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BGU8009 GNSS LNA evaluation board

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1. Introduction

NXP Semiconductors' BGU8009 Global Navigation Satellite System (GNSS) LNA Evaluation Board (BGU8009 GNSS LNA EVB) is designed to evaluate the performance of the GNSS LNA using:

- NXP Semiconductors' BGU8009 GNSS Low Noise Amplifier
- A matching inductor
- A decoupling capacitor

NXP Semiconductors' BGU8009 is a low-noise amplifier for GNSS receiver applications in a plastic, leadless 6 pin, extremely thin small outline SOT1230 at 1.1 x 0.9 x 0.5mm, 0.4mm pitch. The BGU8009 features gain of 18 dB and a noise figure of 0.65 dB at a current consumption of 4.4 mA. 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 results are given, as well as some explanations on GNSS related performance parameters like out-of-band input third-order intercept point O_IIP3, gain compression under jamming and noise under jamming.

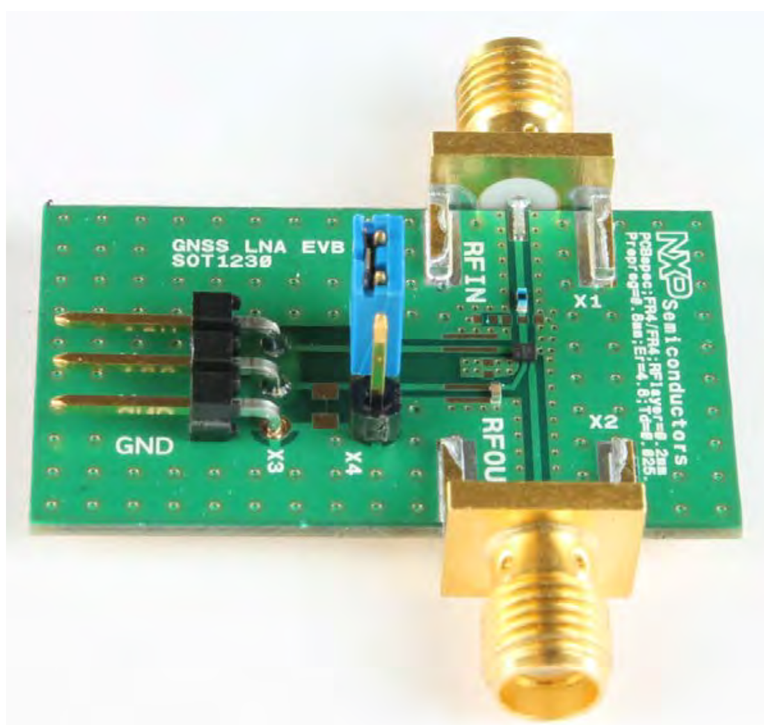


Fig 1. BGU8009 GNSS LNA evaluation board

2. General description

Modern cellular phones have multiple radio systems, so problems like co-habitation are quite common. A GNSS receiver implemented in a mobile phone requires the following factors to be taken into account.

All the different transmit signals that are active in a phone can cause problems like inter-modulation and compression.

Since the GNSS receiver needs to receive signals with an average power level of -130 dBm, sensitivity is very important. Currently there are several GNSS chipsets on the market that can be implemented in cell phones, tablets etc. Although many of these GNSS ICs do have integrated LNA front ends, the noise performance, and as a result the system sensitivity, is not always adequate. The GNSS receiver sensitivity is a measure how accurate the coordinates are calculated. The GNSS signal reception can be improved by a so called GNSS LNA, which improves the sensitivity by amplifying the wanted GNSS signal with a low-noise amplifier.

3. BGU8009 GNSS LNA evaluation board

The BGU8009 LNA evaluation board simplifies the RF evaluation of the BGU8009 GNSS LNA applied in a GNSS front-end, often used in mobile cell phones. The evaluation board enables testing of the device RF performance and requires no additional support circuitry. The board is fully assembled with the BGU8009, including the input series inductor and decoupling capacitor. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The BGU8009 can operate from a 1.5 V to 3.1 V single supply and consumes typical 4.4 mA.

3.1 Application Circuit

The circuit diagram of the evaluation board is shown in Fig 2. With jumper JU1 the enable input can be connected either to Vcc or GND.

