**Document information**

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1. Introduction

NXP Semiconductors' BGU8004 Global Navigation Satellite System (GNSS) LNA Evaluation Board (BGU8004 GNSS LNA EVB) is designed to evaluate the performance of the GNSS LNA using:

- NXP Semiconductors' BGU8004 GNSS Low Noise Amplifier;
- A matching inductor;
- A decoupling capacitor

Currently the world’s smallest GNSS LNA at 0.65mm x 0.44mm, BGU8004 features gain of 17.2 dB and a noise figure of 0.6 dB at a current consumption of 3.5 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 3 mm².

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.
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. BGU8004 GNSS LNA evaluation board

The BGU8004 LNA evaluation board simplifies the RF evaluation of the BGU8004 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 BGU8004, 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 BGU8004 can operate from a 1.5 V to 3.1 V single supply and consumes about 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 BGU8004 LNA evaluation board
3.2 PCB Layout

A good PCB layout is an essential part of an RF circuit design. The LNA evaluation board of the BGU8004 can serve as a guideline for laying out a board using the BGU8004. 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.

Fig 3. Printed-Circuit Board layout of the BGU8004 LNA evaluation board

Fig 4. Stack of the PCB material

(1) Material supplier is ISOLA DURAVER; $\varepsilon_r = 4.6-4.9; T\delta = 0.02$
4. Bill of materials

Table 1. BOM of the BGU8004 GNSS LNA evaluation board

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<tr>
<th>Designator</th>
<th>Description</th>
<th>Footprint</th>
<th>Value</th>
<th>Supplier Name/type</th>
<th>Comment</th>
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<tr>
<td>Marking</td>
<td>BGU8004</td>
<td>0.65 x 0.44 /</td>
<td>1nF</td>
<td>Murata GRM1555</td>
<td>Decoupling</td>
</tr>
<tr>
<td>code: see</td>
<td>PCB</td>
<td>20x35mm</td>
<td></td>
<td>Murata LQW15</td>
<td>Input matching</td>
</tr>
<tr>
<td>datasheet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>Capacitor</td>
<td>0402</td>
<td>6.8nH</td>
<td></td>
<td>Bias connector</td>
</tr>
<tr>
<td>L1</td>
<td>Inductor</td>
<td>0402</td>
<td></td>
<td></td>
<td>RF input/ RF output</td>
</tr>
<tr>
<td>X1, X2</td>
<td>SMA RD connector</td>
<td>-</td>
<td></td>
<td></td>
<td>Bias connector</td>
</tr>
<tr>
<td>X3</td>
<td>DC header</td>
<td>-</td>
<td></td>
<td></td>
<td>Connect Ven to Vcc or separate Ven voltage</td>
</tr>
<tr>
<td>X4</td>
<td>JUMPER Stage</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JU1</td>
<td>JUMPER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1 BGU8004

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 BGU8004 is a Low Noise Amplifier (LNA) for GNSS receiver applications, available in a small plastic 6-pin extremely thin leadless package. The BGU8004 requires one external matching inductor and one external decoupling capacitor. The BGU8004 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 17.0 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 Series inductor

The evaluation board is supplied with Murata LQW15 series inductor of 6.8 nH. 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 2.85 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 BGU8004 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 Vcc and GND terminals. Set the power supply to the desired supply voltage, between 1.5 V and 2.85 V, but never exceed 3.1 V as it might damage the BGU8004.
2. Jumper JU1 is connected between the Vcc terminal of the evaluation board and the V_en pin of the BGU8004.
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 3.6mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around -23 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 avoided, 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 GPS receiver, the system will not have in-band intermodulation problems caused by the GPS-signal itself. Strong out-of-band cell phone TX jammers however can cause linearity problems, and result in third-order intermodulation products in the GPS frequency band. In this chapter the effects of these Jammer-signals on the Noise and Gain performance of the BGU8004 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 In-band 1dB gain compression due to 850MHz and 1850MHz jammers

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 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)](image-url)

The gain of the DUT was measured between port RFin and RFout of the EVB at the GPS 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 787MHz, 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 -10dBm input jamming power at 787MHz (Vcc=1.8V) (Fig 7) and with -12dBm input jamming power at 850MHz (Vcc=1.8V) (Fig 8). With an 1850MHz jamming signal, the 1dB gain compression occurs around -10dB input power level (Fig 12).

Pin 1573 MHz = -45 dBm

**Fig 7.** Icc versus jammer power at 787 MHz

Pin 1575 MHz = -45 dBm

**Fig 8.** Gain versus jammer power at 787 MHz

Pin 1573 MHz = -45 dBm

**Fig 9.** Icc versus jammer power at 850 MHz

Pin 1575 MHz = -45 dBm

**Fig 10.** Gain versus jammer power at 850 MHz
Pin 1573 MHz = -45 dBm

**Fig 11.** Icc versus jammer power at 1850 MHz

Pin 1575 MHz = -45 dBm

**Fig 12.** 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 13 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.

![Diagram of noise under jamming measurement setup](image)

Fig 13. 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 14, 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 15).
9. Typical LNA evaluation board results

Table 2. Typical results measured on the evaluation boards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>LNA EVB</th>
<th>LNA EVB</th>
<th>LNA EVB</th>
<th>LNA EVB</th>
<th>Unit</th>
<th>Remarks</th>
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</thead>
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<tr>
<td>Supply Voltage</td>
<td>$V_{CC}$</td>
<td>1.5</td>
<td>1.8</td>
<td>2.85</td>
<td>3.1</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Supply Current</td>
<td>$I_{CC}$</td>
<td>3.3</td>
<td>3.4</td>
<td>3.6</td>
<td>3.6</td>
<td>mA</td>
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<tr>
<td>Noise Figure</td>
<td>$NF$</td>
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<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
<td>dB</td>
<td>[1]</td>
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<td>Power Gain</td>
<td>$G_p$</td>
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<td>17.0</td>
<td>17.0</td>
<td>17.5</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Input Return Loss</td>
<td>$RL_{in}$</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Output Return Loss</td>
<td>$RL_{out}$</td>
<td>10.7</td>
<td>11</td>
<td>11</td>
<td>10.5</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Reverse Isolation</td>
<td>$ISO_{rev}$</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Input 1dB Gain Compression</td>
<td>$P_{1dB}$</td>
<td>-11.8</td>
<td>-10</td>
<td>-7.5</td>
<td>-7.2</td>
<td>dBm</td>
<td></td>
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<tr>
<td>Output 1dB Gain Compression</td>
<td>$P_{o1dB}$</td>
<td>4.2</td>
<td>6</td>
<td>8.5</td>
<td>9.3</td>
<td>dBm</td>
<td></td>
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<tr>
<td>Input third order intercept point</td>
<td>$IIP3$</td>
<td>-2.2</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>dBm</td>
<td>[2]</td>
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<tr>
<td>Output third order intercept point</td>
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<td>21</td>
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<td>&lt; 1</td>
<td>μs</td>
<td></td>
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[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 0.1dB are not subtracted. Measured at $T_{amb} = 25 \, ^{\circ}C$.

[2] Out of band IP3, jammers at $f_1 = f + 138 MHz$ and $f_2 = f + 276 MHz$, where $f = 1575.42 MHz$. $P_{in}(f_1) = -20 dBm$, $P_{in}(f_2) = -65 dBm$.
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