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BGU8309 GNSS LNA + B13 notch filter evaluation board

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1. Introduction

NXP Semiconductors' BGU8309 Global Navigation Satellite System (GNSS) LNA Evaluation Board is designed to evaluate the performance of the GNSS LNA using:

- NXP Semiconductors' BGU8309 GNSS Low Noise Amplifier
- A matching inductor
- A decoupling capacitor
- Input notch filter for the B13 LTE band

NXP Semiconductors' BGU8309 is a low-noise amplifier for mobile and wearable receiver applications in an extremely small package at 0.8 mm x 0.8 mm x 0.35 mm: SOT1226-2. The BGU8309 features a gain of 17 dB and a noise figure of 0.65 dB at a current consumption of 3.6 mA. Its sufficient linearity performance removes interference and noise from co-habitation cellular transmitters, while retaining sensitivity. The LNA and its components occupy a total PCB area of approximately 2.3 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. The application contains a notch filter to suppress the LTE B13 band.

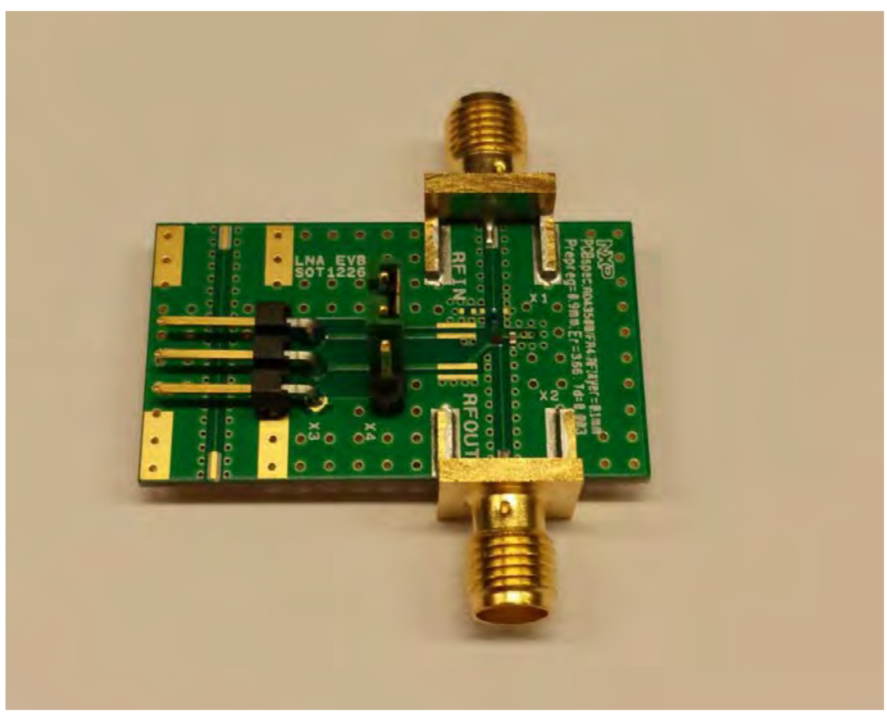

Fig 1. BGU8309 GNSS LNA evaluation board

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 smart phones and tablets 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 mobile and wearable applications. 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 GNSS LNA, which improves the sensitivity by amplifying the wanted GNSS signal with a low-noise amplifier.

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.

3. BGU8309 GNSS LNA evaluation board

The BGU8309 LNA evaluation board simplifies the RF evaluation of the BGU8309 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 BGU8309 including the input series inductor and decoupling capacitor. A notch filter at the input suppresses the B13 LTE band. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The BGU8309 can operate from a 1.5 V to 3.1 V single supply and consumes typical 3.6 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.