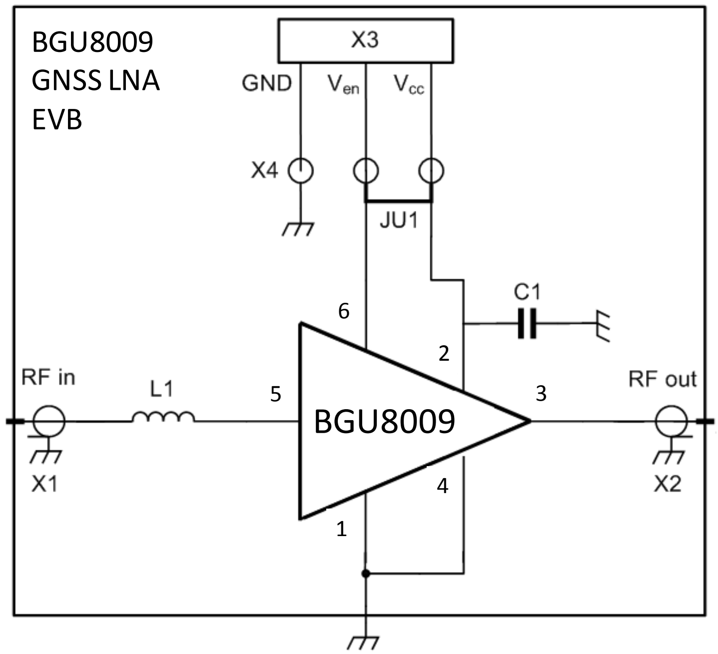


Fig 2. Circuit diagram of the BGU8009 LNA evaluation board

3.2 PCB Layout

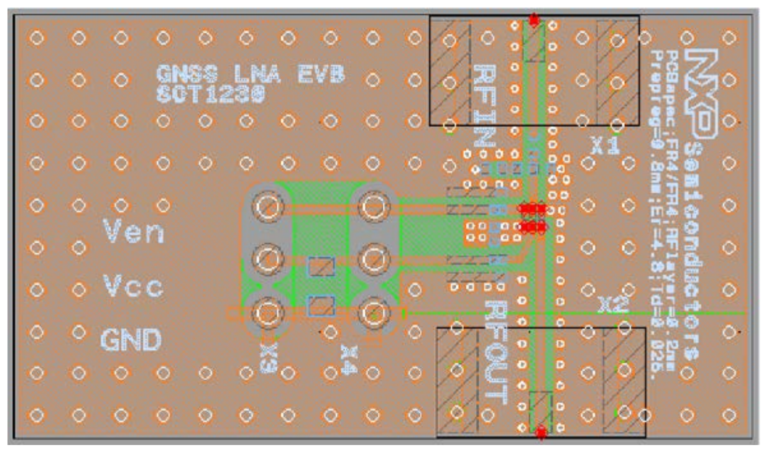
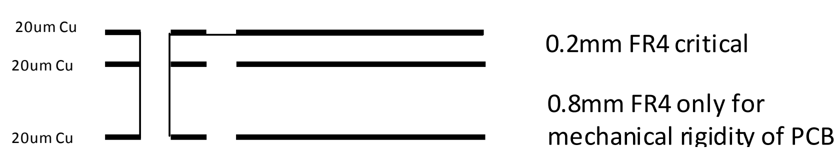


Fig 3. Printed-Circuit Board layout of the BGU8009 LNA evaluation board

A good PCB layout is an essential part of an RF circuit design. The LNA evaluation board of the BGU8009 can serve as a guideline for laying out a board using the BGU8009. Use controlled impedance lines for all high frequency inputs and outputs. Bypass Vcc with decoupling capacitors, preferably located as close as possible to the device. For long bias lines it may be necessary to add decoupling capacitors along the line further away from 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 4.



(1) Material supplier is ISOLA DURAVER; εr = 4.6-4.9: $T\delta = 0.02$

Fig 4. Stack of the PCB material

4. Bill of materials

Table 1. BOM of the BGU8009 GNSS LNA evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
A	BGU8009	1.1x0.9x0.5mm, 0.4mm pitch		NXP	SOT1230.
PCB		20x35mm		BGU8009 GNSS LNA EV Kit	
C1	Capacitor	0402	1nF	Murata GRM1555	Decoupling
L1	Inductor	0402	5.6nH	Murata LQW15	Input matching
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				

4.1 BGU8009

NXP Semiconductors' BGU8009 GNSS low noise amplifier is designed for the GNSS frequency band. The integrated biasing circuit is temperature stabilized, which keeps the current constant over temperature. It also enables the superior linearity performance of the BGU8009. The BGU8009 is also equipped with an enable function that allows it to be controlled via a logic signal. In disabled mode it consumes less than1 μA.

The output of the BGU8009 is internally matched for 1575.42 MHz whereas only one series inductor at the input is needed to achieve the best RF performance. Both the input and output are AC coupled via an integrated capacitor.

It requires only two external components to build a GNSS LNA having the following advantages:

- Low noise
- High gain
- High linearity under jamming
- 1.1 x 0.9 x 0.5, 0.4mm pitch: SOT1230
- Low current consumption
- Short power settling time

4.2 Series inductor

The evaluation board is supplied with Murata LQW15 series inductor of 5.6nH. This is a wire wound type of inductor with high quality factor (Q) and low series resistance (Rs). 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.

