GNSS MMIC LNA: BGA524N6

Low Noise Amplifer for GNSS Applications in 1550 MHz - 1615 MHz with a High Q Inductor for Matching

Application Note AN400

About this document

Scope and purpose

This application note describes Infineon's GNSS MMIC LNA: BGA524N6 as Low Noise Amplifer for Global Navigation Satellite System (1550 MHz – 1615 MHz) applications.

1. This application note investigates the BGA524N6's performance for at 1550 MHz - 1615 MHz using a high quality factor inductor for input matching.
2. The BGA524N6 is a Silicon-Germanium Low Noise Amplifer.
3. The BGA524N6 serves the Global Navigation Satellite System applications such as GPS, GLONASS, Galieo and Beidou.
4. In this application note, the performance parameters are measured for GNSS applications on a FR4 board. The GNSS related Out-of-band IP3 and LTE Band 13 interference are also presented. The high quality factor inductor brings a Noise Figure improvement of 0.05 dB as compared to the low quality factor solution in Application Note AN346.
5. Key performance parameters achieved at 2.8V, 1575.42 MHz
   a. Noise Figure = 0.73 dB
   b. Gain = 19.6 dB
   c. Input P1dB = -12.0 dBm
   d. Input IP3 = -9.1 dBm
   e. Out-of-band IP3 = -4.5 dBm

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1) The graphs are generated with the simulation program AWR Microwave Office®.

1 Introduction of Global Navigation Satellite Systems (GNSS) Applications

Global Navigation Satellite Systems (GNSS) are among the fastest growing businesses in the electronic industry. Today, GNSS is much more than the well-known GPS, which was introduced for civilian use more than a decade ago. Nations around the world are working on their own navigation satellite systems for strategic reasons and also to offer improved user experience. Today, three GNSS systems are operational: the United States GPS, the Russian GLONASS and the Chinese Beidou. The Galileo positioning system being developed by the European Union is expected to be functional by 2014.

From a civilian usage point, additional systems added to GNSS bring with them the advantages of increased satellite signal reception, increased coverage, higher precision and the facility for additional features such as Search And Rescue (SAR). The most important market segments since 2008 are Personal Navigation Devices (PND) and GNSS enabled mobile phones. The architecture and the performance of the so-called RF front-end is the key contributor to fulfill the strict requirements of the GNSS system, because it consists of the whole line-up between the GNSS antenna and the integrated GNSS chipset. The main challenges for the growing GNSS-enabled mobile phone market are to achieve high sensitivity and high immunity against interference of cellular signals driven by government regulations for safety and emergency reasons, for example, in the US and Japan. This means the reception for GPS/GLONASS signals at very low power levels down to less than -160 dBm in mobile phones in the vicinity of co-existing high power cellular signals. In addition, excellent ESD robustness characteristics and low power consumption for long battery usage duration are mandatory features for portable and mobile phones. Below is an application diagram of the GNSS RF front-end.

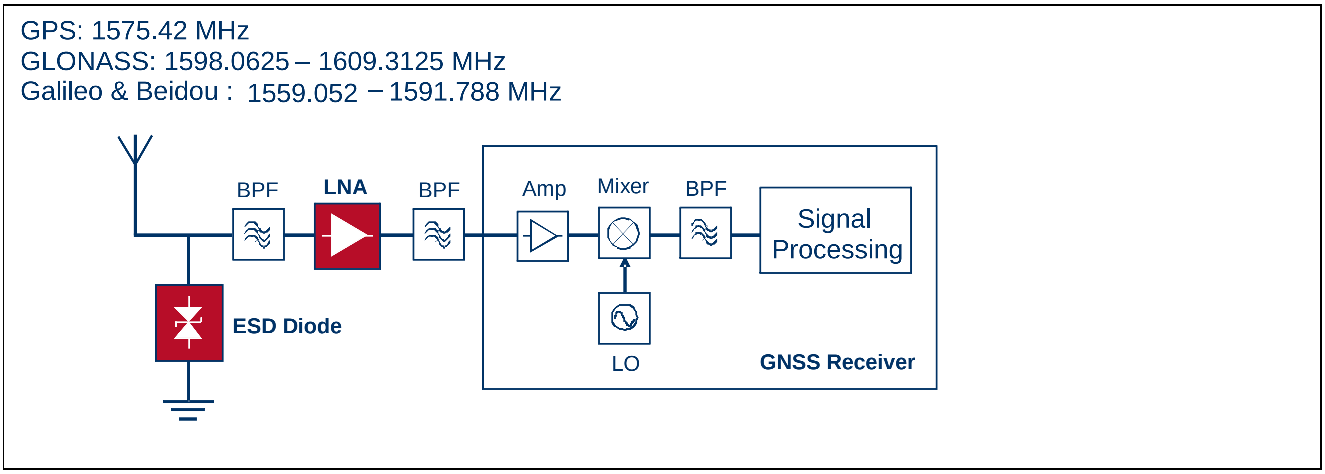

Figure 1 Application Diagram: Receiver Frontend the Global Navigation Satellite System With LNAs and Filter

