AN11338

BGU8011 GNSS front end evaluation board

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Document information

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1. Introduction

NXP Semiconductors' BGU8011 Global Navigation Satellite System (GNSS) Front end Evaluation Board (BGU8011 GNSS FE EVB) is designed to evaluate the performance of the GNSS front end using:

- NXP Semiconductors' BGU8011 GNSS Low Noise Amplifier
- A matching inductor
- A decoupling capacitor
- Two identical GNSS band-pass filters

NXP Semiconductors' BGU8011 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^3, 0.4mm pitch. The BGU8011 features gain of 16.3 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 8.4 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.

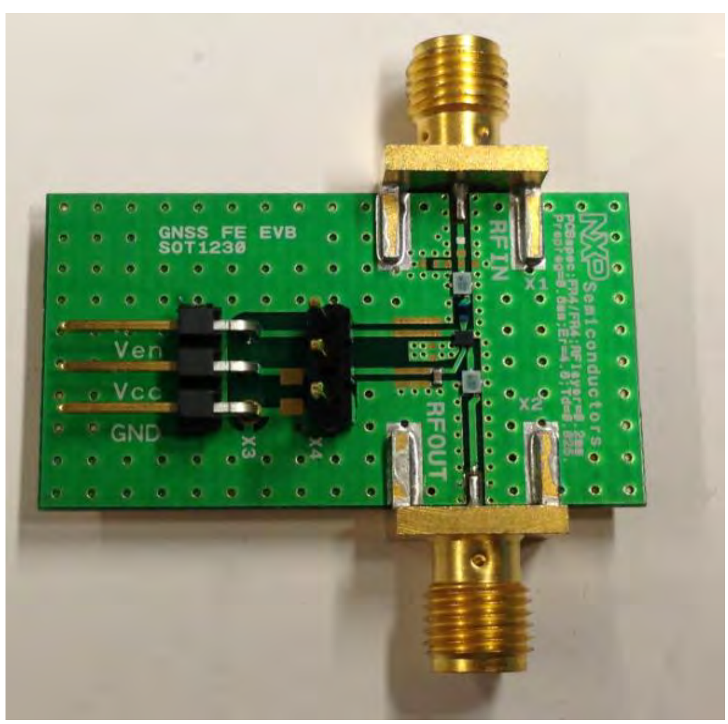


Fig 1. BGU8011 GNSS front end evaluation board

2. General description

Modern smart 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 intermodulation and compression.

Since the GNSS receiver needs to receive signals with an average power level of -130 dBm, sensitivity is very important. Many of the available GNSS ICs have integrated LNA front ends. The noise performance of these integrated LNA front ends, and as a result the system sensitivity, is not always adequate. The GNSS receiver sensitivity is a measure for how accurate the coordinates are calculated. The GNSS signal reception can be improved by a so called GNSS front end, which improves the sensitivity by filtering out the unwanted jamming signals and by amplifying the wanted GNSS signal with a low noise amplifier.

The pre-filters and post filters are needed to improve the overall linearity of the system as well as to avoid overdriving the integrated LNA stage of the GNSS receiver.

3. BGU8011 GNSS front end evaluation board

The BGU8011 front end evaluation board simplifies the RF evaluation of the BGU8011 GNSS LNA applied in a GNSS front end, that is often used in smart phones. The evaluation board enables testing of the device RF performance and requires no additional support circuitry. The board is fully assembled with the BGU8011, including the input series inductor, decoupling capacitor as well as two SAW filters to optimize the linearity performance. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The BGU8011 can operate from a 1.5 V to 3.1 V single supply and consumes about 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.

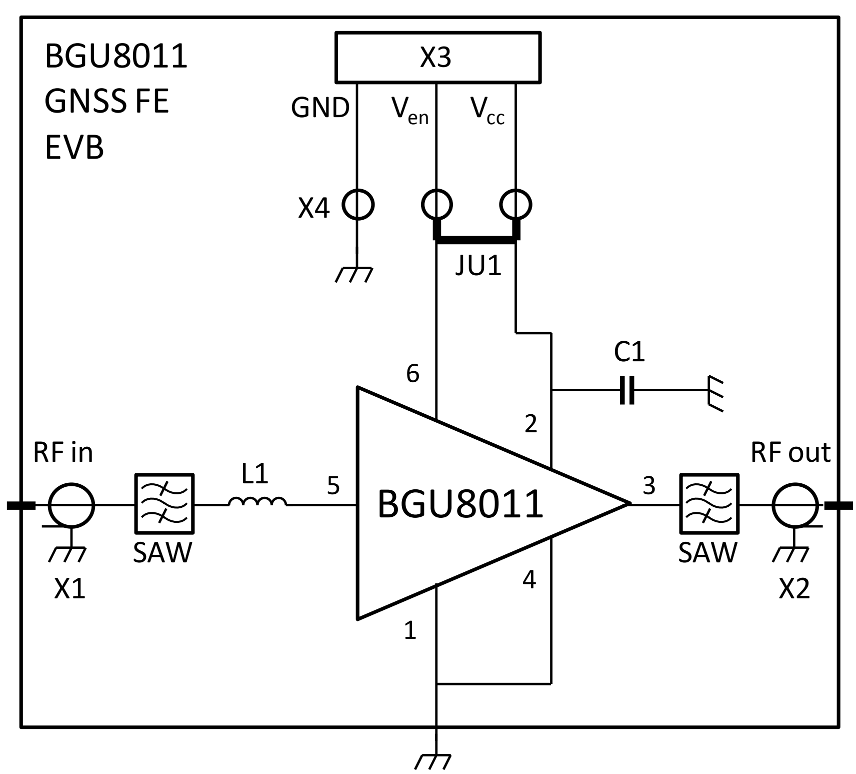


Fig 2. Circuit diagram of the BGU8011 front end evaluation board

3.2 PCB Layout

A good PCB layout is an essential part of an RF circuit design. The front end evaluation board of the BGU8011 can serve as a guideline for laying out a board using the BGU8011. 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 out-of-band rejection of the SAW filters also depends on the grounding of the filter. The material that has been used for the evaluation board is FR4 using the stack shown in Fig 4. The input circuit has also SMD-positions for optional input filtering circuits (not used in this version of the FE EVB).

