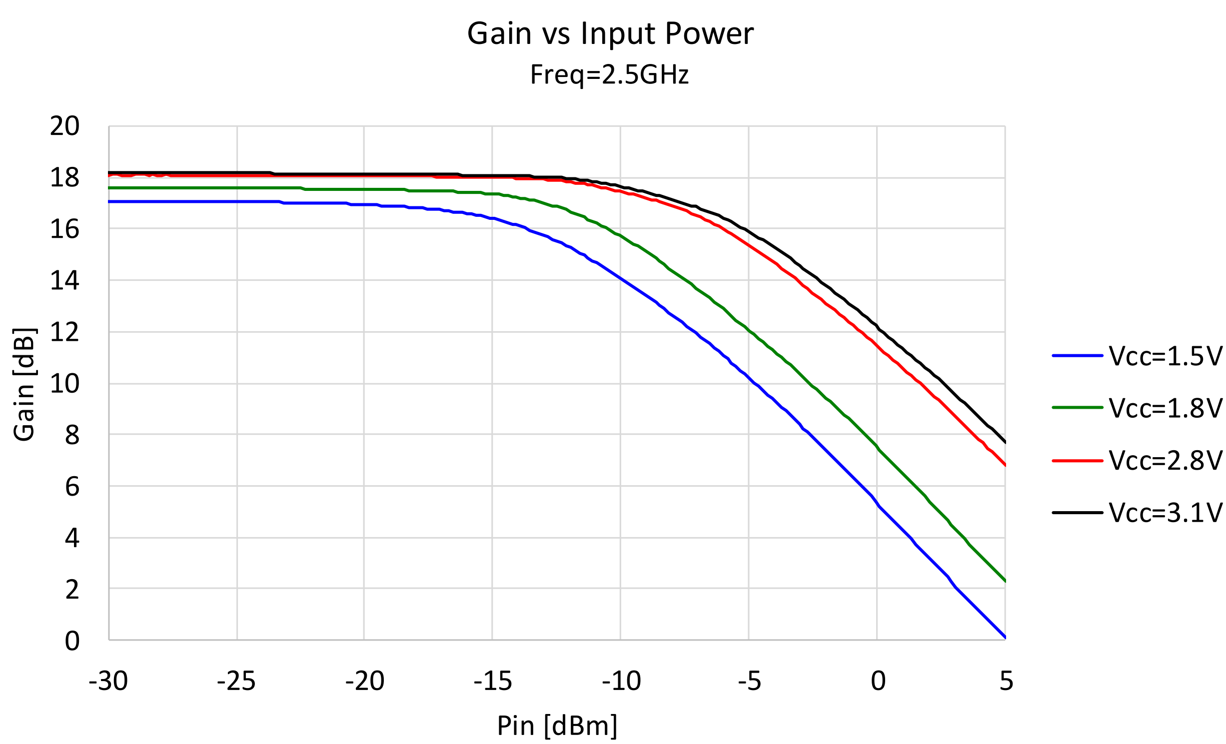

Fig 29. Gain versus input power, f=2.5 GHz, Temperature = 25 ºC.

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7.5 IIP3 2-Tone Test

The figure below show measured input-IP3-results of the DUT measured with a 2-Tone test at the 2650MHz. For the measurements, an LTE3401H EVB is used (see Fig 34). Measurements have been carried out using the setup shown in Fig 35