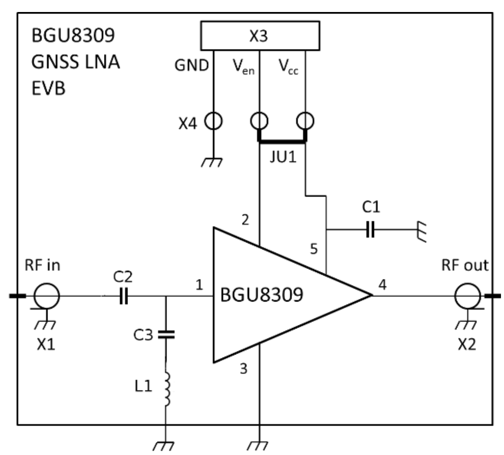

Fig 2. Circuit diagram of the BGU8309 LNA evaluation board

3.2 PCB Layout

The layout of the BGU8309 PCB is given in Fig 3. An extra 50Ω trough-line track is added to this PCB (left side) to check the board losses and matching of the 50Ω lines.

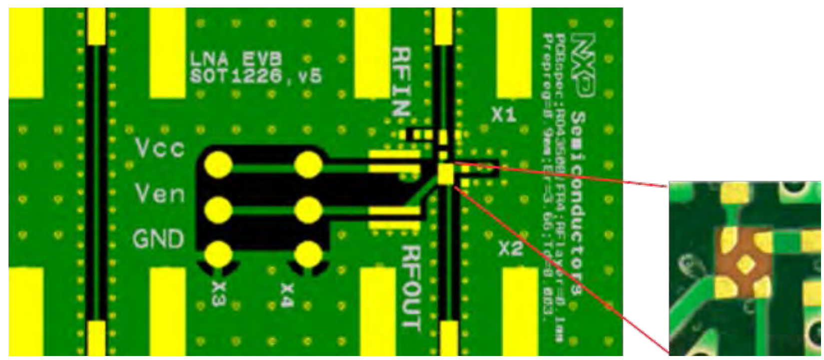

Fig 3. Printed-Circuit Board layout of the BGU8309 LNA evaluation board with detail of the footprint (right).

A good PCB layout is an essential part of an RF circuit design. The LNA evaluation board of the BGU8309 can serve as a guideline for laying out a board using the BGU8309.

- 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 essential for good RF performance. Either connect the GND pins directly to the ground plane or through vias, or do both, which is recommended.
- To ensure optimal performance of BGU8309 in the application it is advised to simulate the overall application performance using the S-parameter and noise models of the device, the models for the external components (SAW filter, input inductor) and the models for the PCB. Models for the BGU8309 are available via www.nxp.com.

The material that has been used for the evaluation board is Rogers RO4350B using the stack shown in Fig 4. The footprint uses a blind-via to the GND plane (metal-2).

(1) Material supplier is RO4350B; $\varepsilon_r = 3.66$: $T\delta = 0.0037$

Fig 4. Stack of the PCB material

3.3 Bill of materials

Table 1. BOM of the BGU8309 GNSS LNA evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
-	BGU8309	0.8 mm x 0.8 mm x 0.35 mm		NXP	WLCSP
PCB		20 x 35mm		BGU8309 GNSS LNA EV Kit	
C1	Capacitor	0402	1nF	Murata GRM1555	Decoupling
C2	Capacitor	0402	2.2 pF	Murata GRM1555	Matching
C3	Capacitor	0402	6.8 pF	Murata GRM1555	Notch filter
L1	Inductor	0402	6.2 nH	Murata LQW15	Notch filter
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				

3.4 BGU8309 product description

NXP Semiconductors' BGU8309 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 BGU8309. The BGU8309 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 BGU8309 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 four external components to build a GNSS LNA with notch filter having the following advantages:

- Low noise
- System optimized gain
- High linearity under jamming
- Notch filter for the B13 LTE band
- 0.8 mm x 0.8 mm x 0.35 mm: SOT1226
- Low current consumption
- Short power settling time

3.5 Series inductor

The evaluation board is supplied with Murata LQW15 series inductors of 4.7 nH and 15 nH. These are wire wound types with high quality factor (Q) and low series resistance (Rs) (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 ESR the noise performance will degrade.

The notch filter contains high-Q components (Murata LQW15 series for the inductor and Murata GRM1555 series for the capacitor) to avoid noise performance degradation.