3.3 Board Layout

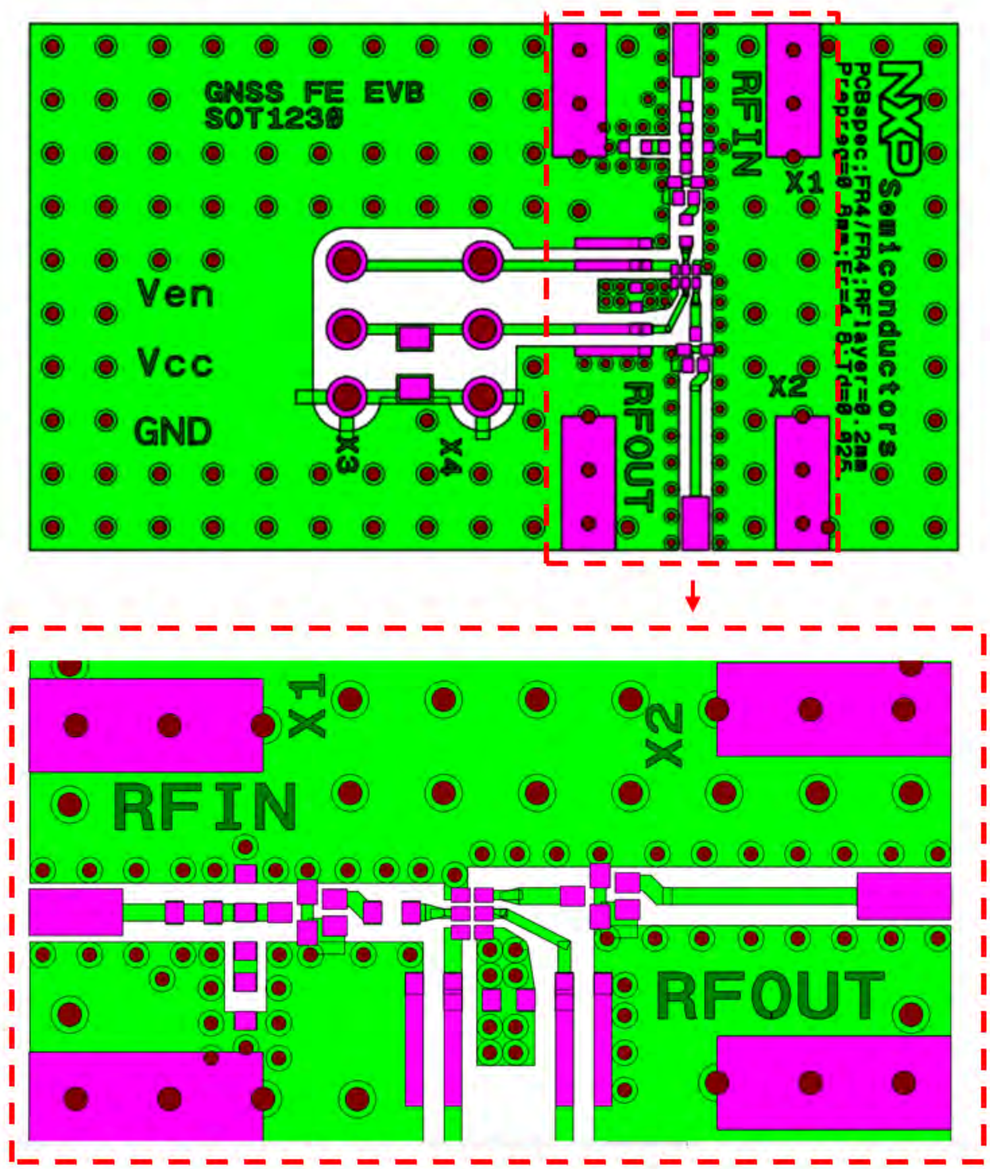


Fig 3. Printed-Circuit Board layout of the BGU8011 front end evaluation board

(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 BGU8011 GNSS front end evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
Marking code: C	BGU8011	1.1 x 0.9 x 0.5 mm^3 0.4 mm pitch		NXP	SOT1230
PCB		20 x 35 mm^2		BGU8011 GNSS FE EV Kit	
C1	Capacitor	0402	1nF	Murata GRM1555	Decoupling
L1	Inductor	0402	5.6nH	Murata LQW15	Input matching
JK	SAW BPF	1.4 x 1.1 x 0.4 mm^3		EPCOS B8313	[1]
X1, X2	SMA RF 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				

[1] Similar performance can also be achieved with GNSS SAW filters from other suppliers. See paragraph 4.2

4.1 BGU8011

By dynamically suppressing strong cellular and WLAN transmit signals, an industry first, these LNAs offer the best reception of weak GPS signals. Linearity improves with a 10 dB better IP3 under -40 to -20 dBm jamming conditions, while NF remains below 1 dB. Requiring only two external components, they save up to 50% in PCB size and 10% in component cost, offering the smallest footprint in the market.

The BGU8011 is a Low Noise Amplifier (LNA) for GNSS receiver applications, available in a small plastic 6-pin extremely thin leadless package. The BGU8011 requires one external matching inductor and one external decoupling capacitor. The BGU8011 adapts itself to the changing environment resulting from co-habitation of different radio systems in modern cellular handsets. It has been designed for low power consumption and optimal performance when jamming signals from co-existing cellular transmitters are present. At low jamming power levels it delivers 16.3 dB gain at a noise figure of 0.65 dB. During high jamming power levels, resulting for example from a cellular transmit burst, it temporarily increases its bias current to improve sensitivity.

4.2 Band pass filters

The band-pass filters that are implemented in the GNSS front end evaluation board are key components regarding the overall system linearity and sensitivity. One of the key performance indicators of these filters is having very high rejection at the different smart phone TX frequencies, and simultaneously having low insertion loss in the GNSS pass-band. The evaluation board is supplied with two EPCOS B8313 SAW-filters (GPS, COMPASS, Galileo and GLONASS). Alternatives to be considered:

1. Murata SAFA1G57KH0F00
2. Murata SAFA1G57KB0F00 low loss variant
3. Fujitsu FAR-F6KA-1G5754-L4AA
4. Fujitsu FAR-F6KA-1G5754-L4AJ

All these filters can use the same footprint. In order to be able to achieve the rejection level as indicated in the data sheet of these filters, it is necessary that the filters are properly grounded. In the layout of the front end evaluation board the suppliers' recommendations have been followed. See Fig 5, please note that every GND pin has its own ground-via and there is a ground path between the input and the output.

