AN11793

BGS8L5 LTE LNA with bypass switch evaluation board

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Document information

Info	Content
Keywords	BGS8L5, LTE, LNA
Abstract	This document explains the design and measurement results of the BGS8L5 LTE LNA evaluation board
Ordering info	BGS8L5 Board-number: OM17035 12NC: 9340 703 16598
Contact information	For more information, please visit: http://www.nxp.com

Revision history

Rev	Date	Description
1	20171207	First publication

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1. Introduction

NXP Semiconductors BGS8L5, is a low-noise amplifier with bypass switch for LTE receiver applications. The LTE LNA Evaluation Board is designed to evaluate the performance of the LNA in its typical application, using:

- NXP Semiconductors BGS8L5 LTE Low Noise Amplifier
- A matching inductor
- A decoupling capacitor

NXP Semiconductors BGS8L5 is a low-noise amplifier with bypass switch for LTE receiver applications in an extremely small Quad Flat No-leads Package (QFN). The BGS8L5 features a gain of 13.7 dB and a noise figure of 0.78 dB at a current consumption of 4.9 mA. The bypass switch insertion loss is 2.1 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.

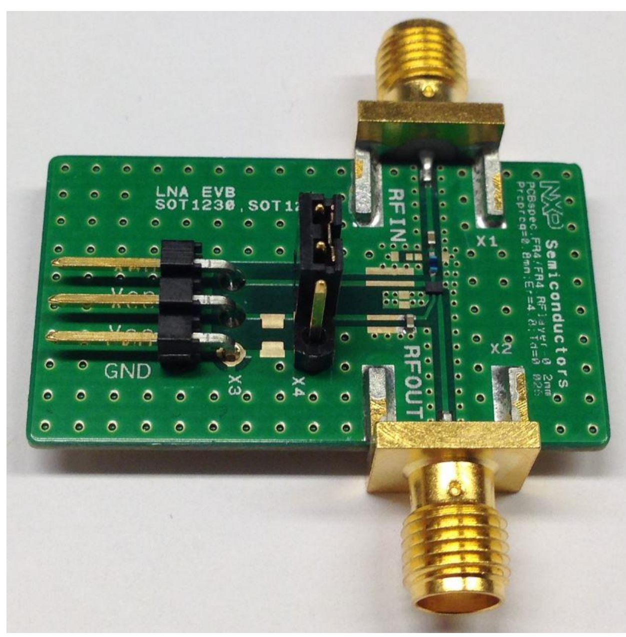

Fig 1. BGS8x5 LNA evaluation board (used for BGS8L5 and BGS8H5)

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2. General description of application & product

Modern mobile applications have multiple radio systems serving different frequency bands, so problems like co-habitation 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. All the different transmit signals that are active in smart phones and tablets can cause problems like inter-modulation and compression, which can be minimized by applying a high linearity LNA.

2.1 BGS8x5: 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.

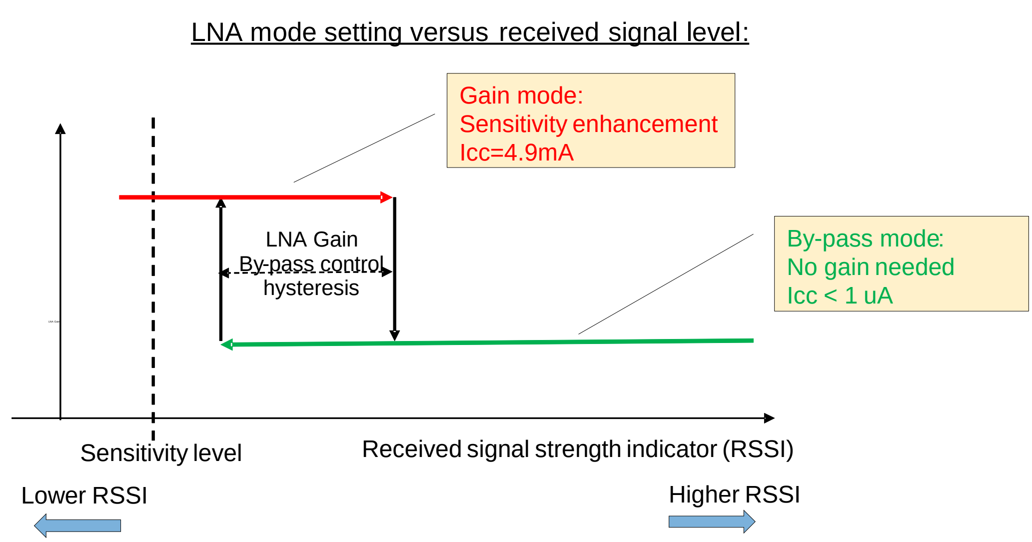

Fig 2. LNA mode setting versus received signal level

To avoid frequent 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. BGS8L5 LTE LNA evaluation board

The BGS8x5 LNA evaluation board simplifies the RF evaluation of the BGS8L5 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 BGS8L5, the input series inductor and a decoupling capacitor. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The BGS8L5 can operate from a 1.5 V to 3.1 V single supply and consumes typical 4.9 mA.

3.1 Application Circuit

The circuit diagram of the evaluation board is shown in Fig 3.

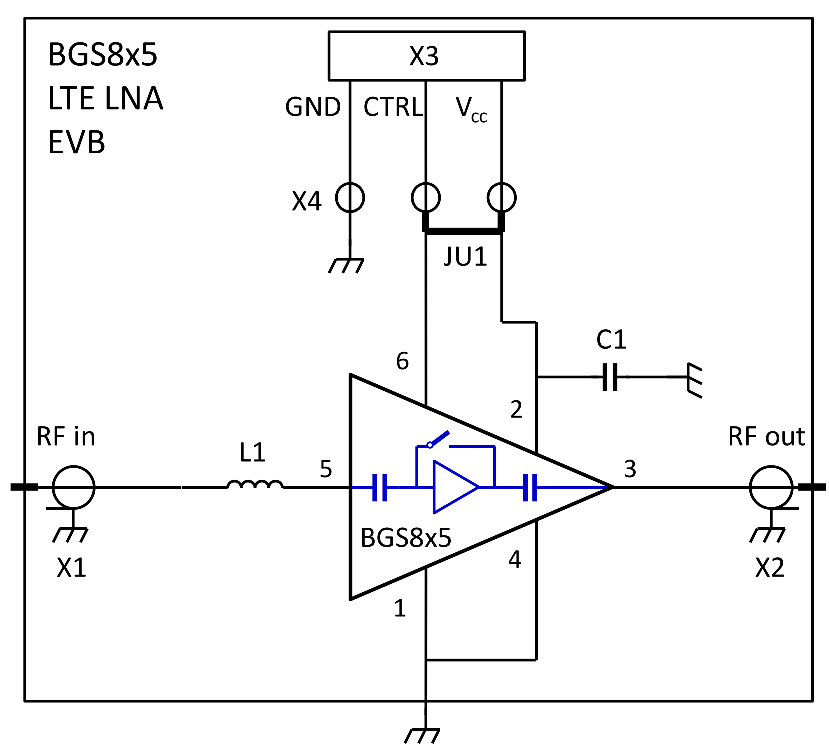

Fig 3. Circuit diagram of the BGS8x5 LNA evaluation board (used for BGS8L5 and BGS8H5)

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3.2 PCB Layout

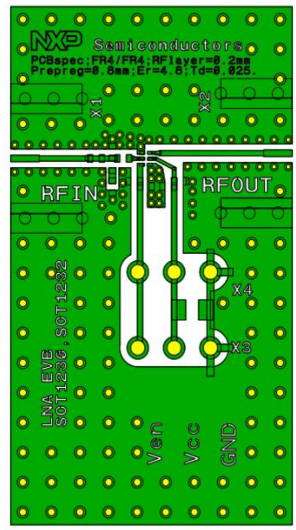

Fig 4. Printed-Circuit Board layout of the BGS8L5 LNA evaluation board (used for BGS8L5 and BGS8H5)

A good PCB layout is an essential part of an RF circuit design. The BGS8x5 LNA evaluation board can serve as a guideline for laying out a board using the BGS8L5.