A major interference signal at the GNSS frequency band is the presence of LTE band 13 second harmonics. For example, a jammer signal from 787 MHz will generate a second harmonic signal at 1574 MHz, and thus add interference to the wanted GNSS signal. In this application note, we measure the influence of LTE band 13 second harmonic with below setup. The bandpass filter before the Device-under-test (DUT) is intended to let through the Band 13 signal, and to filter out the second harmonic generated by the signal generator. The attenuator is used to improve the mismatch at the B13 frequency. The bandpass filter after the Device-under-test is intended to let through the GNSS signal while filtering out the B13 frequency from the DUT output. The attenuator is used to improve the mismatch at the B13 frequency. In below application note, the losses from BPF2 and Attenuator 2 after DUT have been compensated, when measuring the B13 H2out for Table 3 and Table 4.

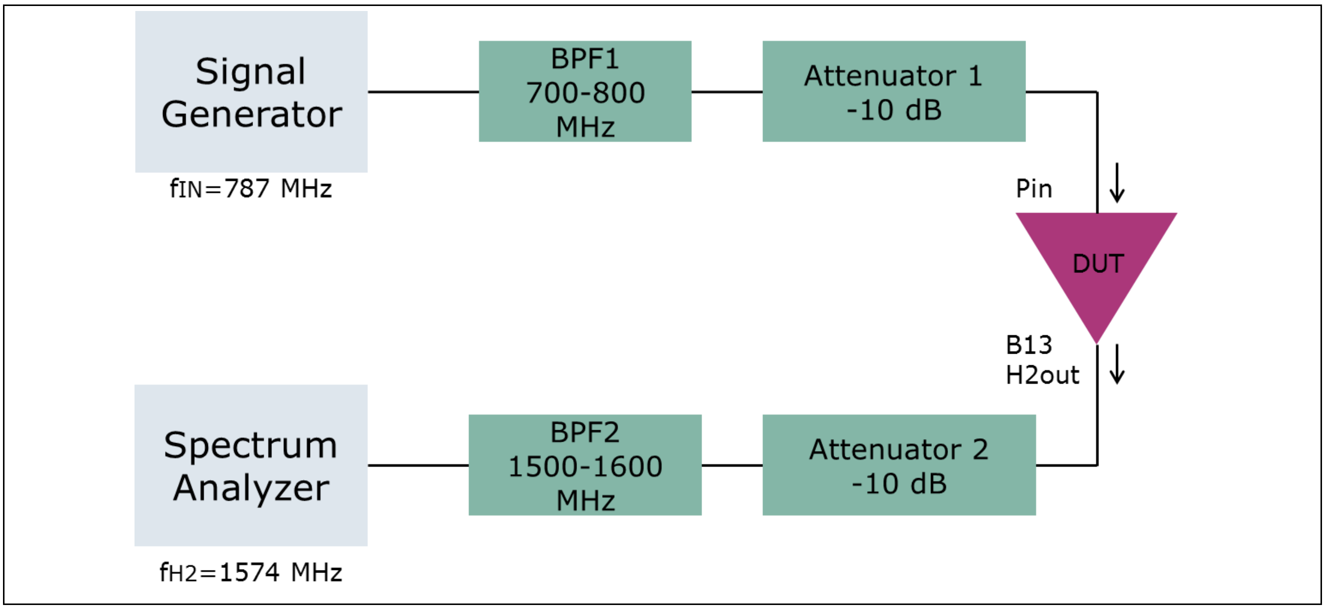

Figure 1 **Measurement setup for LTE Band 13 second harmonic**

For more information on the GNSS system and its system challenges, please visit the application guide for mobile communication at www.infineon.com [1].