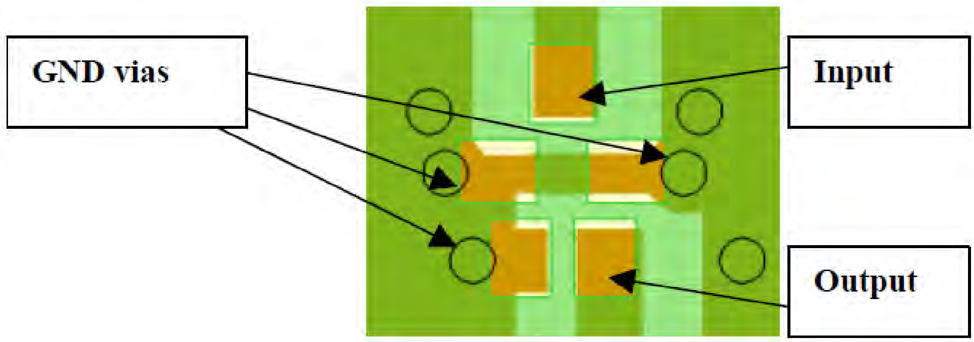


Fig 5. SAW filter footprint

4.3 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 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 BGU8011 GNSS front end evaluation board is fully assembled and tested. Please follow the steps below for a step-by-step guide to operate the front end evaluation board and test 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 BGU8011.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the V_{en} pin of the BGU8011.
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 -40 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 4.4mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around –25 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 15 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 avoided, since this affects the noise figure.

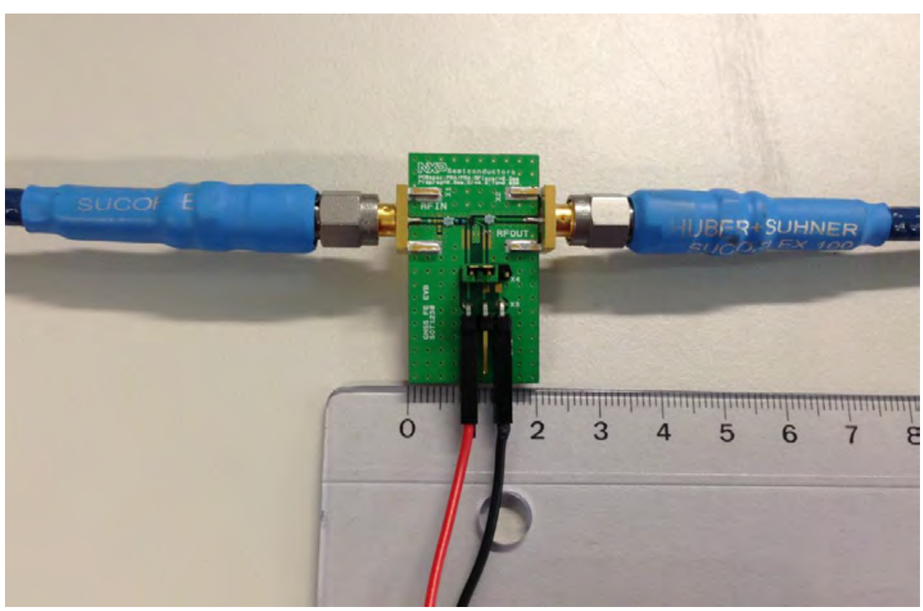


Fig 6. Evaluation board including its connections

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 smart 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 BGU8011 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 GPS LNA.

7.1 Out-of-band input third-order intercept point

This parameter is being measured by a two-tone measurement where the carriers have been chosen as L1+138 MHz and L1+276 MHz. Where L1 is the center of the GNSS band, 1575.42 MHz. So the two carriers are 1713.42 MHz and 1851.42 MHz that can be seen as two TX jammers in UMTS FDD and GSM1800 cell phone systems.

One third-order product ($2f_1$-f_2) generated in the LNA due to amplifier third-order nonlinearities can fall at the desired 1575.42 MHz frequency as follows:
$2f_1$-f_2 = 2(1713.42 MHz)-1851.42 MHz = 1575.42 MHz.

This third-order product can influence the sensitivity of the GNSS receiver drastically. So this third-order intermodulation product needs to be as low as possible, meaning the out-of-band intercept point must be as high as possible.

Fig 7 shows the measurement setup used to measure the out-of-band third order intercept point. Two RF-generators are used to generate the jammers f_1 and f_2. These two jammers are combined by an RF combiner. A notch filter is used to prevent inserting an RF signal at the GNSS frequency into the front end caused by intermodulation of the two generators and RF combiner combination.