- 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.

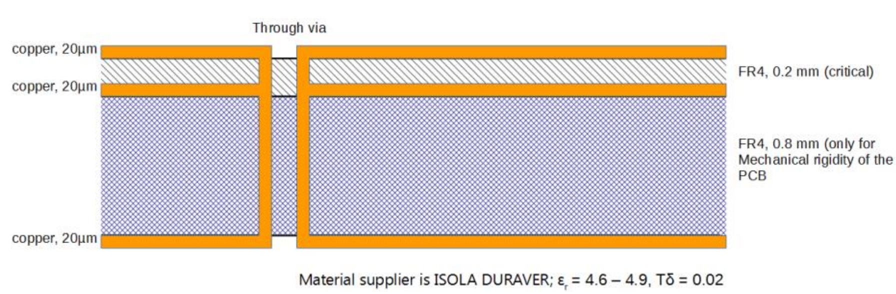

Fig 5. Stack of the PCB material

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3.3 Bill of materials

Table 1. BOM of the BGS8L5 LTE LNA evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
-	BGS8L5	1.1 mm x 0.7 mm x 0.37 mm, 6 terminals, no leads, SOT1232		NXP	BGS8L5
PCB		20 x 35 mm		BGS8L5 LTE LNA EV Kit	
C1	Capacitor	0402	1 µF	Murata GRM1555	Decoupling
L1	Inductor	0402	8.7 nH	Murata LQW15	703 MHz - 960 MHz
			15 nH	Murata LQW15	617 MHz - 652 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 BGS8L5

NXP Semiconductors BGS8L5 LTE low noise amplifier is designed for the LTE low band. The integrated biasing circuit is temperature stabilized, which keeps the bias current constant over temperature. It also enables the superior linearity performance of the BGS8L5. The BGS8L5 is also equipped with a bypass function that allows it to be controlled via a logic signal. In bypass mode it consumes less than 1 μA.

The output of the BGS8L5 is internally matched to 50 ohms between 703 MHz and 960 MHz, whereas only one series inductor at the input is needed to achieve the best RF performance. The output is AC coupled via an integrated capacitor.

It requires only two 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 matching inductor 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.

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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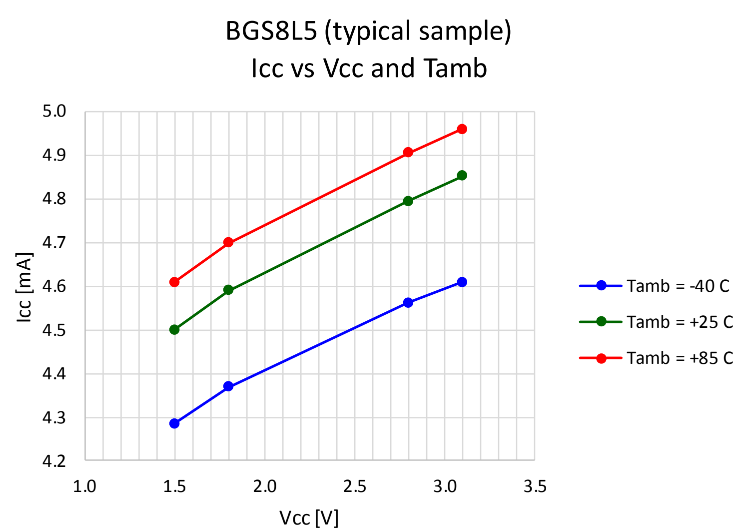
4. Typical LNA evaluation board results BGS8L5 (703 - 960 MHz)

4.1 Supply current

The typical relation between the supply current Icc with Supply voltage Vcc and temperature 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.



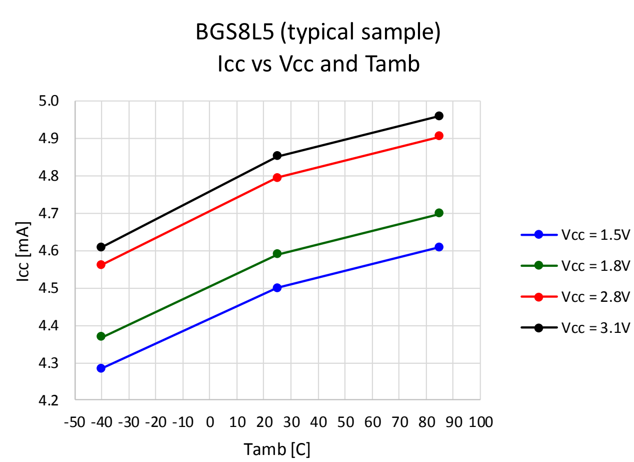


Fig 6. BGS8L5 typical relation between the supply current Icc with Supply voltage Vcc and Temperature, Tamb), Pin=-30 dBm. Gain mode.

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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 BGS8x5-LNA EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27.