1.1 Infineon's Product Portfolio for the GNSS Applications

Infineon Technologies is the market leader in GNSS LNAs for navigation applications in PND and cellular products. Infineon Technologies offers a complete product portfolio to all customers designing high performance flexible RF front-end solutions for GNSS:

- **Low Noise Amplifiers (LNA):** consisting of a wide range of products like high performance MMICs as well as cost effective and high end RF transistors

- **Front-End Module (FEM):** Infineon offers the world's smallest GPS/GLONASS FEMs with LNAs and band-pass filter(s) integrated into a single tiny package with well-optimized performance for navigation in mobile phones
- **Transient Voltage Suppression (TVS) Diodes:** protecting GNSS antenna reliably up to 20 kV

For more information on Infineon's available product portfolio for the GNSS application, please visit Infineon's website at www.infineon.com.

1.2 Key Features of Low Noise Amplifiers (LNAs)

Low Noise Figure & High Gain: The power levels of satellite signals received by a GPS/GNSS receiver are as low as -160 dBm. This poses a challenge on the sensitivity of the system. An external LNA with low noise figure and high gain is required to boost the sensitivity of the system and Time-To-First Fix (TTFF).

High Linearity: In modern mobile phones, the GNSS signals are co-habited by strong interfering cellular signals. The cellular signals can mix to produce Intermodulation products exactly in the GNSS receiver frequency band. To enhance interference immunity of the GNSS systems, LNAs with high linearity characteristics such as input IP3 and input P1dB are required.

Low Current Consumption: Power consumption is an important feature in GNSS devices which are mainly battery operated mobile devices. Infineon's LNAs have an integrated power on/off feature which provides for low power consumption and increased stand-by time for GNSS handsets. Moreover, the low current consumption (down to 2.5 mA) makes Infineon's LNAs suitable for portable technology like GNSS receivers and mobile phones.

2 BGA524N6 Overview

2.1 Features

- High insertion power gain: 19.6 dB
- Out-of-band input 3rd order intercept point: -4 dBm
- Input 1 dB compression point: -12 dBm
- Low noise figure: 0.55 dB
- Low current consumption: 2.5 mA
- Operating frequencies: 1550 - 1615 MHz
- Supply voltage: 1.5 V to 3.3 V
- Digital on/off switch (1 V logic high level)
- Ultra small TSNP-6-2 leadless package (footprint: 0.7 x 1.1 mm^2)
- B7HF Silicon Germanium technology
- RF output internally matched to 50
- Only 1 external SMD component necessary
- 2 kV HBM ESD protection (including AI-pin)
- Pb-free (RoHS compliant) package

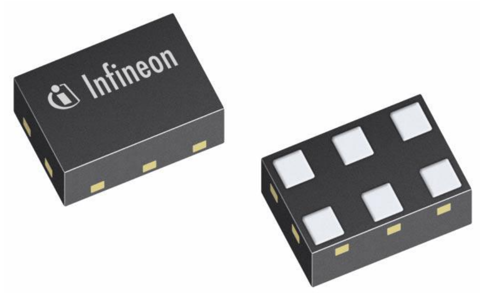

Figure 2 BGA524N6 in TSNP-6-1

2.2 Key Applications of BGA524N6

➢ Ideal for all Global Navigation Satellite Systems (GNSS) applications like
- GPS (US GNSS) working in the L1 band at 1575.42 MHz
- GLONASS (Russian GNSS) working in the L1 band from 1598.0625 MHz to 1605.3125 MHz
- Galileo (European GNSS) working in the E1 band from 1559.052 MHz to 1591.788 MHz
- Beidou (Chinese GNSS) working in E2 band at 1561.098 MHz

2.3 Description

The BGA524N6 is a front-end low noise amplifier for Global Navigation Satellite Systems (GNSS) from 1550 MHz to 1615 MHz like GPS, GLONASS, Galileo, Beidou and others. The LNA provides 19.6 dB gain and 0.55 dB noise figure at a current consumption of 2.5 mA only in the application configuration described in **Chapter 3**. The BGA524N6 is based upon Infineon Technologies B7HF Silicon Germanium technology. It operates from 1.5 V to 3.3 V supply voltage.