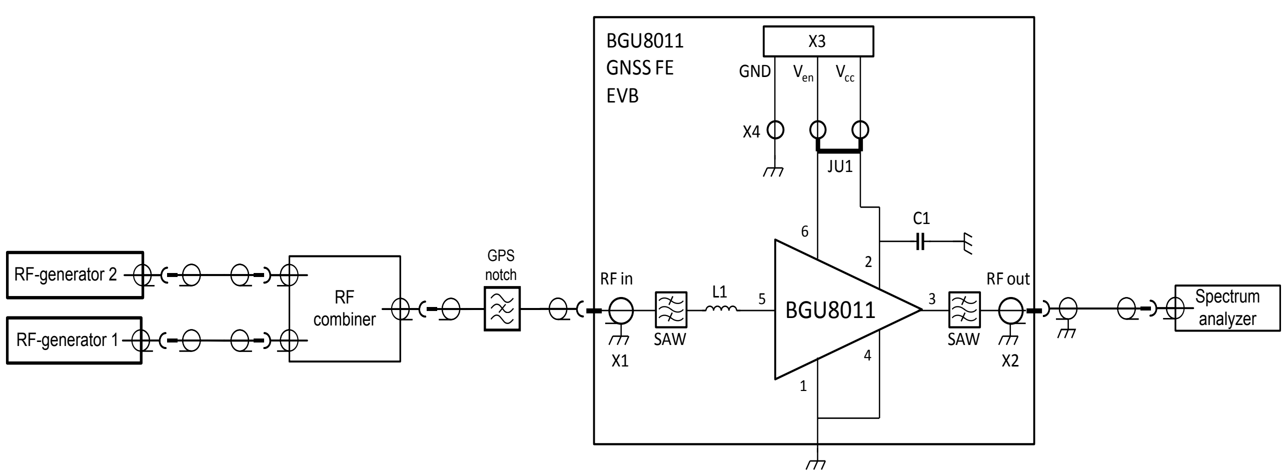


Fig 7. Out-of-band input third order intercept point measurement setup

The input power levels of f_1 and f_2 that have been used to measure the IM3 levels on the front end evaluation board were +10 dBm, shown in Fig 8. Fig 9 shows the IM3 level at the output of the front end, measured at V_{CC} = 2.85 V.

With the levels shown in Fig 8 and Fig 9, the out-of-band input third-order intercept point can be calculated.
As shown in Fig 8 P_{in} of both f_1 and f_2 is +10 dBm.
Left-side OIM3 = -93.7 dBm (see Fig 9)
The gain (G_p) of the front end is 14.9 dB (the typ. insertion loss of the EPCOS B8313 SAW filters is ~0.8dB).

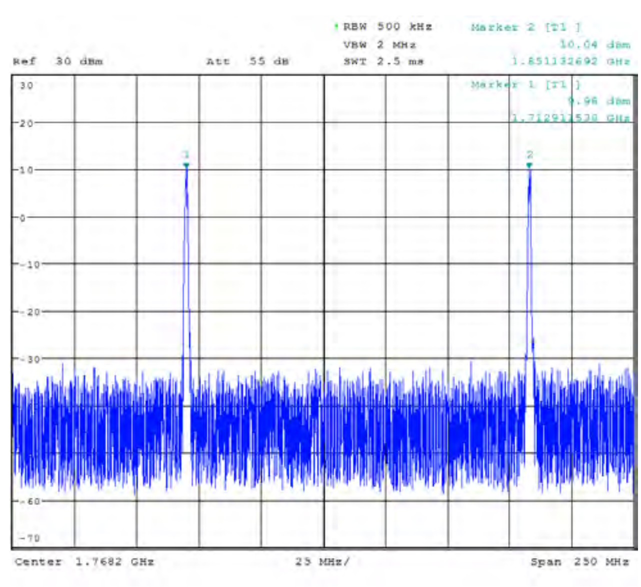


Fig 8. Input jammers for IM3 measurements
f_1=1713MHz/+10dBm and f_2=1851MHz/+10dBm

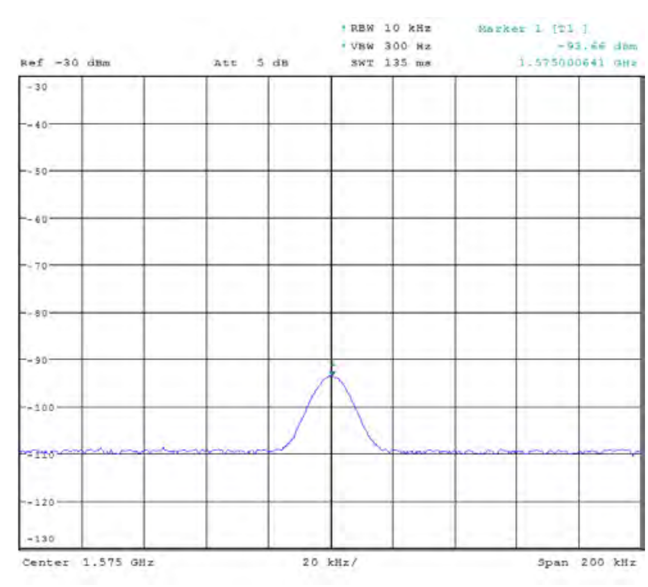


Fig 9. FE output IM3 level at 1575 MHz

7.2 In-band 1dB gain compression due to 787MHz, 850MHz and 1850MHz jammers

For the measurement described below it is necessary to have clean jammer signals with high RF power in order to measure these parameters on the actual front end evaluation board. Since these clean signals are hard to generate, these measurements are performed on a BGU8011 GNSS Low noise amplifier evaluation board (user manual available: AN11337). With the results of these measurements and the typical rejection levels of the band-pass filters at the jamming frequencies, the values valid for the front end evaluation board can be calculated.

As already 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 smart phone TX jammers however is important.

Measurements have been carried out using the setup shown in Fig 10.

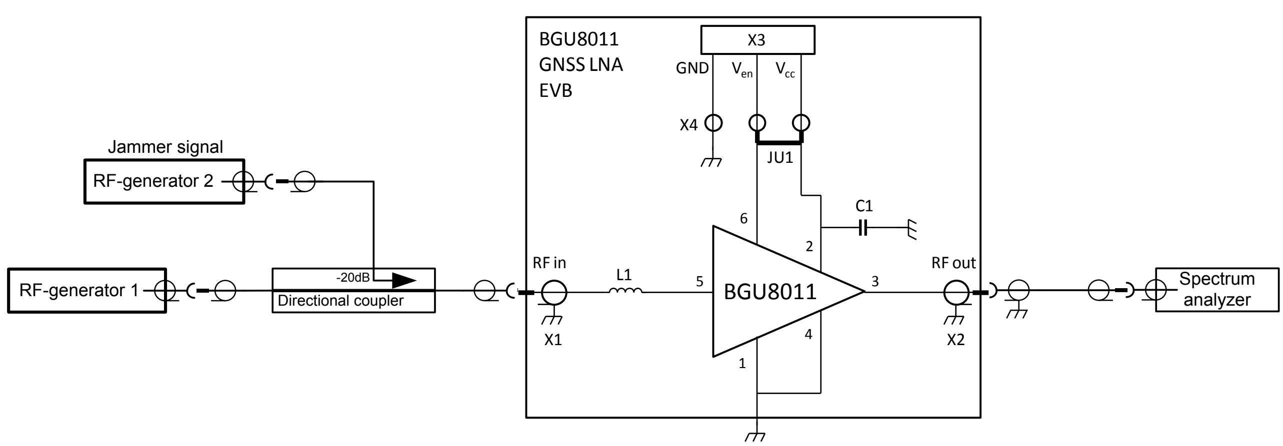


Fig 10. 1dB Gain compression under jamming measurement setup (LNA evaluation board)