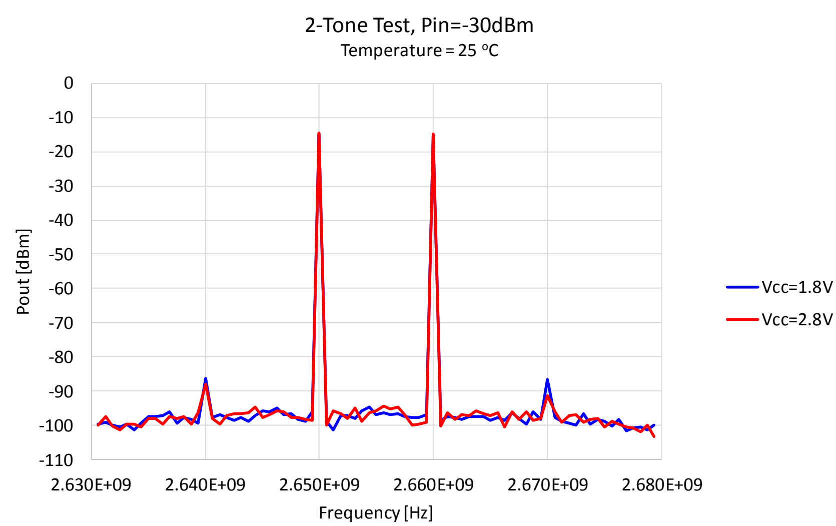

Fig 30. 2 Tone test: Pout=F(Vcc), Pin=-30 dBm

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8. Enable Timing Test

The following diagram shows the setup to test LNA Turn ON and Turn OFF time.

Set the waveform generator to square mode and the output amplitude at 3 Vrms with high output impedance. The waveform generator has adequate output current to drive the LNA therefore no extra DC power supply is required which simplifies the test setup.

Set the RF signal generator output level to -20 dBm at a frequency between 1452 MHz and 2690 MHz (depending on value of L1) and increase its level until the output DC on the oscilloscope is at 5 mV on 1 mV/division, the signal generator RF output level is approximately -5 dBm.

It is very important to keep the cables as short as possible at input and output of the LNA so the propagation delay difference on cables between the two channels is minimized.

It is also critical to set the oscilloscope input impedance to 50 ohm on channel 2 so the diode detector can discharge quickly to avoid a false result on the Turn OFF time testing.

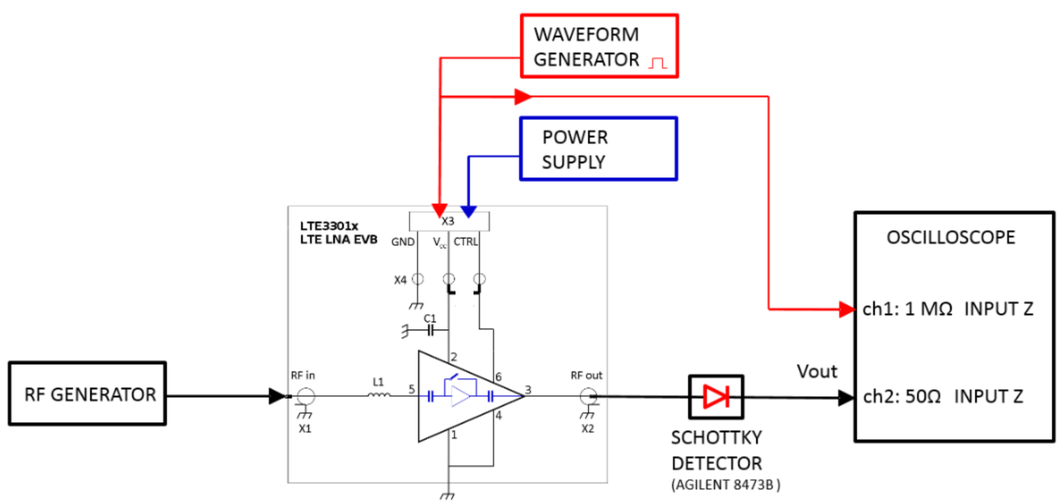

Fig 31. Setup Enable Timing Test

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Fig 32 and Fig 33 show the measured T_{on} and T_{bypass} test.