5. Required Equipment

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

- ✓ DC Power Supply op to 30 mA at 1.5 V to 3.1 V
- ✓ Two RF signal generators capable of generating RF signals at the operating frequency of 1575.42 MHz, as well as the jammer frequencies 1713.42 MHz and 1851.42 MHz
- ✓ An RF spectrum analyzer that covers at least the operating frequency of 1575.42 MHz as well as a few of the harmonics. Up to 6 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

6. Connections and setup

The BGU8009 GNSS LNA evaluation board is fully assembled and tested. 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 BGU8009.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the V_{en} pin of the BGU8009.
3. Connect the RF signal generator and the spectrum analyzer to the RF input and the RF output of the evaluation board, respectively. Do not turn on the RF output of the signal generator yet, set it to -45 dBm output power at 1575.42 MHz, set the spectrum analyzer at 1575.42 MHz center frequency and a reference level of 0 dBm.
4. Turn on the DC power supply and it should read approximately 4.4 mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around –27 dBm at 1575.42 MHz.
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.
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.

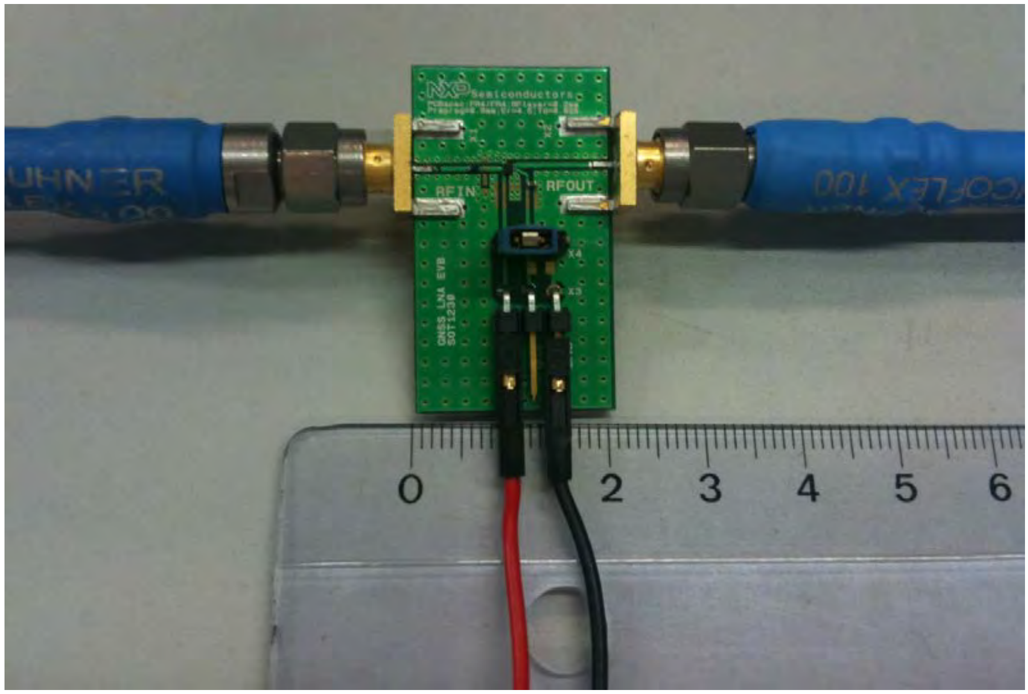


Fig 5. Evaluation board including its connections

7. Linearity

At the average power levels of –130 dBm that have to be received by a GNSS receiver, the system will not have in-band intermodulation problems caused by the GNSS-signal itself. Strong out-of-band cell phone TX jammers however can cause linearity problems, and result in third-order intermodulation products in the GNSS frequency band. In this chapter the effects of these Jammer-signals on the Noise and Gain performance of the BGU8009 are described. The effect of these Jammers on the In-band and Out-of-Band Third-Order Intercept points are described in more detail in a separate User Manual: UM10453: 2-Tone Test BGU7005 and BGU7007 GNSS LNA.

7.1 In-band 1dB gain compression due to 850MHz and 1850MHz jammers

As stated before, signal levels in the GNSS frequency band of -130dBm average will not cause linearity problems in the GNSS band itself. This of course is also valid for the 1dB gain compression in-band. The 1dB compression point at 1575.42MHz caused by cell phone TX jammers however is important.

Measurements have been carried out using the setup shown in Fig 6.