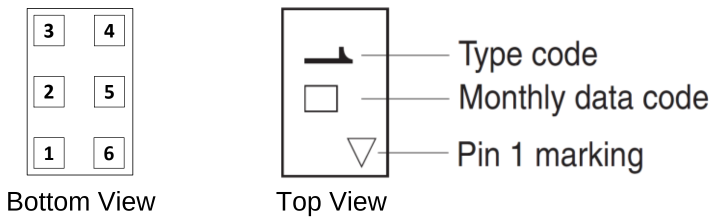

Figure 3 Package and pin connections of BGA524N6

Table 1 Pin Assignment of BGA524N6

Pin No.	Symbol	Function
1	GND	Ground
2	VCC	DC supply
3	AO	LNA output
4	GND	Ground
5	AI	LNA input
6	PON	Power on control

Table 2 Mode Selection of BGA524N6

LNA Mode	Symbol	ON/OFF Control Voltage at PON pin	
		Min	Max
ON	PON, on	1.0 V	VCC
OFF	PON, off	0 V	0.4 V

Please visit the product page of **BGA524N6 (Link)** for more information.

3 Application Circuit and Performance Overview

In this chapter the performance of the application circuit, the schematic and bill-on-materials are presented.

Device:	**BGA524N6**
Application:	**Low Noise Amplifer for GNSS applications with a high Q inductor for matching**
PCB Marking:	**M260814 V3.1**
EVB Order No.:	**AN400**

3.1 Summary of Measurement Results

Ther performance of BGA524N6 for GNSS applications are summarized in the following table.

Table 3 Electrical Characteristics (at room temperature) at Vcc =1.8V

Parameter	Symbol	Value			Unit	Comment/Test Condition
DC Voltage	Vcc	1.8			V	$V_{PON} = V_{CC}$
DC Current	Icc	2.7			mA	
Navigation System	Sys	Beidou	GPS Galileo	GLONASS		
Frequency Range	Freq	1559 - 1563	1575.42 1559-1591	1598-1609	MHz	Beidou: 1561.098MHz GPS / Galieo: 1575.42MHz GLONASS: 1602 MHz
Gain	G	19.6	19.5	19.4	dB	
Noise Figure	NF	0.74	0.74	0.75	dB	Loss of input line of 0.06 dB is deembeded
Input Return Loss	RLin	11.1	11.3	11.5	dB	
Output Return Loss	RLout	17.0	20.8	25.4	dB	
Reverse Isolation	IRev	37.0	37.1	37.1	dB	
Input P1dB	IP1dB	-15.4	-15.6	-15.9	dBm	
Output P1dB	OP1dB	3.2	2.9	2.5	dBm	
Input IP3	IIP3	-9.7	-9.6	-9.1	dBm	$f_{1Beidou}$ = 1561.098 MHz, $f_{2\ gal}$ = 1562.098 MHz; $f_{1gps/galileo}$ = 1575.42 MHz, $f_{2gps/Galileo}$ = 1576.42 MHz; $f_{1GLONASS}$ = 1602 MHz, $f_{2GLONASS}$ = 1603 MHz; Pin = -30 dBm
Output IP3	OIP3	9.9	9.9	10.3	dBm	
Out-of-band IP3 (Input referred)	IIP3_oob	-5.9			--	f1 = 1712.7 MHz; f2 = 1850 MHz, Pin =-20dBm Measure at 1575.4 MHz
Out-of-band IP3 (Output referred)	OIP3_oob	13.6			--	

Table 3 Electrical Characteristics (at room temperature) at Vcc =1.8V

Parameter	Symbol	Value	Unit	Comment/Test Condition
LTE band-13 2nd Harmonic (Input referred)	B13 H2in	-41.8	dBm	Calculated based on B13 H2out and S21@f_{H2}
LTE band-13 2nd Harmonic (Output referred)	B13 H2out	-22.3	dBm	f_{IN} = 787.7 MHz, P_{IN} = -25 dBm; f_{H2} = 1575.4 MHz
Stability	k	>1		Unconditionnally stable from 0 to 10GHz