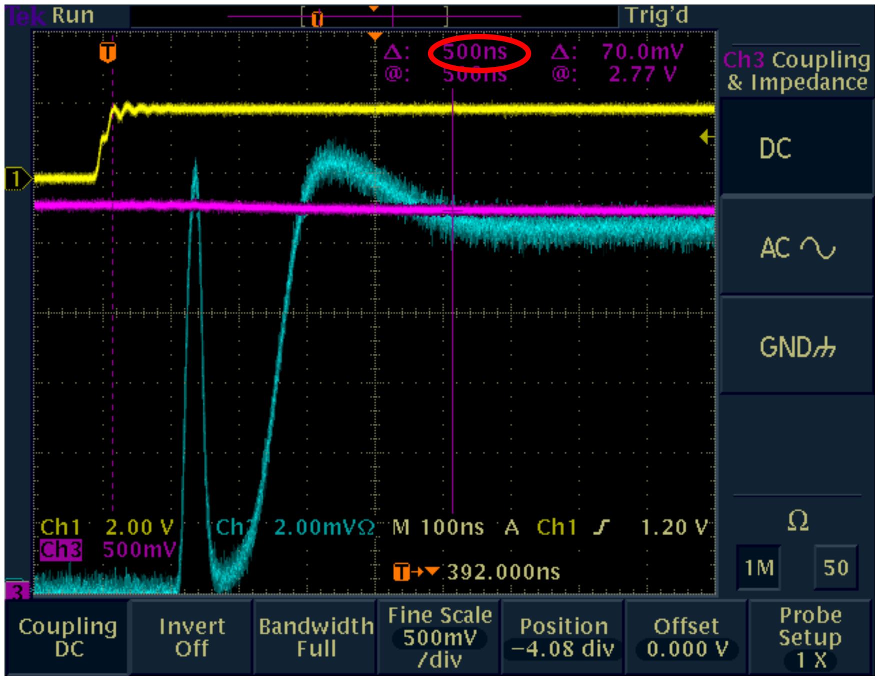

Fig 32. Results Enable Timing Test. Freq=2.5 GHz, Pin=-20 dBm, Vcc=2.8 V : Ton~500 ns.

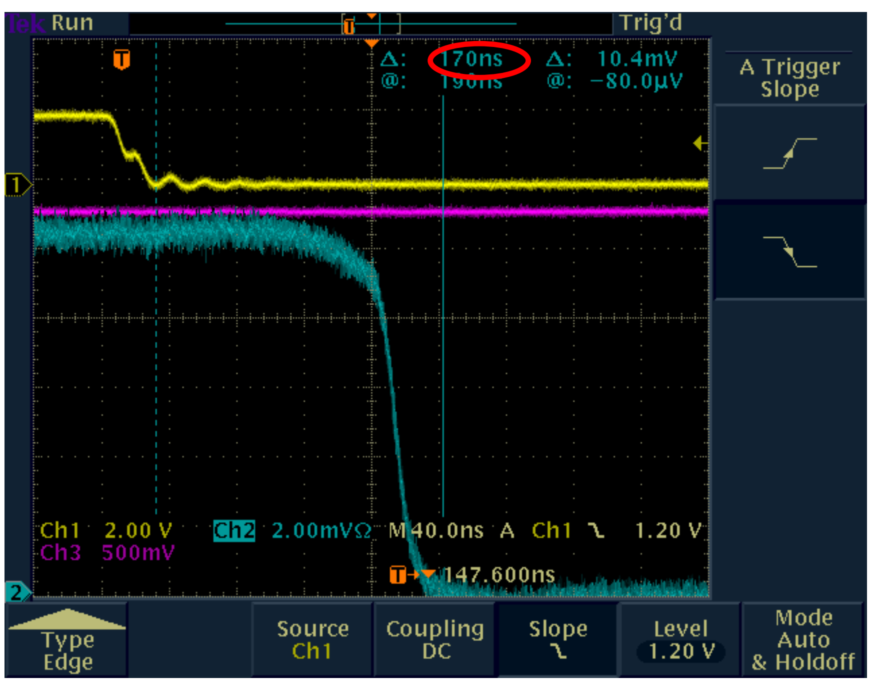

Fig 33. Results Enable Timing Test. Freq=2.5 GHz, Pin=-20 dBm, Vcc=2.8 V : T_Bypass~170 ns.