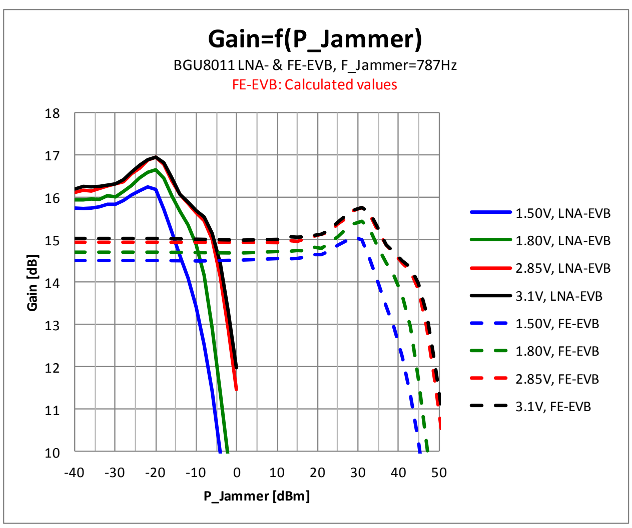
The gain was measured between port RFin and RFout of the EVB at the GNSS frequency, while simultaneously a jammer power signal was swept at 20dB attenuated input of the directional coupler. Please note that the drive power of the jammer is 20dB lower at the input of the DUT caused by the directional coupler. Fig 11, Fig 12 and Fig 13 show the gain compression curves with 787MHz, 850MHz and 1850MHz jammers respectively (taking into account the approx 20 dB attenuation of the directional coupler and RF-cable from Jammer-Generator to the directional coupler).

Calculating the power level at the front end gain with 1 dB compression is done as follows:

At 1 dB gain drop the jammer input power for 850MHz jammer is approx. at -6 dBm (Vcc = 2.85 V, Fig 11). This is for the LNA only. Using the typical rejection of the SAW filter at 850 MHz which is 51dB[(1)] the 1dB compression jammer signal level equals:
-6 + 51 = +45 dBm.

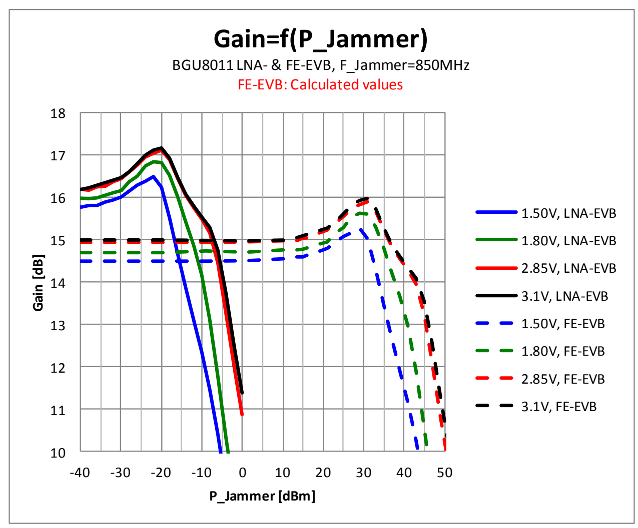
At 1 dB gain drop the jammer input power for 850MHz jammer is approx. at -6 dBm (Vcc = 2.85 V, Fig 12). This is for the LNA only. Using the typical rejection of the SAW filter at 850 MHz which is 51dB[(2)] the 1dB compression jammer signal level equals:
-6 + 51 = +45 dBm.

For 1850 MHz jammer the jammer input power is approx. at -3 dBm (Vcc = 2.85 V, Fig 13). Again this is for the LNA only. Using the typical rejection of the SAW filter at 1850 MHz which is 43 dB[(3)] the 1 dB compression jammer signal level equals: -3 + 43 = +40 dBm.



(Pin 1575 MHz = -45 dBm)

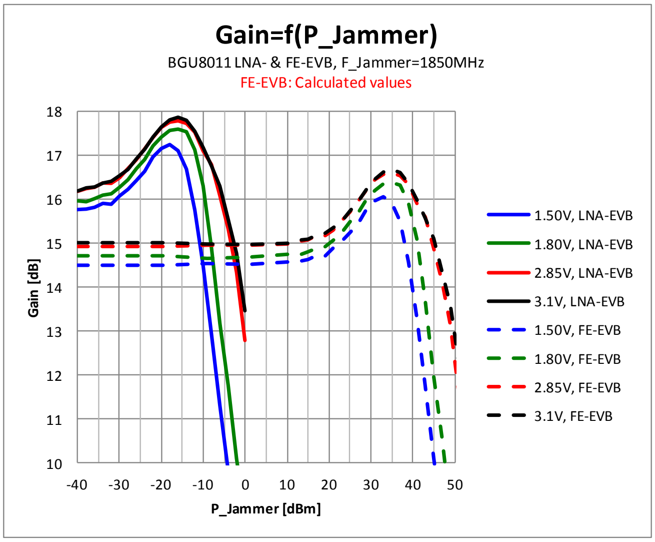
Fig 11. Gain versus jammer power at 787 MHz



(Pin 1575 MHz = -45 dBm)

Fig 12. Gain versus jammer power at 850 MHz

1. Typical rejection at 787MHz from datasheet of EPCOS B8313 SAW filter
2. Typical rejection at 850MHz from datasheet of EPCOS B8313 SAW filter
3. Typical rejection at 1850MHz from datasheet of EPCOS B8313 SAW filter



(Pin 1575 MHz = -45 dBm)

Fig 13. Gain versus jammer power at 1850 MHz

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

For the measurement described below it is necessary to have clean jammer signals with high RF power in order to measure these parameters on the actual front end evaluation board. Since these clean signals are hard to generate, these measurements are performed on a BGU8011 GNSS Low noise amplifier evaluation board (user manual available: AN11230). With the results of these measurements and the typical rejection levels of the band-pass filters at the jamming frequencies, the values valid for the front end evaluation board can be calculated.