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

4. Typical LNA evaluation board results

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 BGU8309 are described. First the s-parameters are depicted with and without the notch filter. Third-Order Intercept points are described in more detail in a separate User Manual: UM10453: 2-Tone Test BGU7005 and BGU7007 GNSS LNA.

4.1 S-parameters

Figure 5 depicts the s-parameters of the LNA with the LTE B13 notch filter.

Next picture shows the s-parameters of the application. The S21 forward transmission shows a notch at 750 MHz. In the pass band the gain of the application is approx. 17 dB.

The S11 and S22 are around 10 dB but can be improved when adding an in- and output matching network.

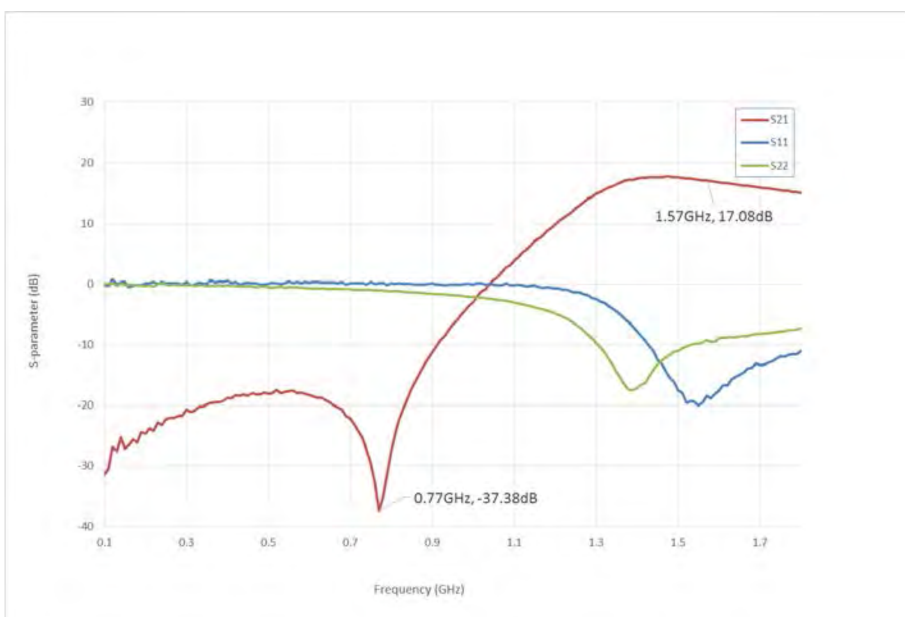

Fig 5. S-parameters of the circuit with the LTE B13 notch filter

Figure 6 depicts the s-parameters of the LNA without the LTE B13 notch filter.

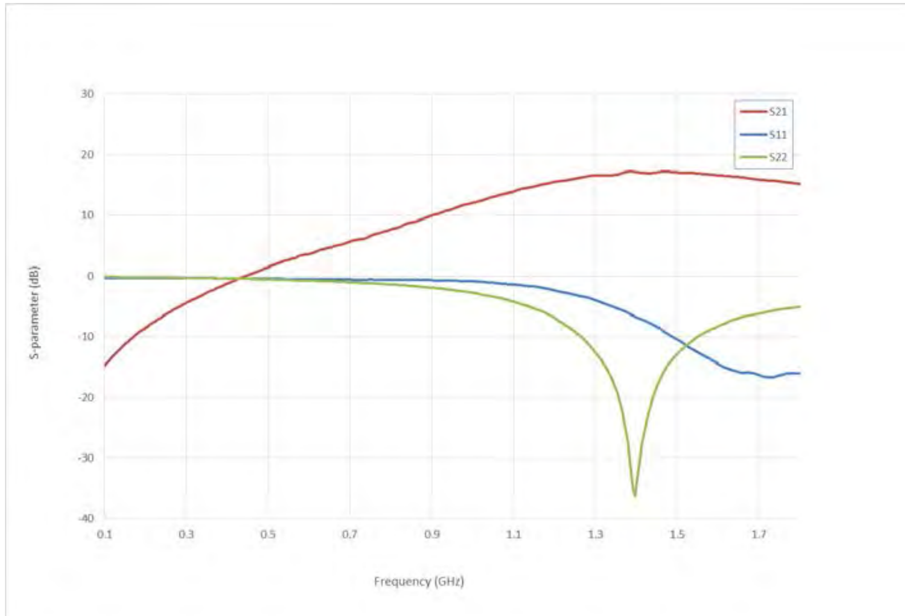

Fig 6. S-parameters of the circuit without the LTE B13 notch filter

4.2 In-band 1dB gain compression

The in-band P1dB compression point is measured with different supply voltages. The used CW frequency is 1580 MHz.