Table 4 Electrical Characteristics (at room temperature) at Vcc =2.8V

Parameter	Symbol	Value			Unit	Comment / Test Condition
DC Voltage	Vcc	2.8			V	$V_{PON} = V_{CC}$
DC Current	Icc	2.8			mA	
Navigation System	Sys	Beidou	GPS Galileo	GLONASS		
Frequency Range	Freq	1559 - 1563	1575.42 1559 - 1591	1598-1609	MHz	Beidou: 1561.098 MHz GPS/Galieo: 1575.42 MHz GLONASS: 1602 MHz
Gain	G	19.6	19.6	19.5	dB	
Noise Figure	NF	0.72	0.73	0.74	dB	Loss of input line of 0.06 dB is deembeded
Input Return Loss	RLin	11.1	11.3	11.5	dB	
Output Return Loss	RLout	15.0	18.5	26.9	dB	
Reverse Isolation	IRev	37.0	37.1	37.2	dB	
Input P1dB	IP1dB	-11.9	-12.0	-12.1	dBm	
Output P1dB	OP1dB	6.7	6.6	6.4	dBm	
Input IP3	IIP3	-9.2	-9.1	-8.7	dBm	$f_{1Beidou}$ = 1561.098 MHz, $f_{2\ gal}$ = 1562.098 MHz; $f_{1gps/galileo}$ = 1575.42 MHz, $f_{2gps/Galileo}$ = 1576.42 MHz; $f_{1GLONASS}$ = 1602 MHz, $f_{2GLONASS}$ = 1603 MHz; Pin = -30 dBm
Output IP3	OIP3	10.4	10.5	10.8	dBm	
Out-of-band IP3 (Input referred)	IIP3_oob	-4.5			dBm	f1 = 1712.7 MHz; f2 = 1850 MHz, Pin =-20dBm Measure at 1575.4 MHz
Out-of-band IP3 (Output referred)	OIP3_oob	15.1			dBm	
LTE band-13 2nd Harmonic (Input referred)	B13 H2in	-43.0			dBm	Calculated based on B13 H2out and S21@f_{H2}
LTE band-13 2nd Harmonic (Output referred)	B13 H2out	-23.4			dBm	f_{IN} = 787.7 MHz, P_{IN} = -25 dBm; f_{H2} = 1575.4 MHz
Stability	k	>1			--	Unconditionnally stable from 0 to 10GHz

3.2 BGA524N6 as Low Noise Amplifer for GNSS Applications Using a High Q Inductor for Matching

This application note presents the BGA524N6 performance on a FR4 board at 1550 MHz – 1615 MHz. Results under 1.8 V and 2.8 V supply voltages are presented. The LNA BGA524N6 features a current consumption of less than 3 mA at both supply conditions.

At 1.8V, 1575.42MHz, the BGA524N6 LNA obtains gain of 19.5 dB and noise figure of 0.74 dB excluding SMA and line losses. The input return loss and output return loss are above 10 dB. If offers an input 1 dB compression point of – 15.6 dBm. Using two tones of -30 dBm spacing 1 MHz , the input Third-order intercept point is -9.6 dBm. The input out-of-band Third-order intercept point is –5.9 dBm using two tones of -20 dBm per tone at 1712.7 MHz and 1850 MHz. The LTE band 13 second harmonic is -41.8dBm (input referred)at 1575.4 MHz using one tone of - 25 dBm per tone at 787.7 MHz.

At 2.8V, 1575.42MHz, the BGA524N6 LNA obtains gain of 19.6 dB and a noise figure of 0.73 dB excluding SMA and line losses. The input return loss and output return loss are above 10 dB. If offers an input 1 dB compression point of – 12.0 dBm. Using two tones of -30 dBm spacing 1 MHz , the input Third-order intercept point is -9.1 dBm. The input out-of-band Third-order intercept point is –4.4 dBm using two tones of -20 dBm per tone at 1712.7 MHz and 1850 MHz . The LTE band 13 second harmonic is -43.0 dBm (input referred) at 1575.4 MHz using one tone of - 25 dBm per tone at 787.7 MHz.

The circuit is unconditionablelly stable up to 10 GHz.

Note: for more information regarding to out-of-band IP3 and LTE band 13 second harmonic, please refer to the Application Guide 'Mobile Communication, Edition 2014' [1].

3.3 Schematics and Bill-of-Materials

Ther schematic of BGA524N6 for GNSS applications is presented in **Figure 4** and its bill-of-materials is shown in **Table 5**.