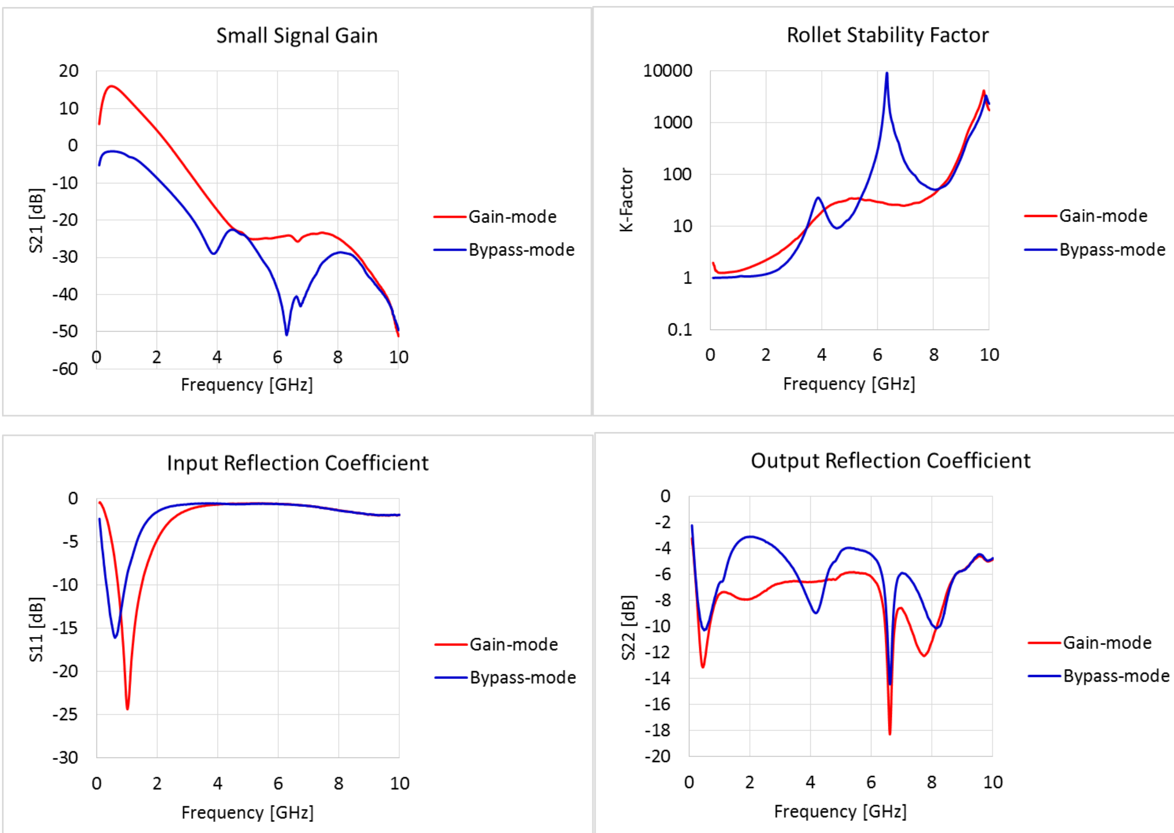

Fig 7. BGS8L5 S-Parameters (typical values). L1=8.7 nH, Vcc=1.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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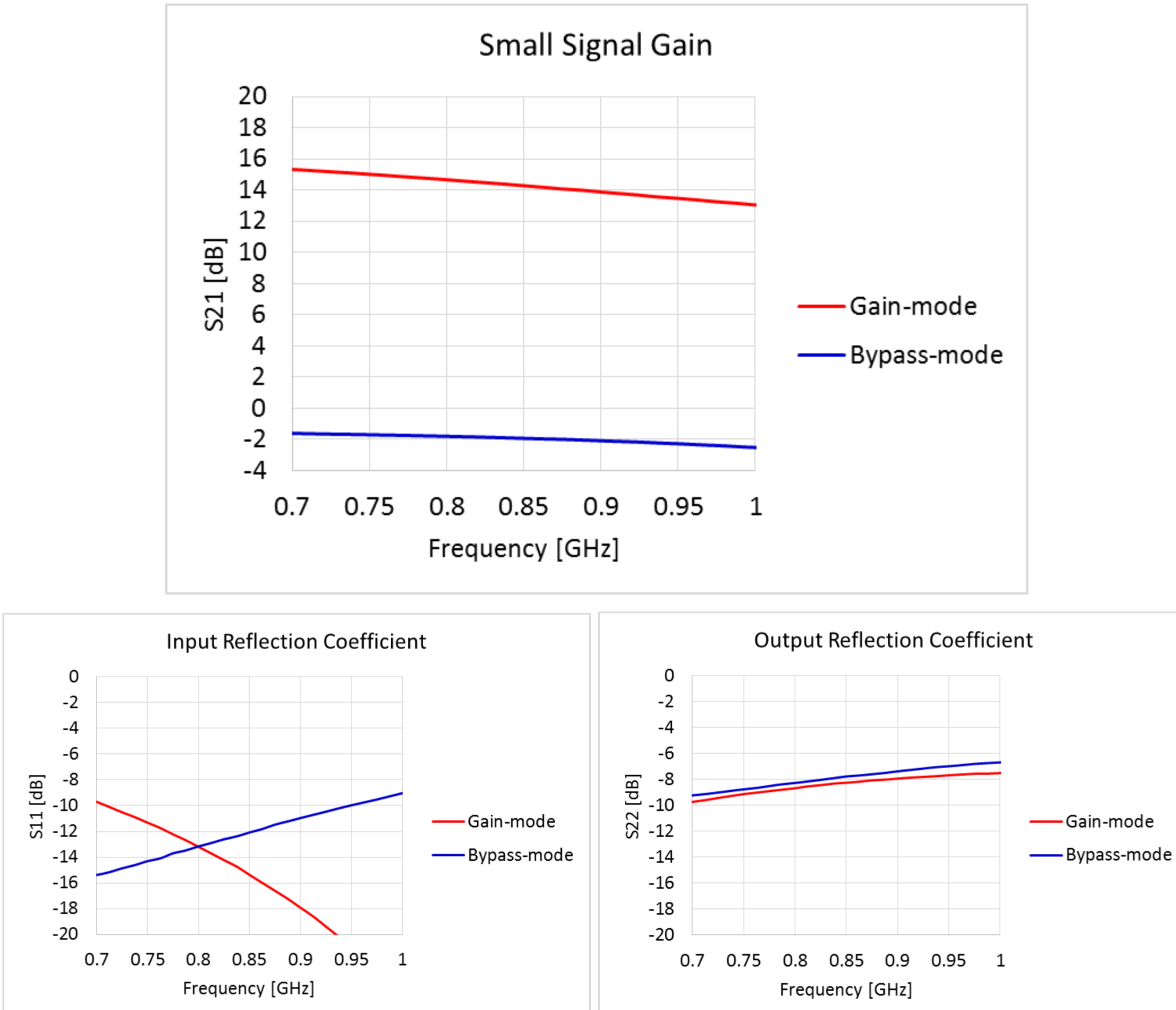

Fig 8. BGS8L5 S-Parameters (typical values). L1=8.7 nH, Vcc=1.8 V, Pin=-30 dBm, Gain mode and Bypass mode (frequency range zoomed in).

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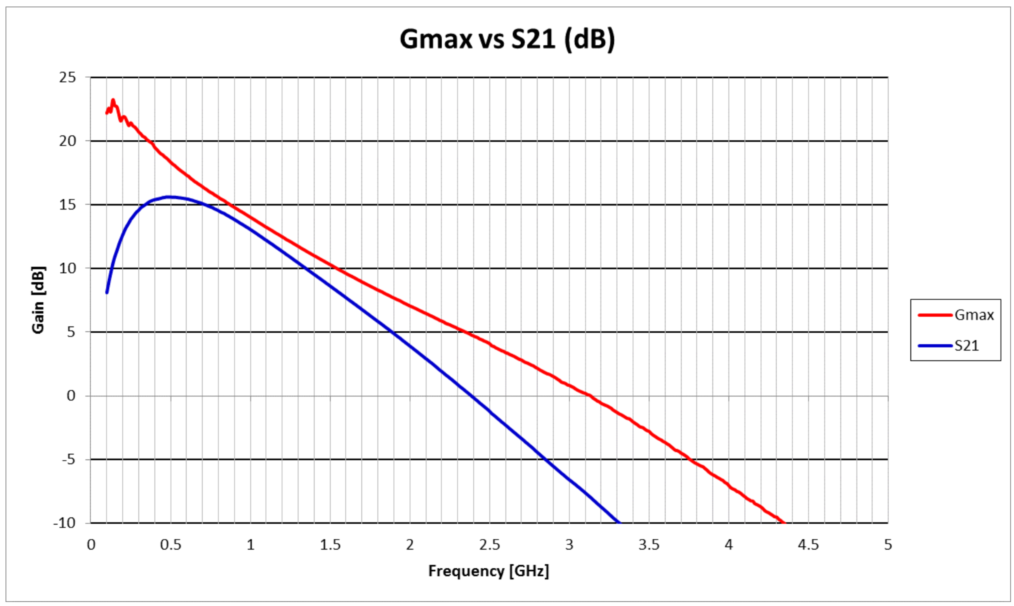
4.3 Improving the Gain by optimized matching

The design of the BGS8L5 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 a BGS8L5 EVB.



freq [MHz]	Gmax [dB]	S21 [dB]	S11 [dB]	S22 [dB]	S12 [dB]
700	16.40	15.08	-9.83	-10.35	-24.55
800	15.58	14.53	--13.48	-9.37	-23.58
950	14.41	13.45	-21.16	-8.48	-22.61

Fig 9. S21 and Maximum achievable gain (Gmax) typ. values (Gain mode)

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4.4 Noise Figure

The measured results for Noise Figure (NF) of the BGS8L5 evaluation board can be seen in Fig 10 below. The measurements have been carried out using the setup as shown in Fig 28.