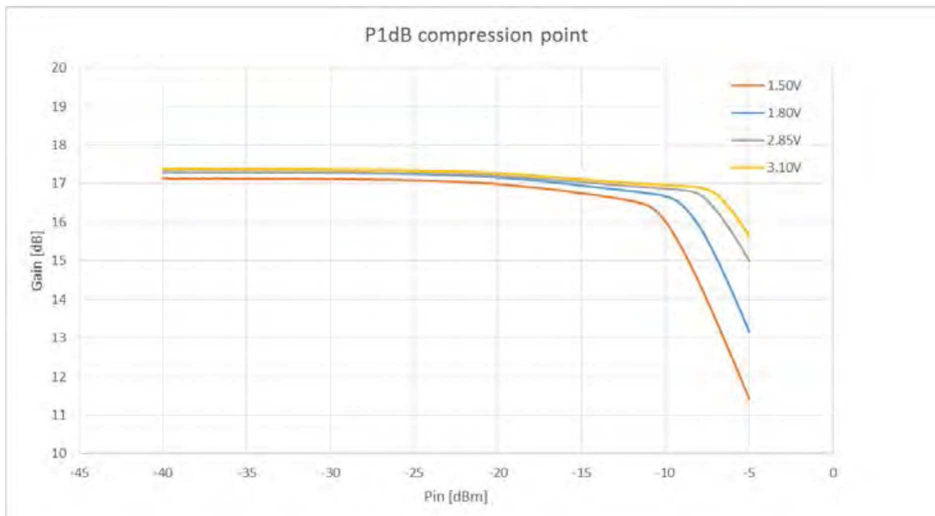

Fig 7. P1dB compression point results

Table 3. P1dB compression point at different supply voltages

Supply Voltage	IP1dB	OP1dB	Unit
1.50 V	-10.3	5.9	dBm
1.80 V	-8.7	7.6	dBm
2.85 V	-7.1	9.3	dBm
3.10 V	-6.2	10.2	dBm

4.3 Intermodulation distortion

The IM3 measurement is performed with two-tones with a separation of 138 MHz.

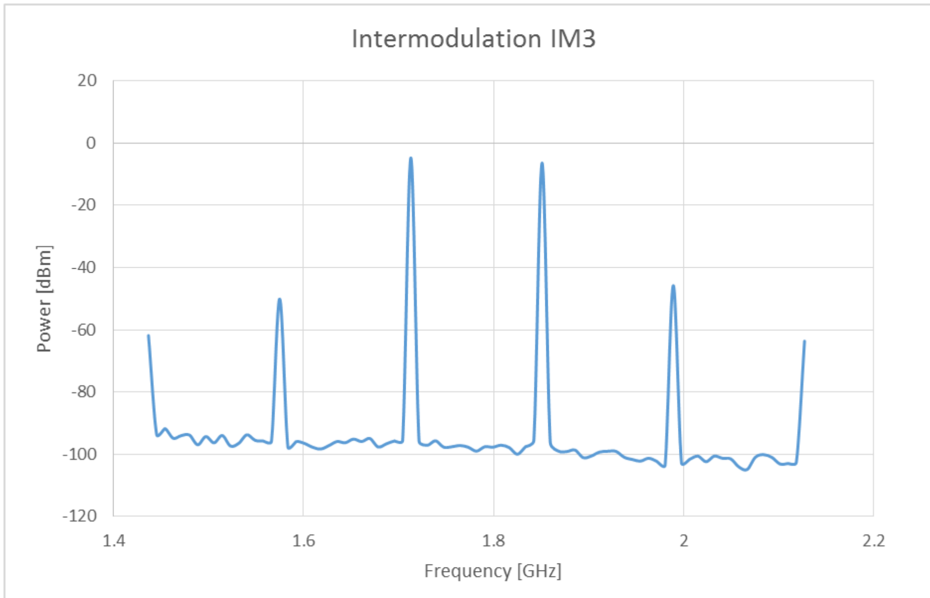

Fig 8. IM3 measurement

The calculated OIP3 point is at different supply voltages is shown in Table 4.