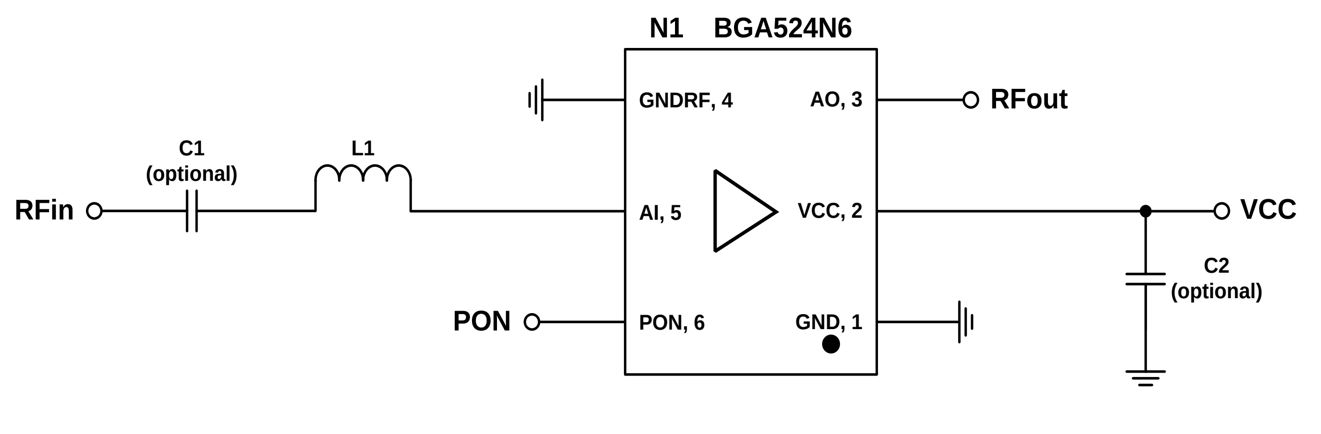

Figure 4 Schematics of the BGA524N6 Application Circuit

Table 5 Bill-of-Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
C1 (optional)	>=1	nF	0402	Various	DC block
C2 (optional)	>10	nF	0402	Various	RF bypass
L1	8.2	nH	0402	Murata LQW15 series	Input matching
N1	BGA524N6		TSNP-6-2	Infineon	SiGe LNA

Note: DC block function is NOT integrated at input of BGA524N6. The DC block capacitor C1 is not necessary if the DC block function on the RF input line can be ensured by the previous stage.

Note: The RF bypass capacitor C2 at the DC power supply pin filters out the power supply noise and stabilize the DC supply. The RF bypass capacitor C2 is not necessary if a clean and stable DC supply can be ensured.

4 Measurement Graphs

The performance of the application circuit is presented with the following graphs.