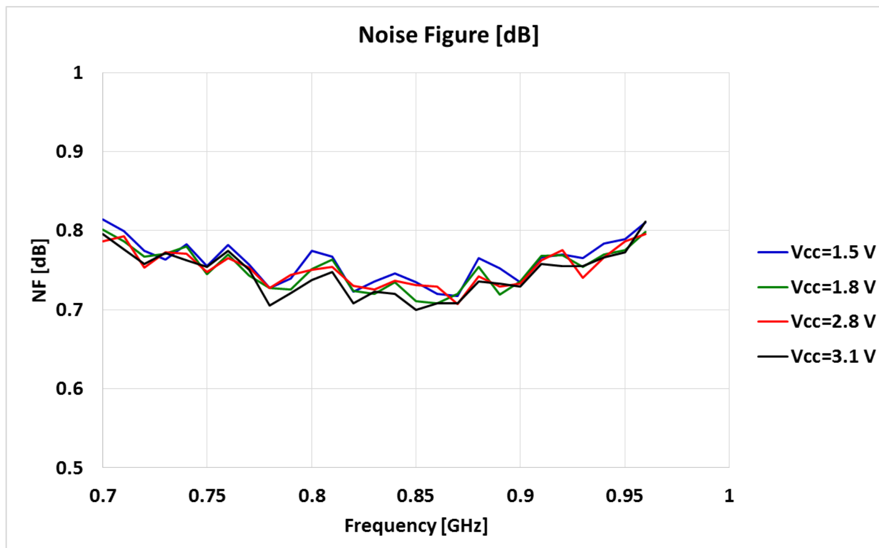

Fig 10. Typical Noise Figure (NF) in Gain mode, ambient temperature is is 25 ºC.

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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, a BGS8L5x EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the low LTE center frequencies. The figures below show the gain compression curves at LNA-board.

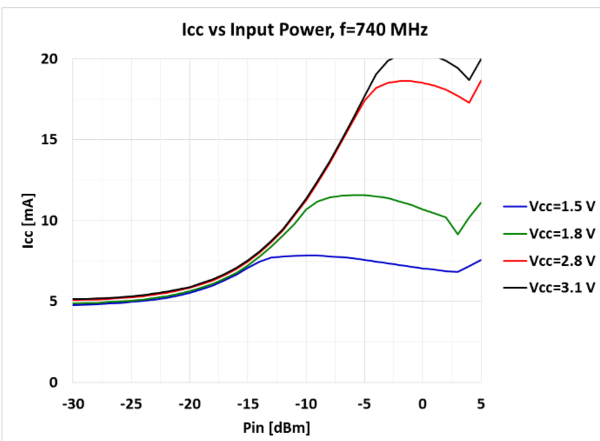

Fig 11. Icc versus input power , f=740 MHz (band 1)

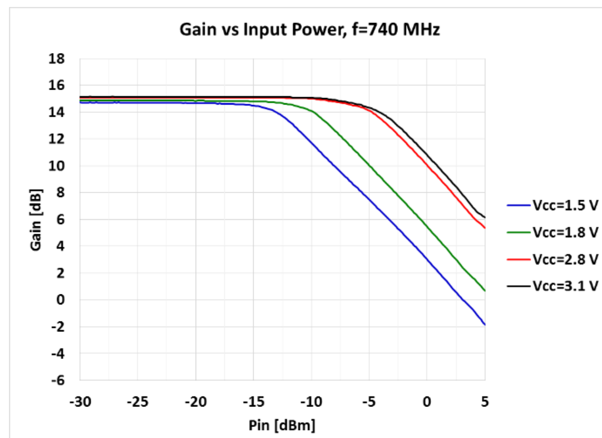

Fig 12. Gain versus input power , f=740 MHz (band 1)

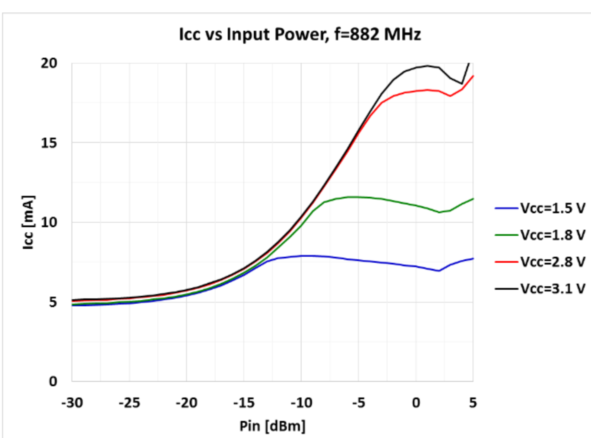

Fig 13. Icc versus input power , f=882 MHz (band 2)

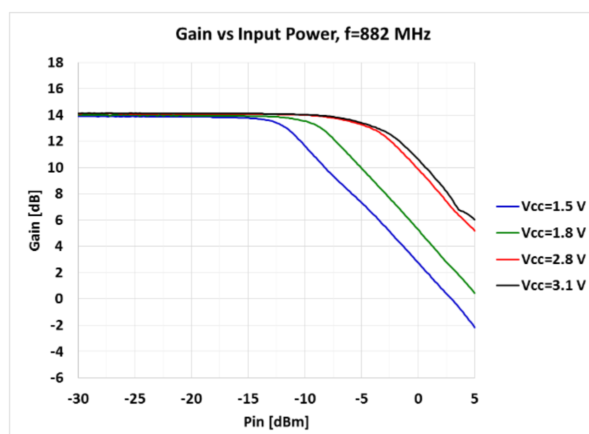

Fig 14. Gain versus input power , f=882 MHz (band 2)

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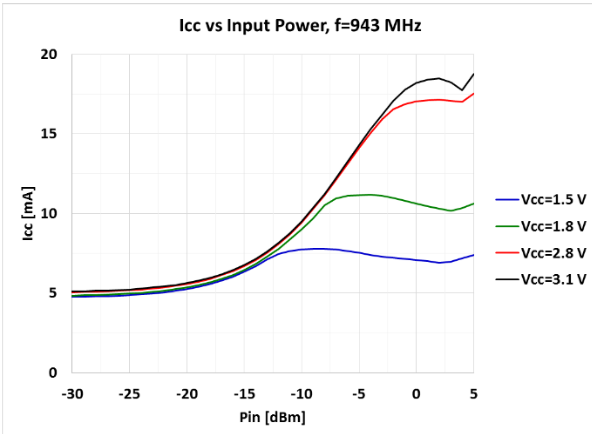

Fig 15. Icc versus input power , f=943 MHz (band 3)

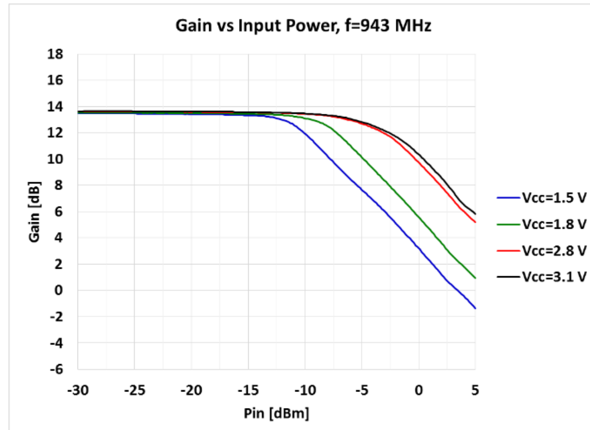

Fig 16. Gain versus input power , f=943 MHz (band 3)

4.6 IIP3 2-Tone Test

The figures below show measured input-IP3-results of the DUT measured with a 2-Tone test at the LTE-bands. For the measurements, a BGS8L5 EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27.