Table 4. Calculated OIP3 at different supply voltages

Supply Voltage	LSB_OIP3	USB_OIP3	Unit
1.50 V	15.6	13.7	dBm
1.80 V	16.1	14.0	dBm
2.85 V	17.1	14.1	dBm
3.10 V	17.2	14.2	dBm

4.4 Noise figure

The noise figure is measured at different operating voltages. Next picture shows the results of these measurements:

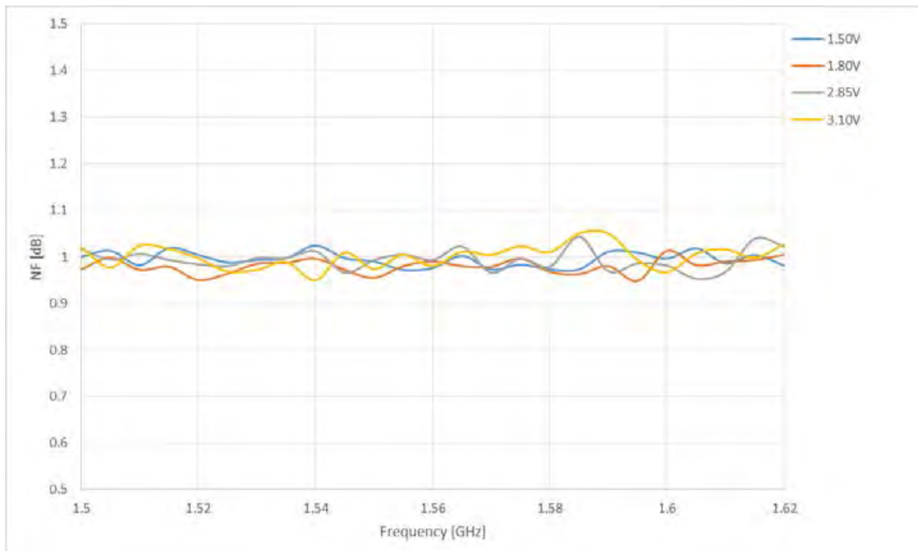

Fig 9. Noise figure measurements

The noise figure is independent of the supply voltage and is measured around 1.0 dB.

4.5 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.

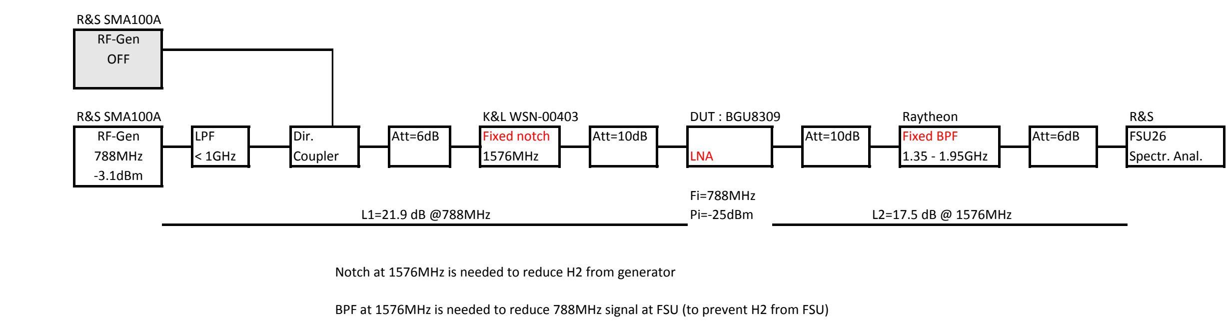

Fig 10. LTE rejection input match measurement setup (LNA evaluation board)

Table 5. LTE rejection results

Operating temp = 25°C.