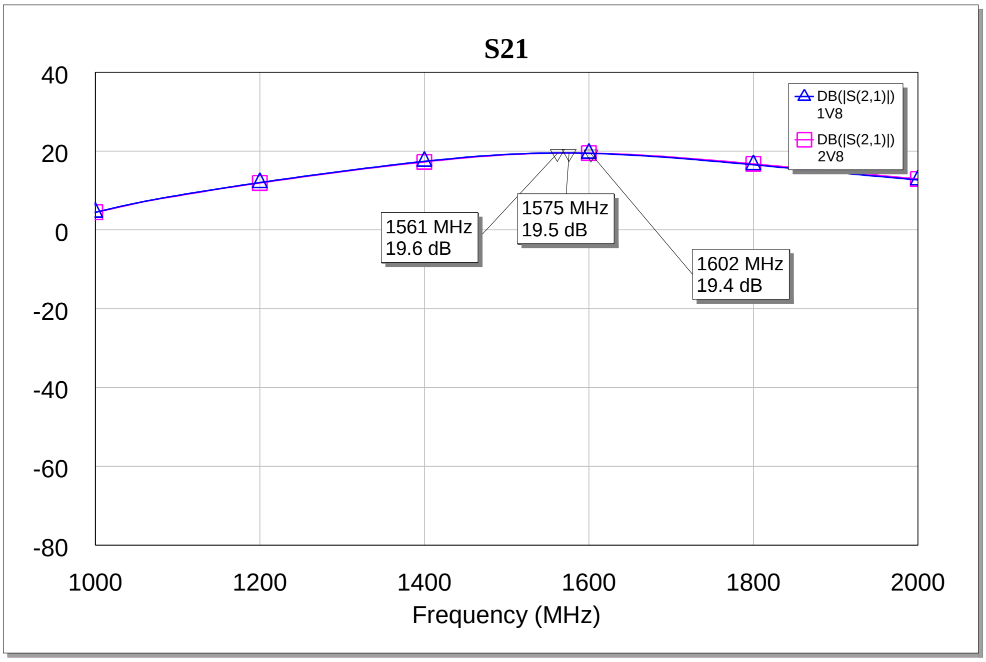

Figure 5 Narrowband Gain of the BGA524N6 as LNA for GNSS applications

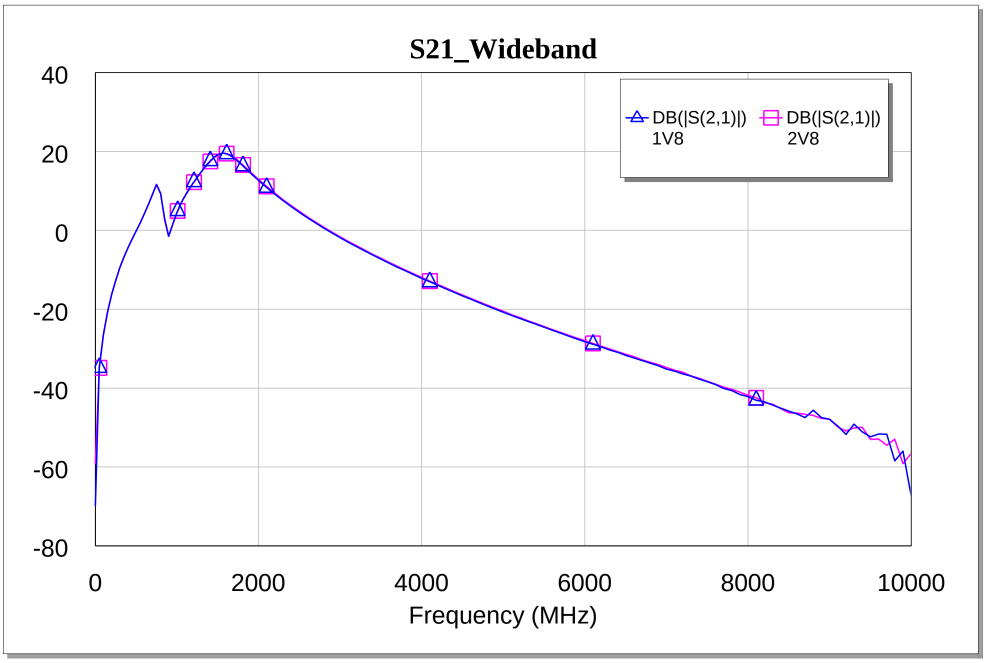

Figure 6 Wideband Gain of BGA524N6 as LNA for GNSS applications

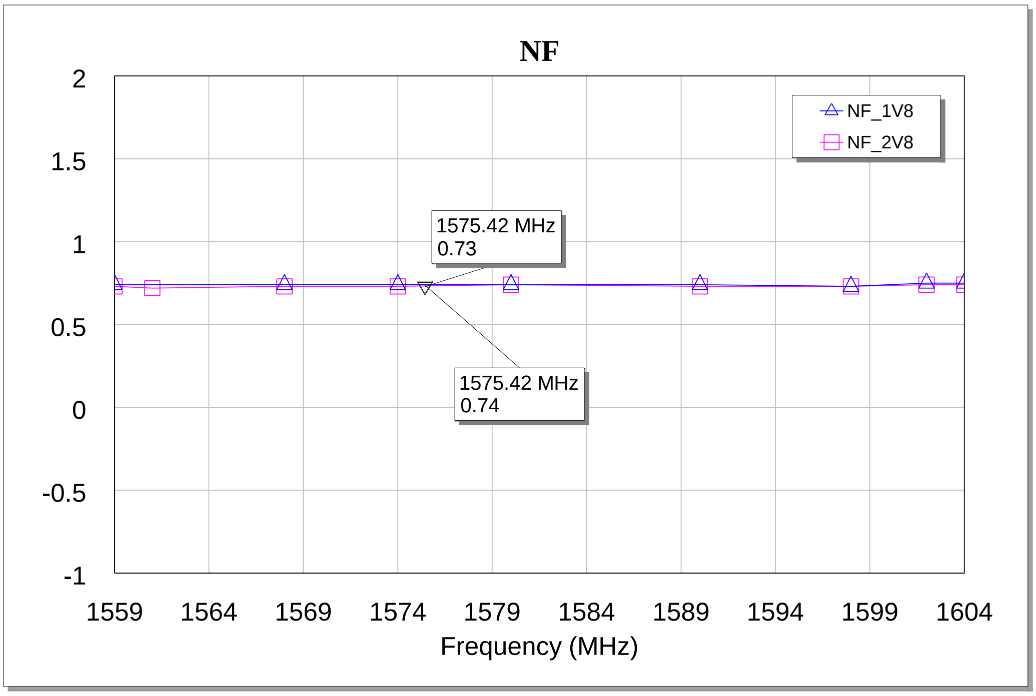