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 14 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.

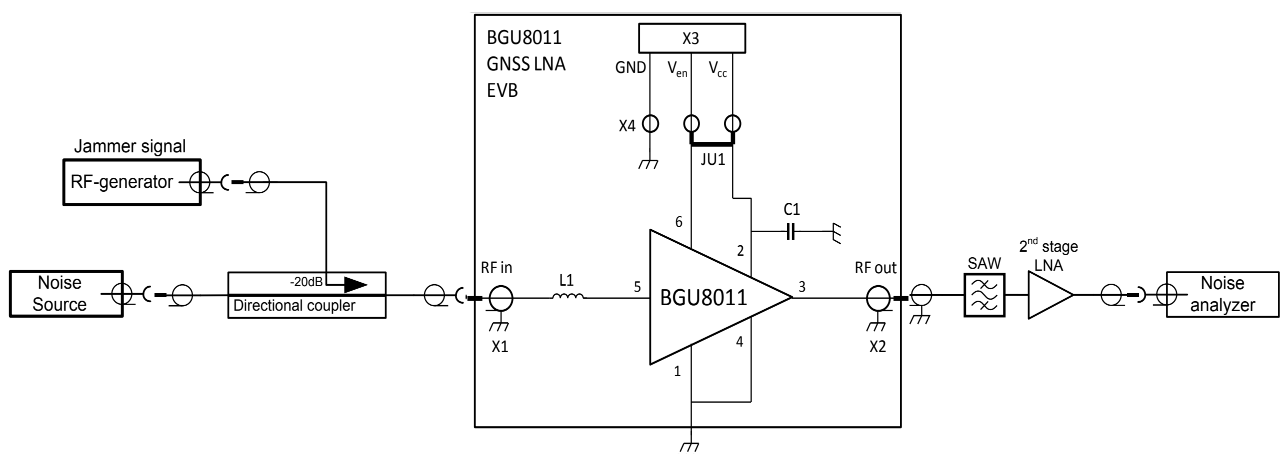


Fig 14. Noise under jamming measurement setup (LNA evaluation board)

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

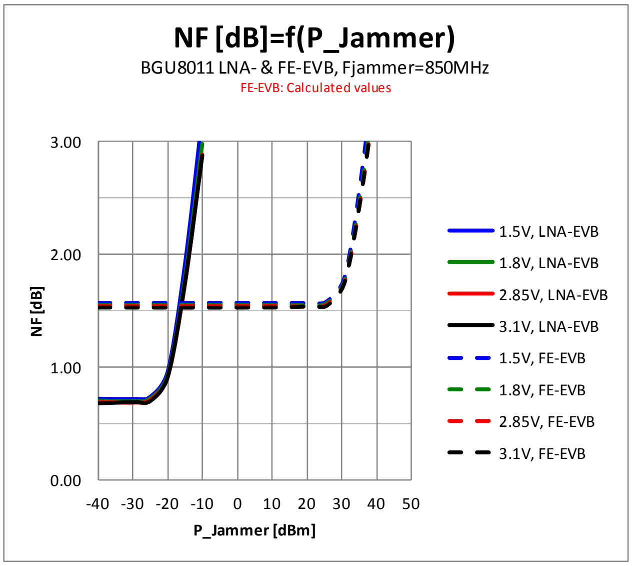
Calculating the power level at which the front end noise starts to increase is done as follows:

As can be seen in Fig 15 with a 850 MHz jammer the LNA starts increasing the noise at P_{jam} = -25 dBm (Vcc = 2.85 V). For the front end the TX rejection of the first BPF needs to be added. For the SAW filter used the rejection at 850 MHz is 51 dB[4]. This means the noise of the front end will start increasing at an 850 MHz jammer level of P_{jam} = -25 + 51 = +26 dBm.

For the 1850 MHz jammer the LNA noise starts to increase at P_{jam} = -30 dBm (Vcc = 2.85 V, see Fig 16). The rejection of the SAW filter at 1850 MHz is 43 dB[5]. This means the

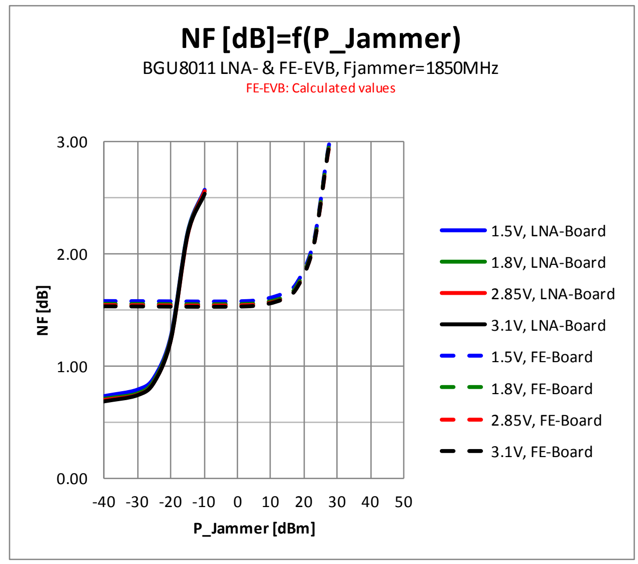
4. Rejection at 850MHz from datasheet of EPCOS B8313 SAW filter
5. Rejection at 1850MHz from datasheet of EPCOS B8313 SAW filter

noise of the front end will start increasing at an 1850 MHz jammer level of P_{jam} = -30 +43 = +13 dBm.



Incl. the losses of the connectors and the PCB.
Measured at T_{anb} = 25 °C.

Fig 15. NF at 1575 MHz versus jammer power at 850 MHz



Incl. the losses of the connectors and the PCB.
Measured at T_{anb} = 25 °C.

Fig 16. NF at 1575 MHz versus jammer power at 1850 MHz

9. TX rejection levels

When measuring the front end evaluation board the input level of the network analyzer has to be on -45 dBm to avoid activating the adaptive biasing. This low input level results in a very inaccurate measurement result of the TX rejection. Fig 17 and Fig 18 show the typical TX rejection levels measured more accurate due to segmented power calibration.