Gain [dB]	Vcc [V]	Icc [mA]	H2_FSU [dBm]	H2_out [dBm]	H2_in [dBm]
17	1.8	3.6	-125.0	-107.5	-124.5
17	2.85	3.7	-126.0	-108.5	-125.5

Table 6. Measured performance of 2 different input match configurations

Operating frequency is f = 1576 MHz unless otherwise specified. Temp = 25°C.

Parameter	Symbol	Default input circuit	3 el. Inp LTE rej. circuit	Unit	Remarks
Supply voltage	Vcc	2.85	2.85	V	
Supply current	Icc	4.2	4.2	mA	
Noise Figure	NF		1.0	dB	[1]
Power gain	G_p	16.6	17.1	dB	
Input return loss	RL_{in}	-13.5	-19.5	dB	
Output return loss	RL_{out}	-9.1	-9.1	dB	
Reverse Isolation	ISO_{rev}	-22.5	-22.8	dB	
P_H2 (input referred)	P_H2	-45	-125.5	dBm	[2]
Input 1dB Gain Compression	P_{i1dB}		-7.1	dBm	
Output 1dB Gain Compression	P_{o1dB}		9.3	dBm	
Input third order intercept point	LSB_IIP3		0.0	dBm	
	MSB_IIP3		-3.0	dBm	
Output third order intercept point	LSB_OIP3		17.1	dBm	[3]
	USB_OIP3		14.1	dBm	[3]

[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_{amb} = 25 °C.

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

[3] Two tones at f1=f-69MHz and f2=f+69MHz, where f=1782MHz. P_{in}(f1)=-20dBm, P_{in}(f2)=-20dBm.

5. Required 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 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 BGU8309 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 BGU8309.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the V_{en} pin of the BGU8309.
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 3.6 mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around –28 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.

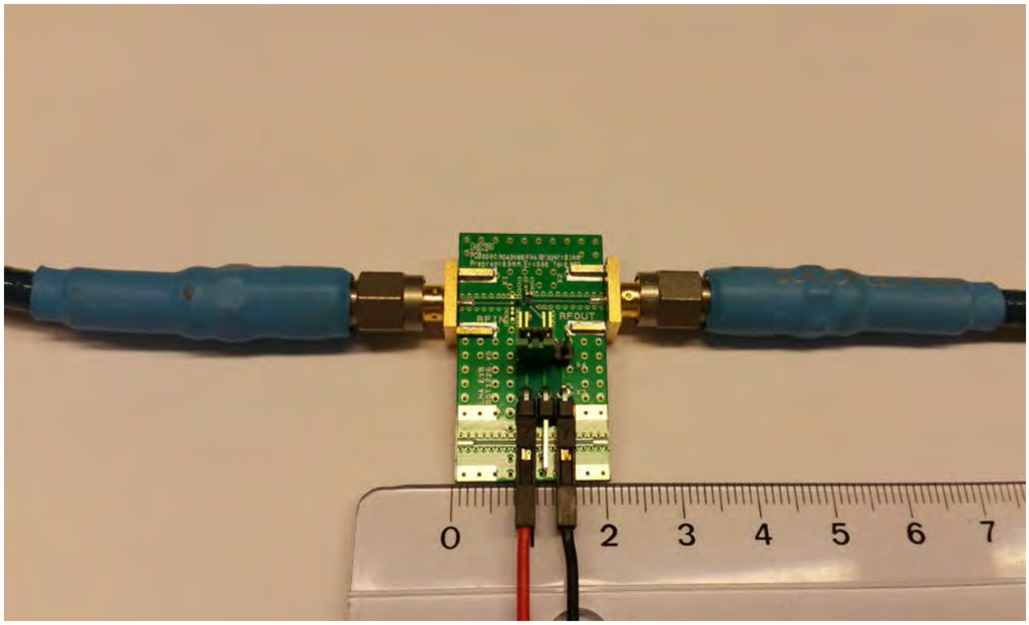

Fig 11. Evaluation board including its connections

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