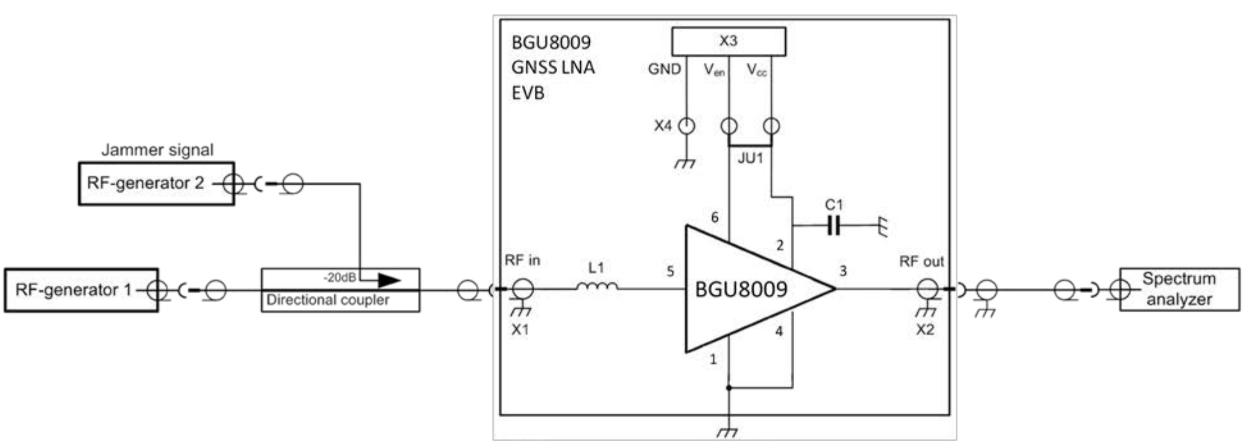
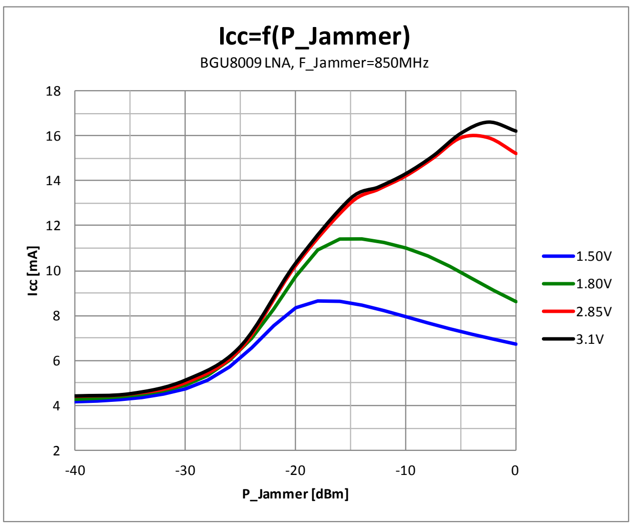


Fig 6. 1dB Gain compression under jamming measurement setup (LNA evaluation board)

The gain of the DUT was measured between port RFin and RFout of the EVB at the GNSS
frequency 1575 MHz, while simultaneously a jammer power signal was swept at the 20 dB attenuated input port of the Directional Coupler. Please note that the drive power of the jammer is 20 dB lower at the input of the DUT caused by the directional coupler.

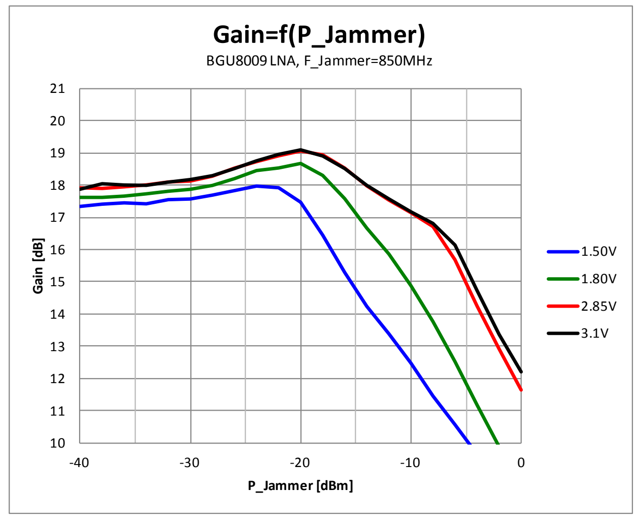
The figures below show the supply-current (Icc) and gain compression curves with 850MHz and 1850 MHz jammers (input jammer power at LNA-board, taking into account the approx 20 dB attenuation of the directional coupler and RF-cable from Jammer-Generator to the directional coupler).

The gain drops 1dB with approximately -16dBm input jamming power at 850MHz (Vcc=1.8V) (Fig 8). With an 1850MHz jamming signal, the 1dB gain compression occurs around -15dBm input power level (Fig 10).