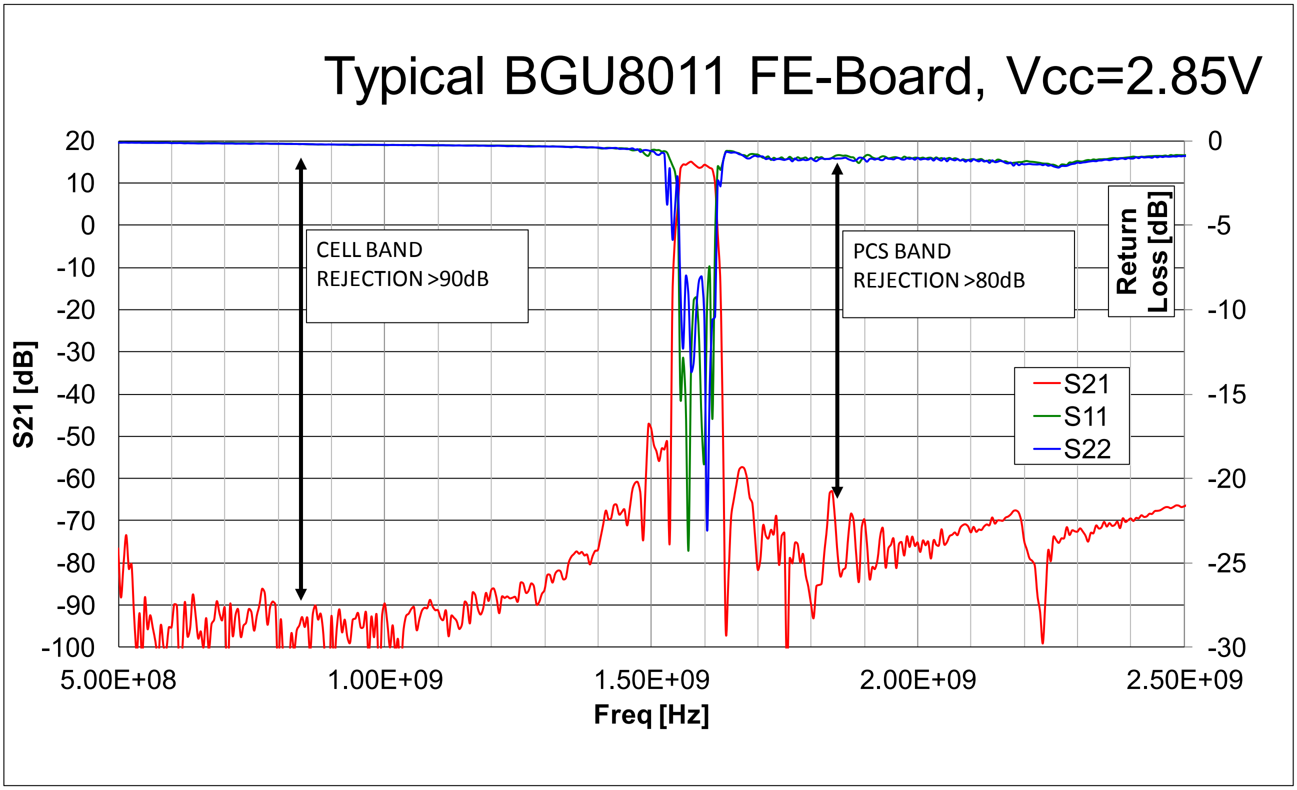


Fig 17. Typical S-parameter plot at Vcc = 2.85 V

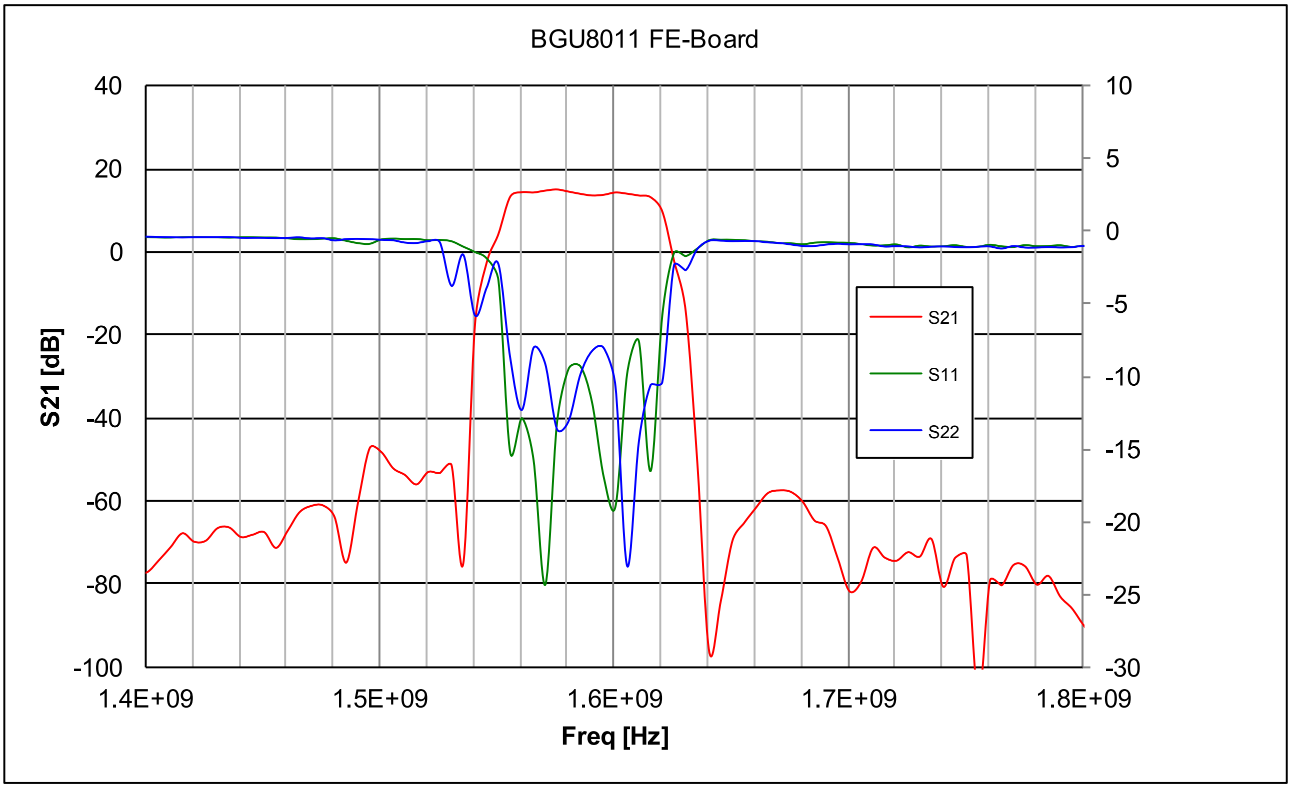


Fig 18. Typical pass band response at Vcc = 2.85 V

10. LTE rejection level

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. To test the Second Harmonic (H2) –performance, a measurement has been done.