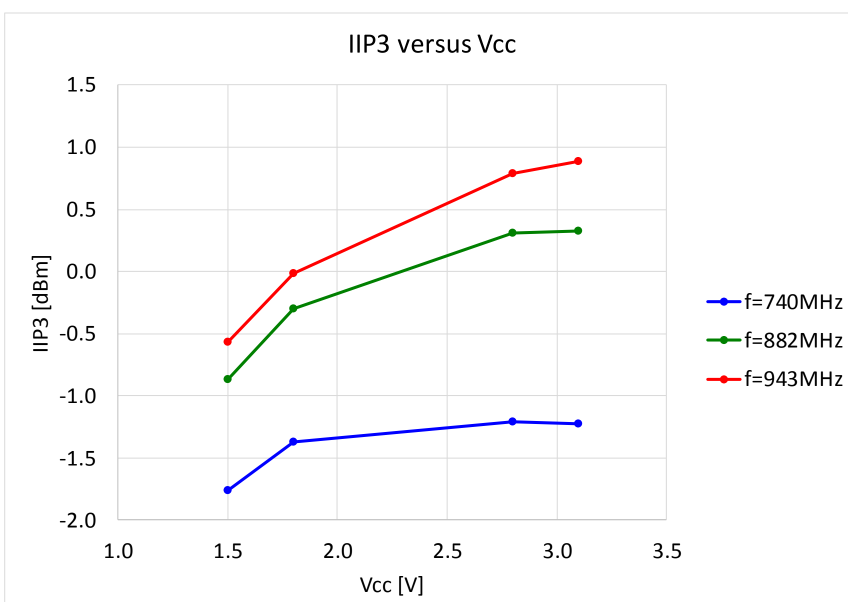

Fig 17. IIP3=F(Vcc), Pin=-30 dBm

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5. Typical LNA evaluation board results BGS8L5 tuned for LTE band 71

5.1 S-Parameters

If L1 is increased to 15nH (see Fig 3), the BGS8L5 can be used for LTE band 71 (617 to 652 MHz). The performance of the BGS8L5 tuned for band 71 will be discussed in this chapter.

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, an BGS8x5-LNA EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27.

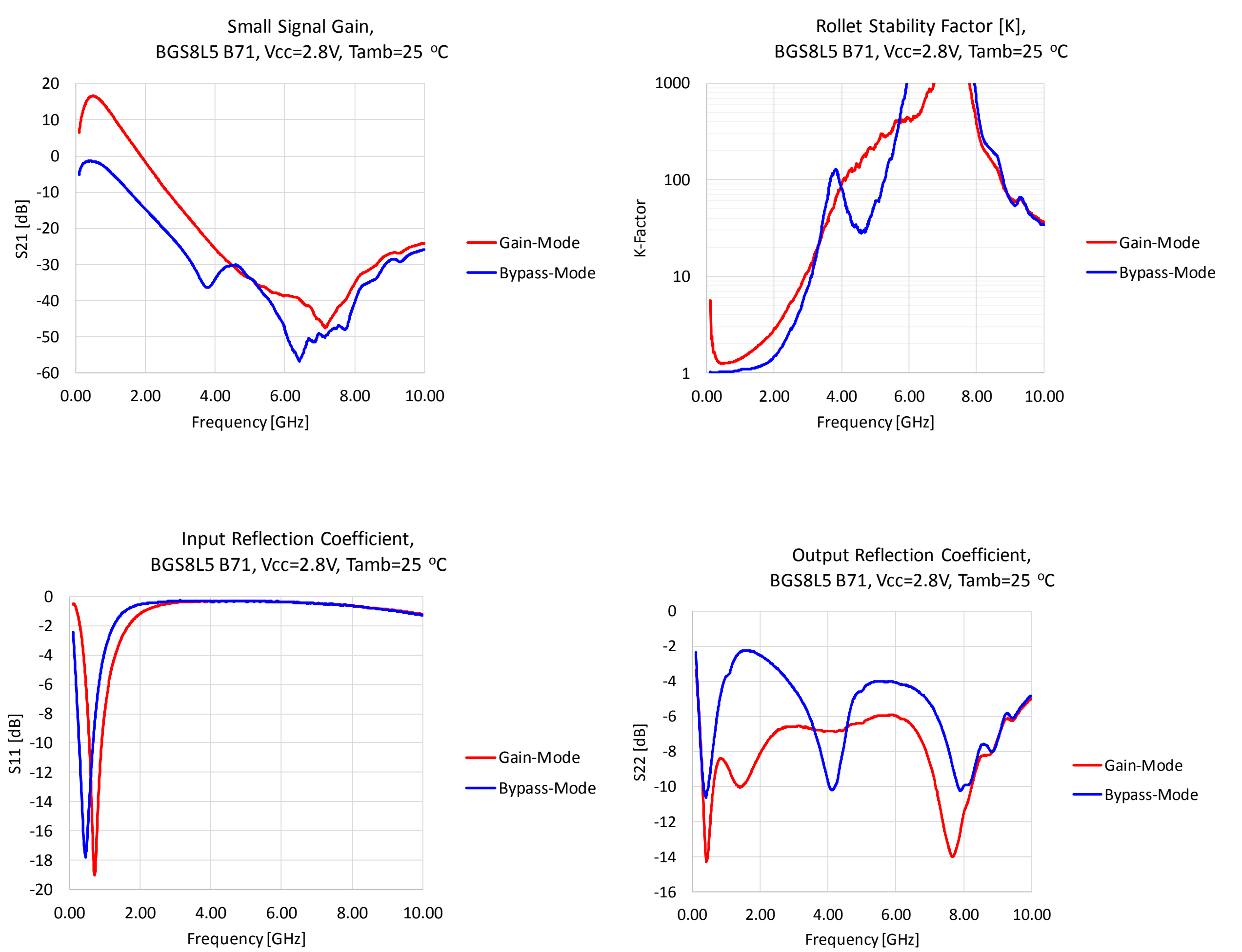

Fig 18. BGS8L5 S-Parameters (typical values). L1=15 nH, Vcc=1.8 V, Pin=-30 dBm. Gain mode and Bypass mode