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9. Required Measurement Equipment

In order to measure the evaluation board the following is necessary:

- ✓ DC Power Supply up to 30 mA at 1.5 V to 3.1 V.
- ✓ Two RF signal generators capable of generating RF signals at the LTE operating frequencies between 1452 MHz and 2690 MHz.
- ✓ An RF spectrum analyzer that covers at least the LTE operating frequencies of 1452 MHz to 2690 MHz as well as a few of the harmonics. Up to 15 GHz should be sufficient.
  "Optional" a version with the capability of measuring noise figure is convenient
- ✓ Amp meter to measure the supply current (optional)
- ✓ A network analyzer for measuring gain, return loss and reverse isolation
- ✓ Noise figure analyzer and noise source
- ✓ Directional coupler
- ✓ Proper RF cables

10. Connections and setup

The LTE3401H LTE LNA evaluation board is fully assembled and tested (see Fig 34). Please follow the steps below for a step-by-step guide to operate the LNA evaluation board and testing the device functions.

1. Connect the DC power supply to the V_{cc} and GND terminals. Set the power supply to the desired supply voltage, between 1.5 V and 3.1 V, but never exceed 3.1 V as it might damage the LTE3401H.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the Ctrl pin of the LTE3401H.
3. Connect the RF signal generator and the spectrum analyzer to the RF input and the RF output of the evaluation board, respectively (Fig 34). Do not turn on the RF output of the signal generator yet, set it to approximately -30 dBm output power at center frequency of the wanted LTE-band and set the spectrum analyzer at the same center frequency and a reference level of 0 dBm.
4. Turn on the DC power supply and it should read approximately ~13 mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around –15 dBm.
6. Instead of using a signal generator and spectrum analyzer one can also use a network analyzer in order to measure gain as well as in- and output return loss, P1dB and IP3 (see Fig 35).
7. For noise figure evaluation, either a noise figure analyzer or a spectrum analyzer with noise option can be used. The use of a 5 dB noise source, like the Agilent 364B is recommended. When measuring the noise figure of the evaluation board, any kind of adaptors, cables etc. between the noise source and the evaluation board should be minimized, since this affects the noise figure (see Fig 36).

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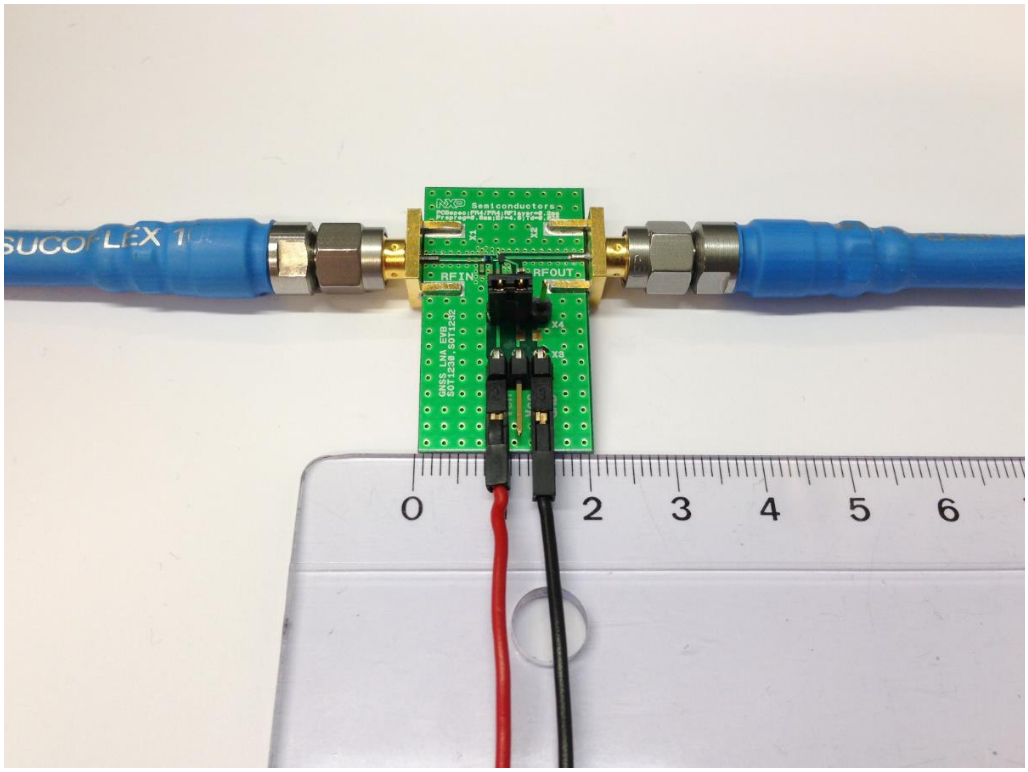