The measurement setup is given in Fig 19. 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).

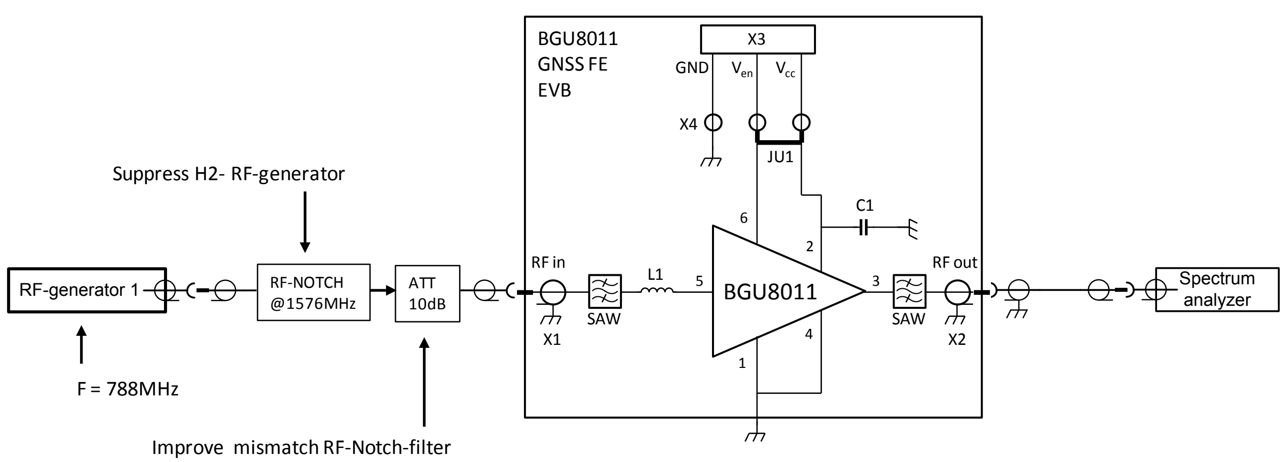


Fig 19. LTE rejection measurement setup (LNA evaluation board)

Table 2 shows an overview of the measured performance (as comparison also the P_H2 results of the BGU8011 LNA-EVB is given; source: AN11288, BGU8011 GNSS LNA evaluation board).

Table 2. Measured performance of BGU8011 LNA- and FE EVB's

Vcc=2.85V, Icc ~4.7mA, Temp = 25 °C

Parameter	Symbol	P_{in}=0dBm	P_{in}=+5dBm	P_{in}=+10dBm	Unit	Remarks
P_H2 (input referred)	P_H2	-102	-92	-82	dBm	[1]

[1] F_{in} = 788MHz, F_{meas} = 1576MHz.

11. Typical front end evaluation board results

Table 3. Typical results measured on the evaluation boards
Operating Frequency is f = 1575.42 MHz unless otherwise specified; Temp = 25 °C

Parameter	Symbol	FE EVB	FE EVB	FE EVB	FE EVB	Unit	Remarks
Supply Voltage	V_{CC}	1.5	1.8	2.85	3.1	V	
Supply Current	I_{CC}	4.1	4.2	4.4	4.5	mA	
Noise Figure	NF	1.6	1.6	1.5	1.5	dB	[2]
Power Gain	G_p	14.5	14.7	14.9	15.0	dB	
Input Return Loss	RL_{in}	11.8	12.3	12.8	12.9	dB	
Output Return Loss	RL_{out}	13.8	13.6	13.5	13.5	dB	
Reverse Isolation	ISO_{rev}	29.4	29.4	29.5	29.5	dB	
Input 1dB Gain Compression	P_i1dB	-9.6	-7.8	-5.2	-5.0	dBm	
Output 1dB Gain Compression	P_o1dB	3.8	5.8	8.8	9.0	dBm	
Input 1dB Gain Compression jammer level at 850MHz	P_i1dB_{850MHz}			+40		dBm	[4]
Input 1dB Gain Compression jammer level at 1850MHz	$P_i1dB_{1850MHz}$			+45		dBm	[4]
P_H2 (input referred)	P_H2			-82		dBm	[3][4]
Cell band rejection at 850 MHz relative to 1575.42 MHz	TX_rej_{850MHz}			>90		dBc	[4]
Cell band rejection at 1850 MHz relative to 1575.42 MHz	$TX\_rej_{1850MHz}$			>80		dBc	[4]
Output third order intermod.	OIM3			-93.7		dBm	[5]
Power settling time	T_{on}	< 2	< 2	< 2	< 2	µs	
	T_{off}	< 1	< 1	< 1	< 1	µs	

[2] 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 0.1dB are not subtracted. Measured at T_{anb} = 25 °C.

[3] F_{in} = 788MHz, Pin = +10dBm, F_{meas} = 1576MHz.

[4] These parameters are mainly determined by the TX rejection levels of the used BPFs, in this case the EPCOS B8313 SAW filter, but the performance can also be achieved with the use of GNSS SAW filters from other suppliers that are on the market.
See paragraph 4.2.

[5] Out of band IM3-component (OIM3) at 1575MHz, jammers at f_1=f+138MHz and f_2=f+276MHz, where f=1575MHz.
$P_{in}(f_1)=P_{in}(f_2)$=+10dBm

12. Legal information

12.1 Definitions

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