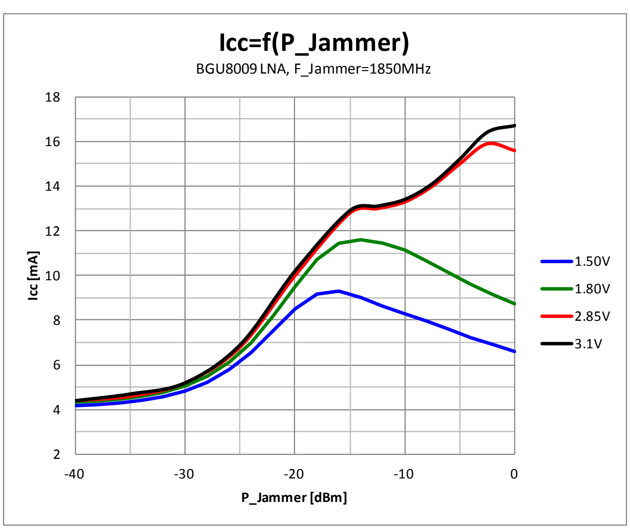
Pin 1575 MHz = -45 dBm

Fig 7. Icc versus jammer power at 850 MHz



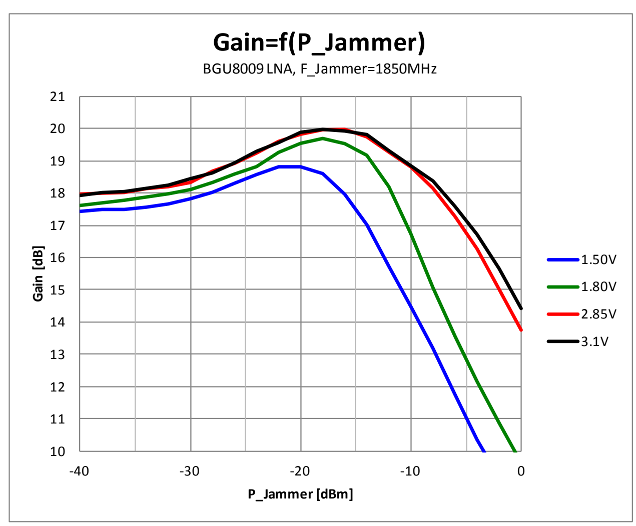
Pin 1575 MHz = -45 dBm

Fig 8. Gain versus jammer power at 850 MHz



Pin 1575 MHz = -45 dBm

Fig 9. Icc versus jammer power at 1850 MHz



Pin 1575 MHz = -45 dBm

Fig 10. Gain versus jammer power at 1850 MHz

8. Noise figure as function of jammer power at 850MHz and 1850MHz

Noise figure under jamming conditions is a measure of how the LNA behaves when e.g. a GSM TX interfering signal is at the input of the GNSS antenna. To measure this behavior the setup shown in Fig 11 is used.

The jammer signal is coupled via a directional coupler to the DUT: this is to avoid the jammer signal damaging the noise source. The GNSS BPF is needed to avoid driving the second-stage LNA in saturation.

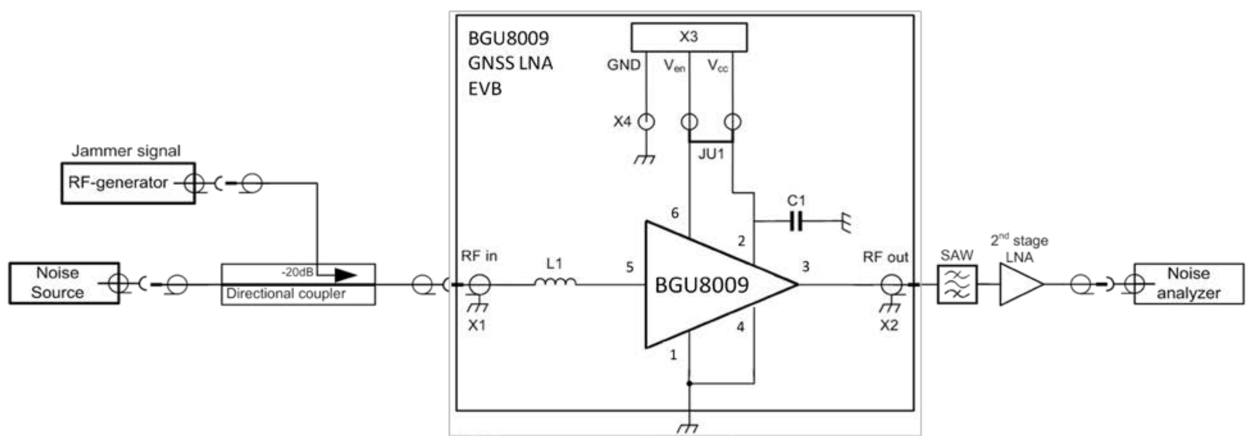
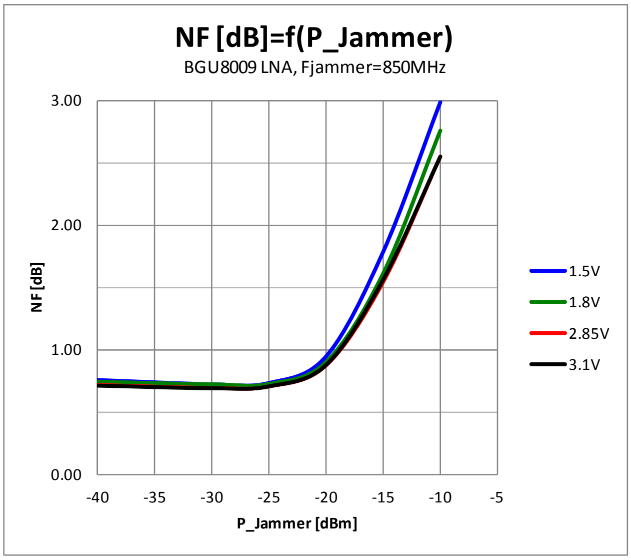