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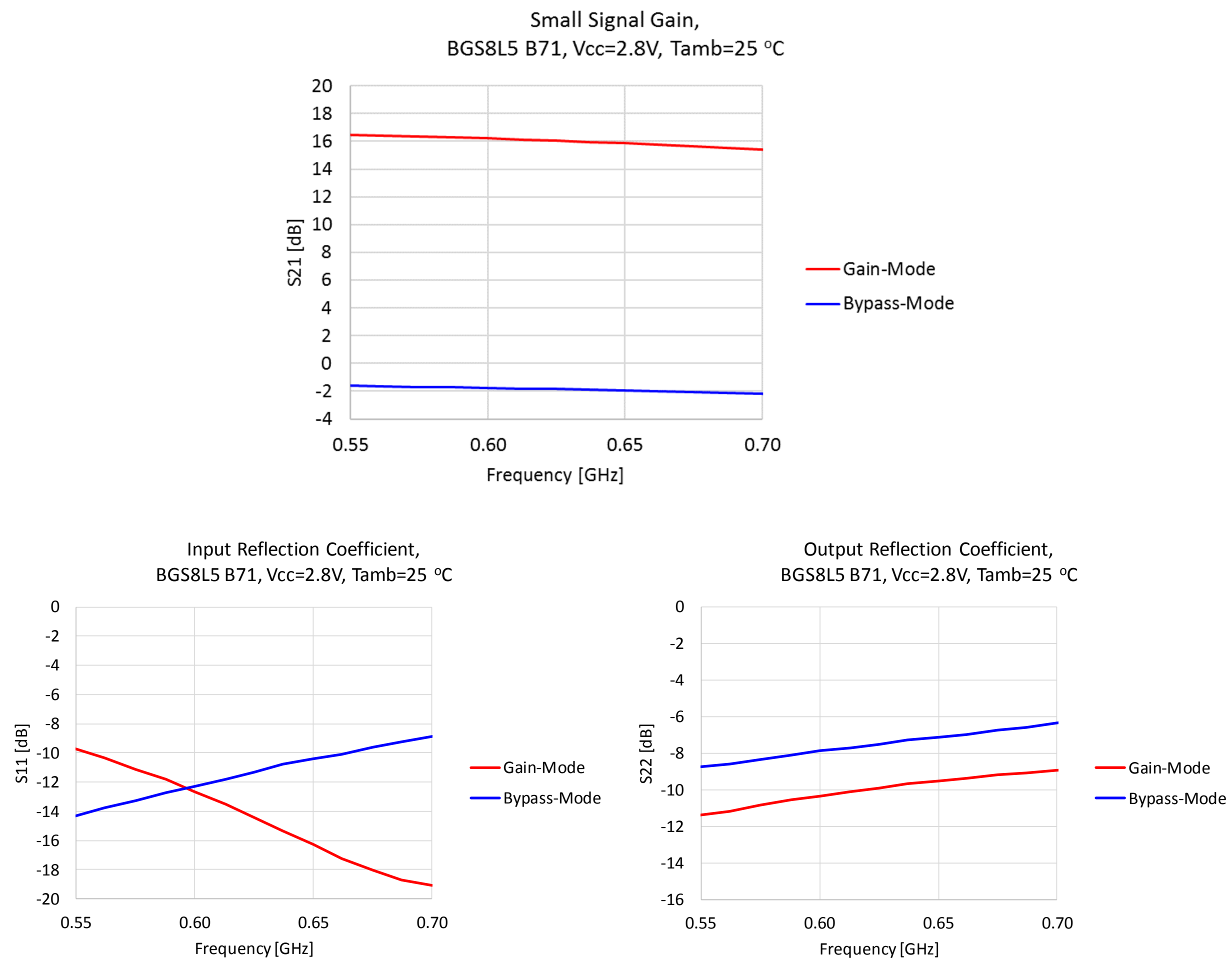

Fig 19. BGS8L5 S-Parameters (typical values). L1=15 nH, Vcc=1.8 V, Pin=-30 dBm, Gain mode and Bypass mode (frequency range zoomed in).

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5.2 Noise Figure

The measured results for Noise Figure (NF) of the BGS8L5 evaluation board tuned for band 71 can be seen in Fig 20 below. The measurements have been carried out using the setup as shown in Fig 28.

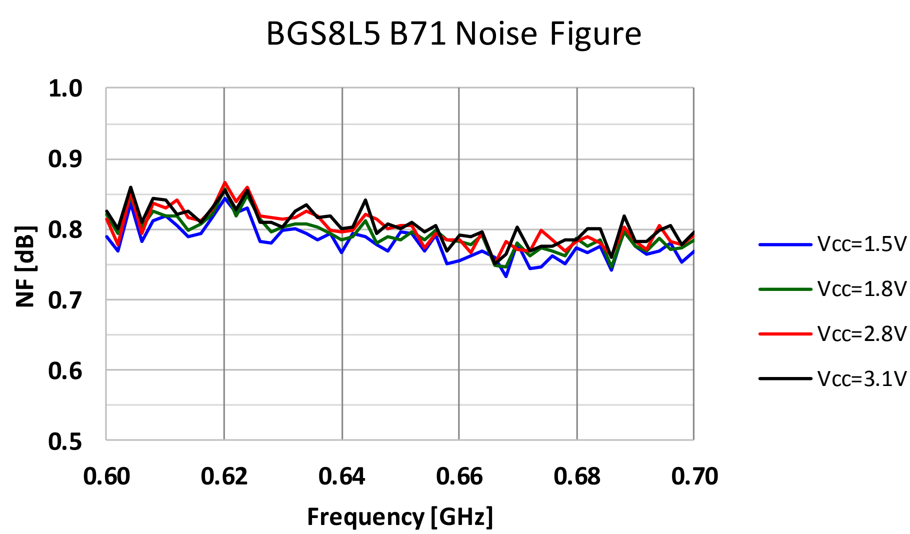

Fig 20. Typical Noise Figure (NF) in Gain mode, , ambient temperature is is 25 ºC.

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5.3 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, a BGS8L5x EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the low LTE center frequencies. The figures below show the gain compression curves at LNA-board.

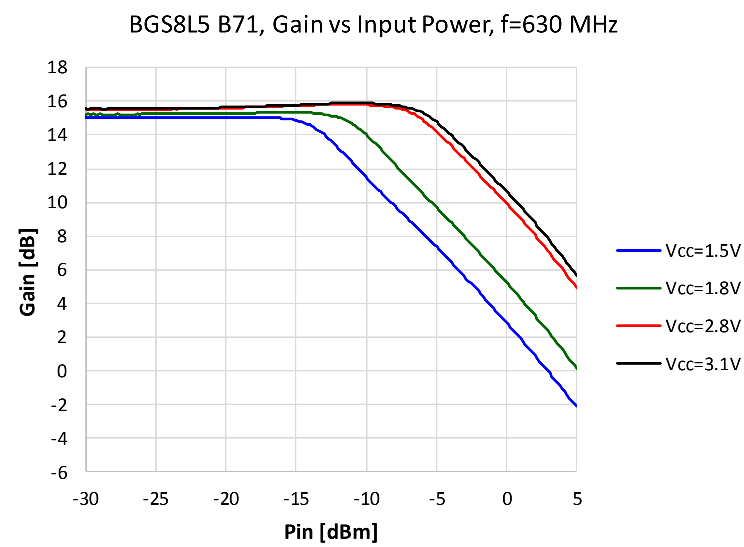

Fig 21. Gain versus input power , f=630 MHz (band 71)

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5.4 IIP3 2-Tone Test

The figures below show measured input-IP3-results of the DUT measured with a 2-Tone test at the LTE-bands. For the measurements, a BGS8L5 EVB is used (see Fig 26). Measurements have been carried out using the setup shown in Fig 27.