Fig 34. LTE3401H Evaluation board including its connections

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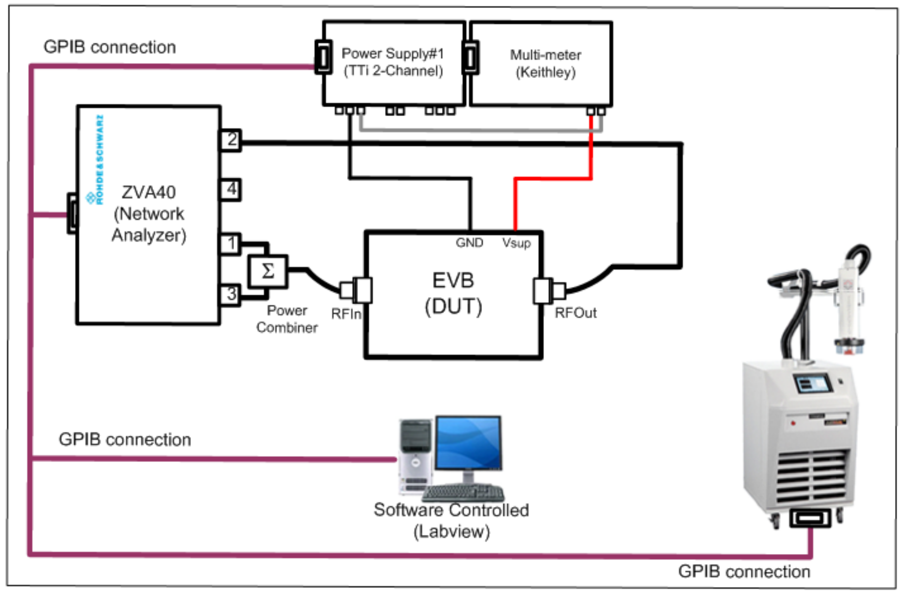

Fig 35. 2-Tone Setup for 50Ω LNA board tests (S-Parameters, P1dB and 2-Tone-tests)

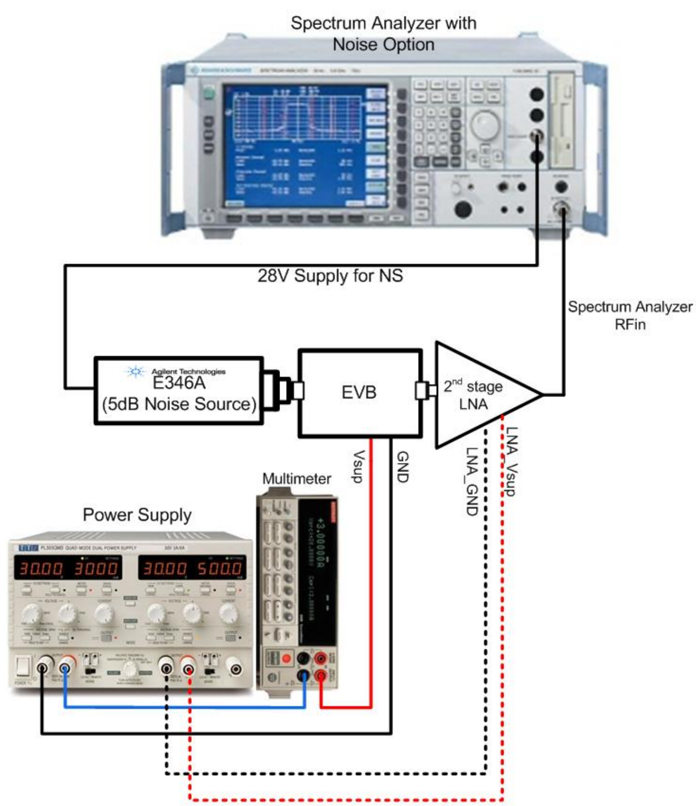

Fig 36. Setup diagram for 50 Ω LNA-board NF-Measurements.

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