Fig 11. Noise under jamming measurement setup (LNA evaluation board)

With the results of these measurements and the specification of the SAW filter, the jammer power levels that cause noise increase can be calculated.

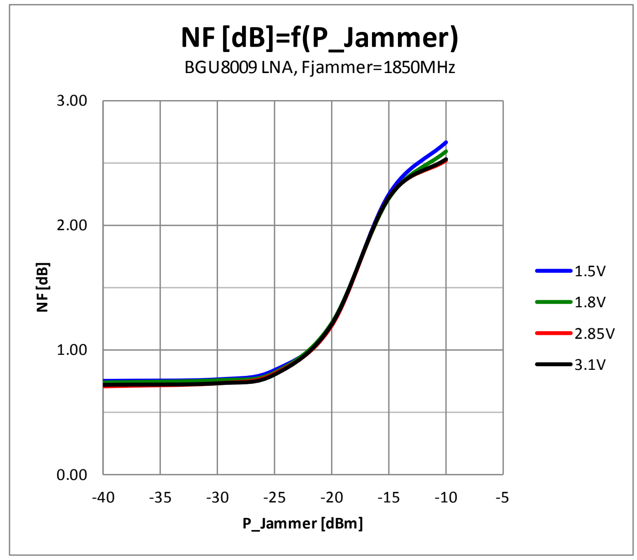
As can be seen in Fig 12, with a 850 MHz jammer the NF of the LNA starts to increase at P_{jam} = -25 dBm (input jammer power at LNA-board, taking into account the approx 20 dB attenuation of the directional coupler and RF-cable from Jammer-Generator to the directional coupler). For the 1850 MHz jammer the NF of the LNA starts to increase at P_{jam} = -30 dBm (see Fig 13).



Incl. the losses of the connectors and the PCB.

Measured at T_{anb} = 25 °C.

Fig 12. NF versus jammer power at 850 MHz



Incl. the losses of the connectors and the PCB.

Measured at T_{anb} = 25 °C.

Fig 13. NF versus jammer power at 1850 MHz

9. Typical LNA evaluation board results

Table 2. Typical results measured on the evaluation boards

Operating Frequency is f = 1575.42 MHz unless otherwise specified; Temp = 25 °C

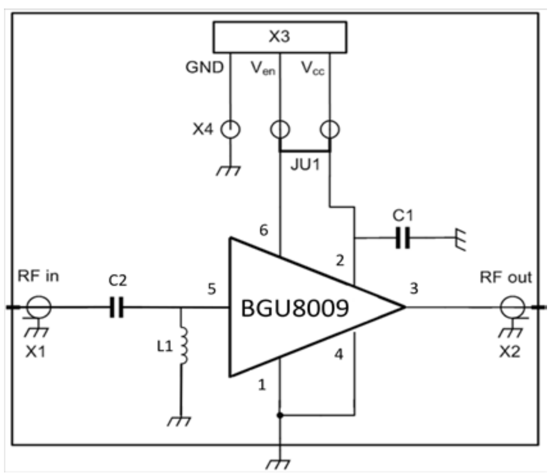
Parameter	Symbol	LNA EVB	LNA EVB	LNA EVB	LNA EVB	Unit	Remarks
Supply Voltage	V_{CC}	1.5	1.8	2.85	3.1	V	
Supply Current	I_{CC}	3.9	4.2	4.4	4.4	mA	
Noise Figure	NF	0.7	0.7	0.7	0.7	dB	[1]
Power Gain	G_p	17.4	17.6	17.8	17.8	dB	
Input Return Loss	RL_{in}	8.5	9	9	9	dB	
Output Return Loss	RL_{out}	15	15	15	15	dB	
Reverse Isolation	ISO_{rev}	37	37	37	37	dB	
Input 1dB Gain Compression	P_i1dB	-12.2	-10	-7	-7	dBm	
Output 1dB Gain Compression	P_o1dB	4.2	6.6	9.8	9.8	dBm	
Input third order intercept point	IIP3	-3.4	3	6	6	dBm	[2]
Output third order intercept point	OIP3	14	20.6	23.8	23.8	dBm	[2]
Power settling time	T_{on}	<2	< 2	< 2	< 2	µs	
	T_{off}	<1	< 1	< 1	< 1	µs	

[1] The noise figure and gain figures are measured at the SMA connectors of the evaluation board. The losses of the connectors and the PCB of approximately 0.05 dB are not subtracted. Measured at T_{anb} = 25 °C.