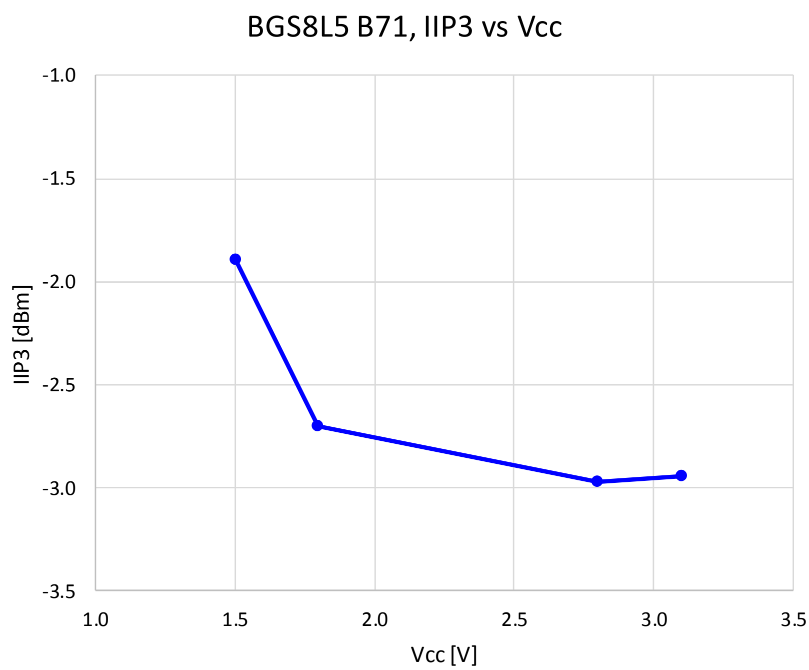

Fig 22. IIP3=F(Vcc), Pin=-30 dBm

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6. 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 703 MHz and 960 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.

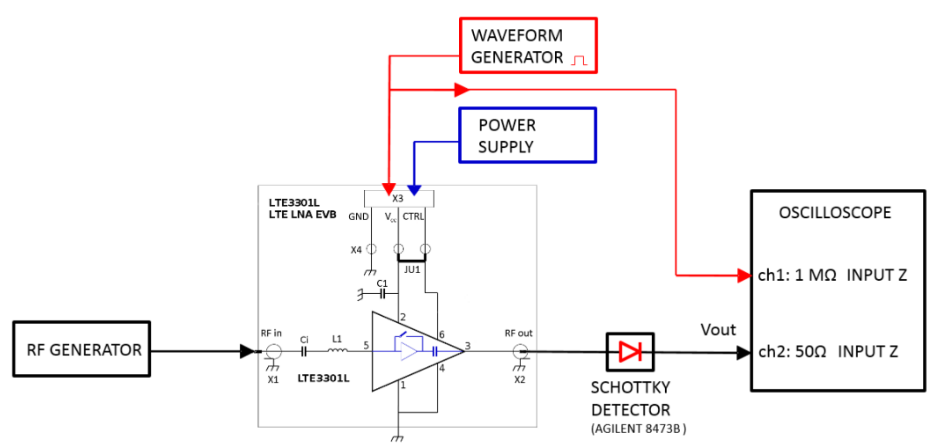

Fig 23. Setup Enable Timing Test

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Fig 24 and Fig 25 show the measured T_{on} and T_{bypass} test.

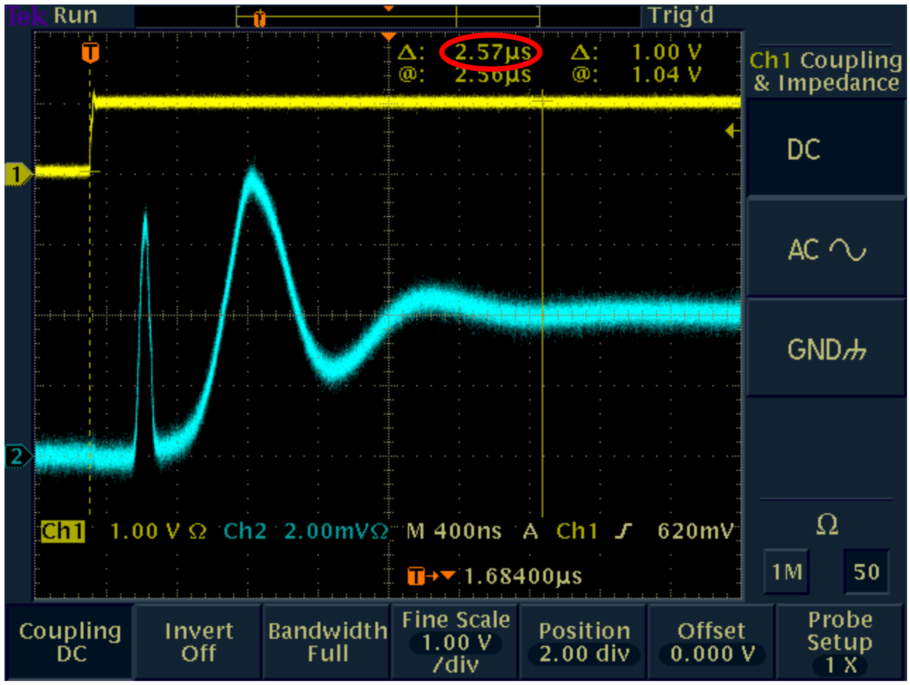

Fig 24. Results Enable Timing Test. Freq=882 MHz, Pin=-20 dBm, Vcc=2.8 V : Ton~2.6 us.

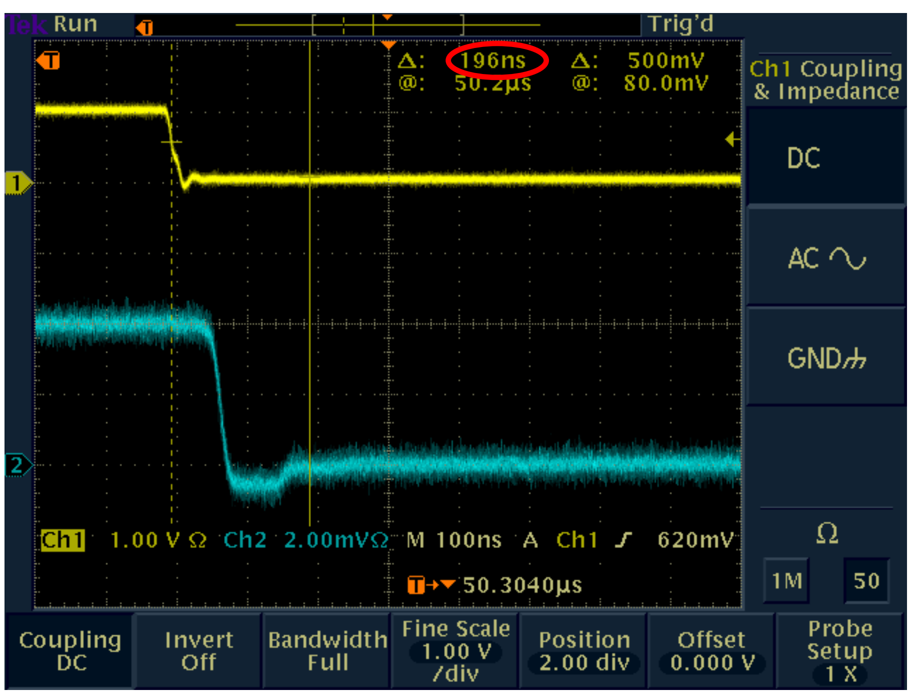

Fig 25. Results Enable Timing Test. Freq=882 MHz, Pin=-20 dBm, Vcc=2.8 V : T_Bypass~200 ns.