[2] Out of band IP3, jammers at f_1=f+138MHz and f_2=f+276MHz, where f=1575.42MHz. $P_{in}(f_1)=P_{in}(f_2)$=-20dBm

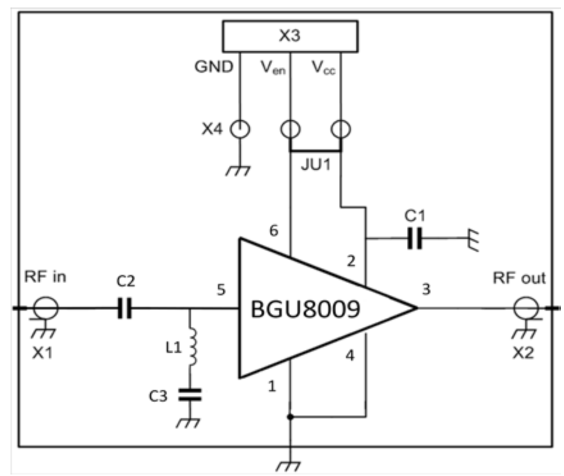
10. LTE rejection input match

The second harmonic of an LTE-signal (788MHz) falls into the GNSS-band (2x 788MHz = 1576MHz) and can be responsible for a reduction of the sensitivity of the GNSS-system. With a modified input circuit for the GNSS-LNA, the incoming LTE-signal can be reduced. Fig 14 and Fig 15 show a 2- and 3-element LTE-reduction input matching circuit designed for the BGU8009 LNA. The BOM is given in Table 3.



P_H2 ~ -60dBm (input referred)

Fig 14. LNA EVB with 2 element LTE rejection input match



P_H2 ~ -113dBm (input referred)

Fig 15. LNA EVB with 3 element LTE rejection input match

Table 3. BOM of the BGU8009 with 2 and 3 element LTE rejection input match

Designator	Description	Footprint	Value	Supplier Name/type	Comment
A	BGU8009	1.1x0.9x0.5mm, 0.4mm pitch		NXP	SOT1230.
PCB		20x35mm		BGU8009 GNSS LNA EV Kit	
C1	Capacitor	0402	1nF	Murata GRM1555	Decoupling
C2	Capacitor	0402	2.2pF	Murata GRM1555	Decoupling
C3	Capacitor	0402	7.5pF	Murata GRM1555	Decoupling
L1	Inductor	0402	5.6nH	Murata LQW15	Input matching
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				

The measurement setup is given in Fig 16. A notch is used to reduce the second harmonic caused by the input generator. A 10dB attenuator is used to get a good 50Ω impedance (some notch-filters have an output-impedance which is not 50Ω over a wide frequency range).

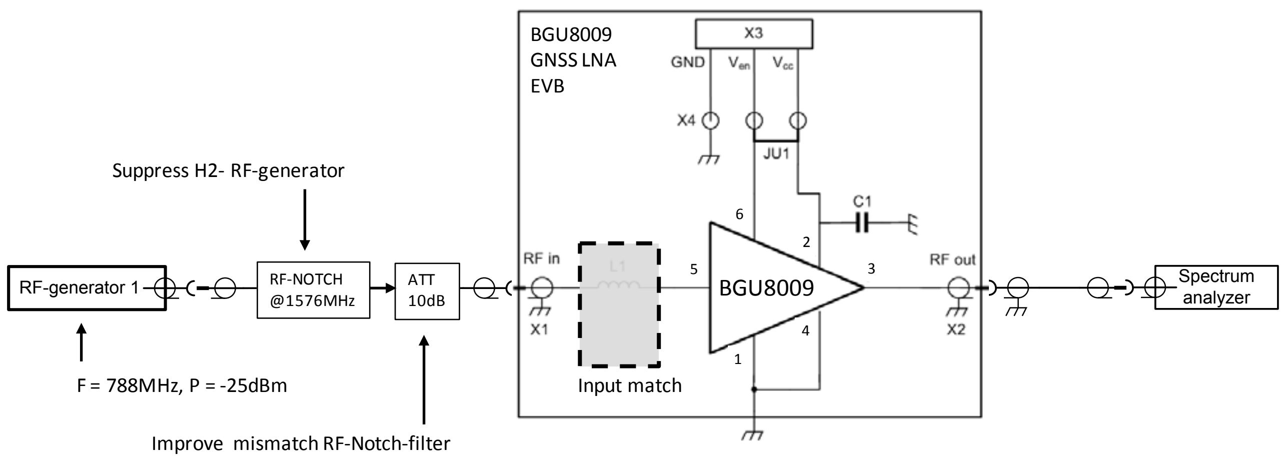


Fig 16. LTE rejection input match measurement setup (LNA evaluation board)

Fig 17 shows the Gain as function of frequency for the default LNA circuit, the 2- and the 3-element LTE-reduction input circuits. Table 4 shows an overview of the measured performance of the 3 input-circuit configurations.

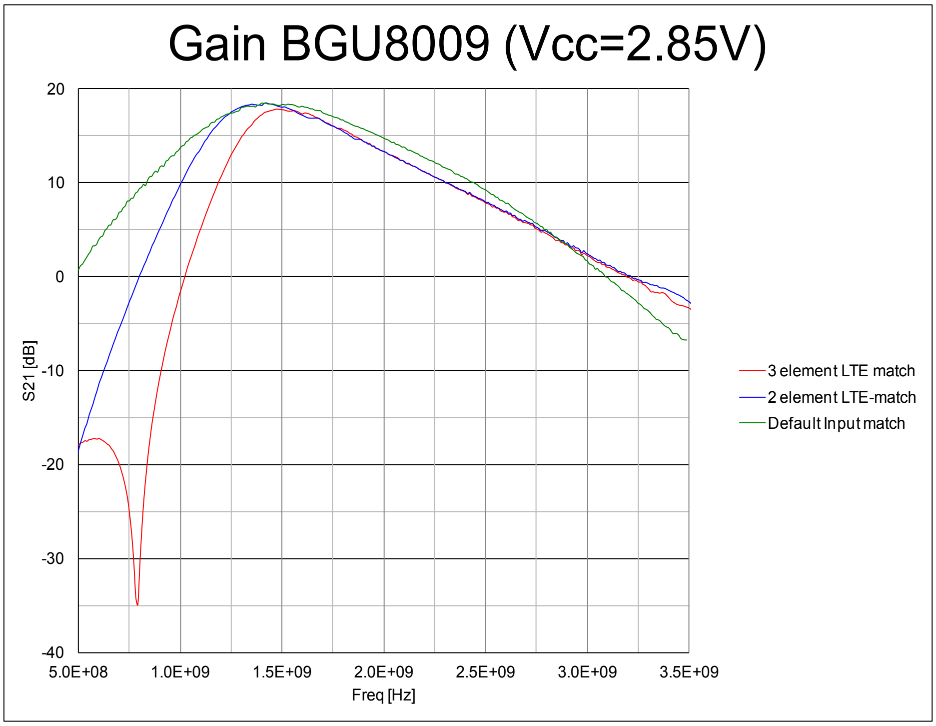


Fig 17. Gain of 3 different input match configurations

Table 4. Measured performance of 3 different input match configurations

Operating Frequency is f = 1575.42 MHz unless otherwise specified; Temp = 25 °C

Parameter	Symbol	Default Input circuit	2 el. inp. LTE rej. circuit	3 el. inp. LTE rej. circuit	Unit	Remarks
Supply Voltage	V_{CC}	2.85	2.85	2.85	V	
Supply Current	I_{CC}	4.4	4.4	4.4	mA	
Noise Figure	NF	0.7	0.9	1.0	dB	[3]
Power Gain	G_p	17.8	17.4	17.4	dB	
Input Return Loss	RL_{in}	9	9	11	dB	
Output Return Loss	RL_{out}	15	15	15	dB	
Reverse Isolation	ISO_{rev}	37	37	37	dB	
P_H2 (input referred)	P_H2	-43	-60	-113	dBm	[4]
Input 1dB Gain Compression	P_i1dB	-7	-6.6	-6.6	dBm	
Output 1dB Gain Compression	P_o1dB	9.8	9.8	9.8	dBm	
Input third order intercept point	IIP3	6	6.4	6.4	dBm	[5]
Output third order intercept point	OIP3	23.8	23.8	23.8	dBm	[5]

[3] The noise figure and gain figures are measured at the SMA connectors of the evaluation board. The losses of the connectors and the PCB of approximately 0.05 dB are not subtracted. Measured at T_{anb} = 25 °C.

[4] F_{in} = 788MHz, P_{in} = -25dBm

[5] Out of band IP3, jammers at f_1=f+138MHz and f_2=f+276MHz, where f=1575.42MHz. $P_{in}(f_1)=P_{in}(f_2)$=-20dBm

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