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7. 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 703 MHz and 960 MHz.
- ✓ An RF spectrum analyzer that covers at least the LTE operating frequencies of 703 MHz to 960 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

8. Connections and setup

The BGS8L5 LTE LNA evaluation board is fully assembled and tested (see Fig 26). 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 BGS8L5.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the Ctrl pin of the BGS8L5.
3. Connect the RF signal generator and the spectrum analyzer to the RF input and the RF output of the evaluation board, respectively (Fig 26). 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 4.9 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 27).
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 28).

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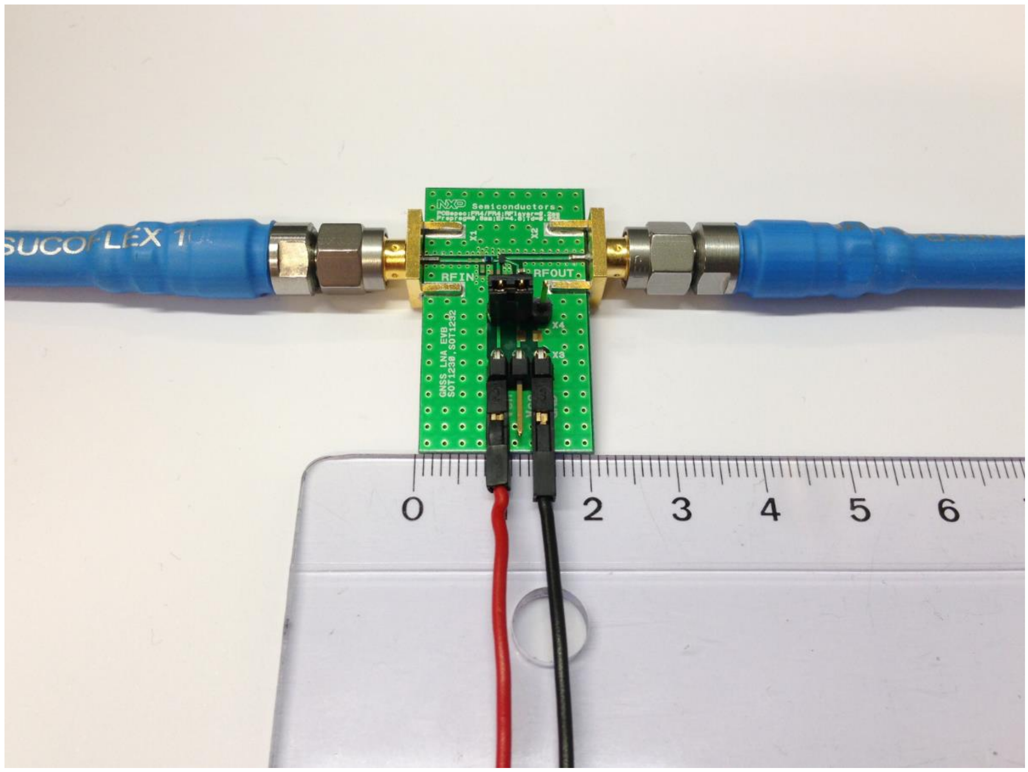

Fig 26. BGS8L5 Evaluation board including its connections

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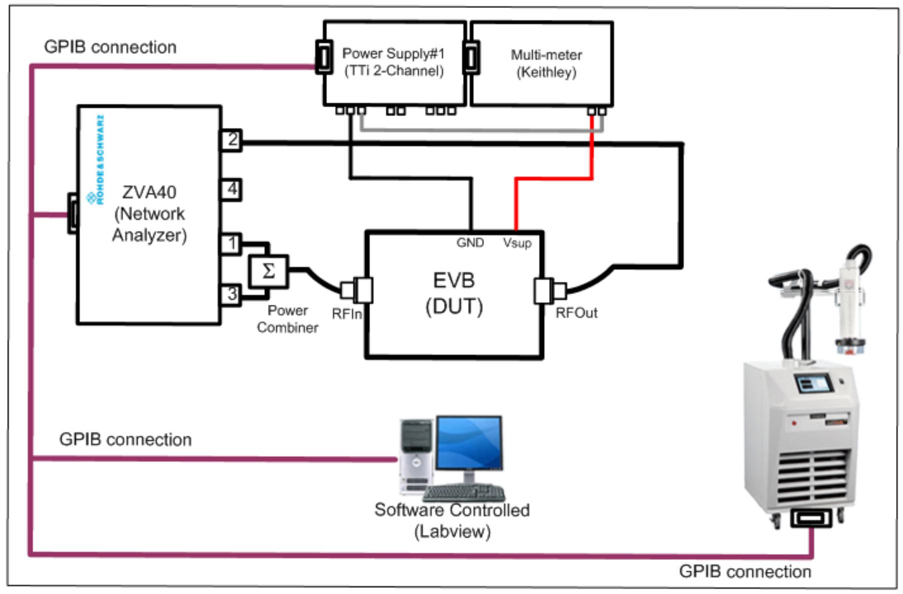

Fig 27. 2-Tone Setup for 50Ω LNA board tests (S-Parameters, P1dB and 2-Tone-tests)

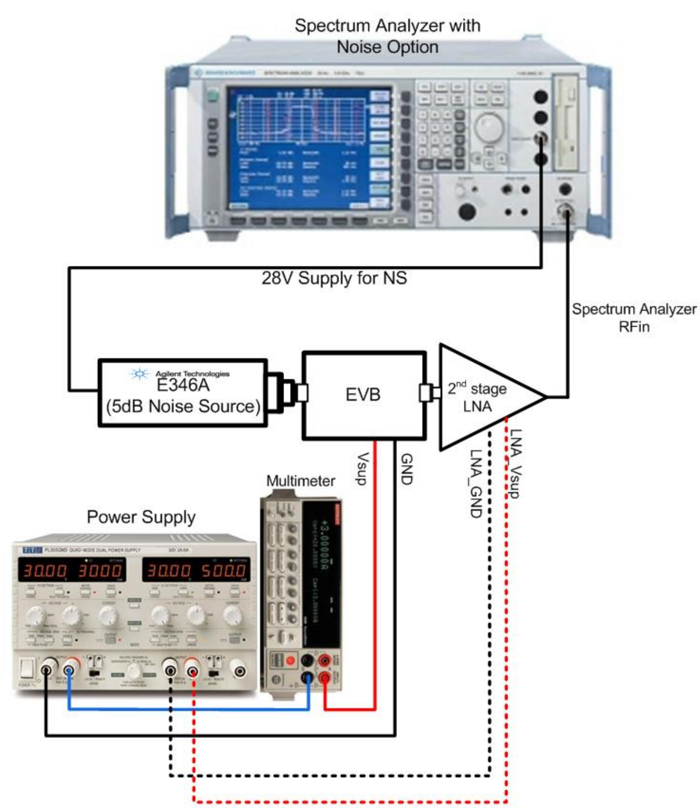

Fig 28. Setup diagram for 50 Ω LNA-board NF-Measurements.

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9. Legal information

9.1 Definitions

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