Figure 7 Noise Figure of BGA524N6 as LNA for GNSS applications

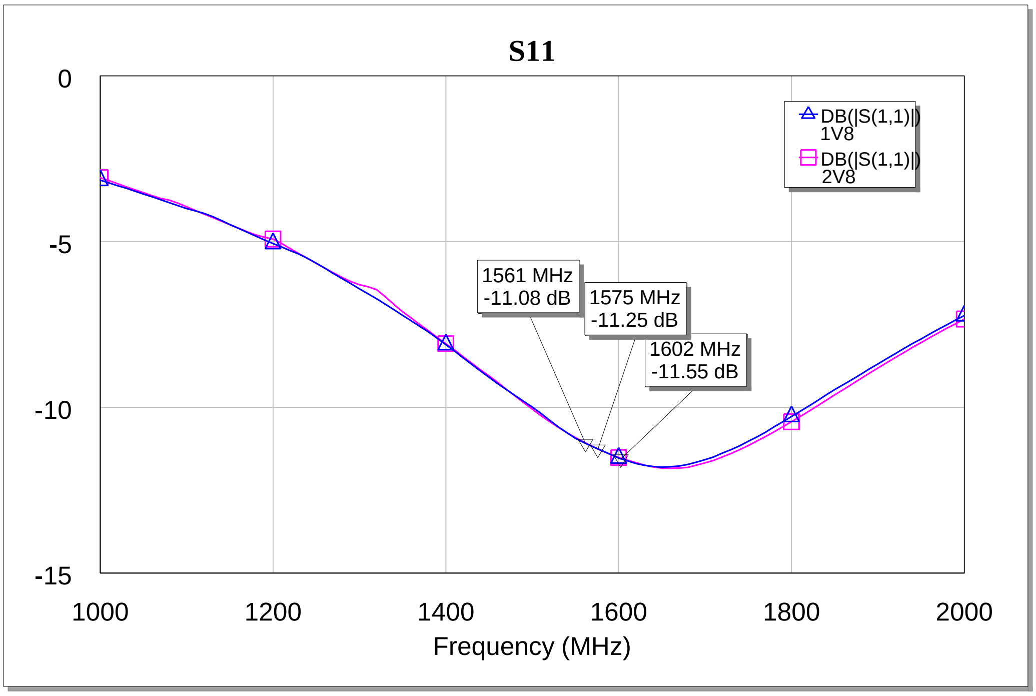

Figure 8 Input matching of BGA524N6 as LNA for GNSS applications

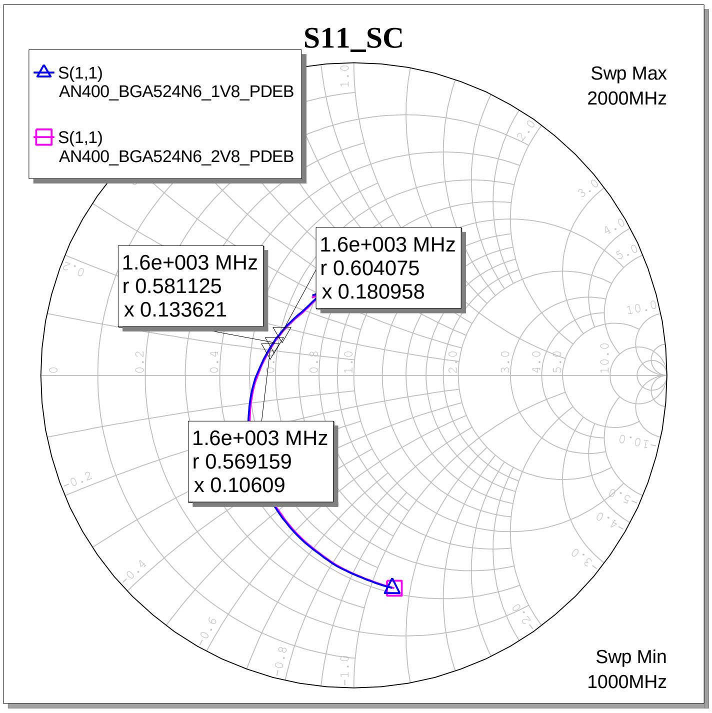

Figure 9 Input matching (Smith chart) of BGA524N6 as LNA for GNSS applications

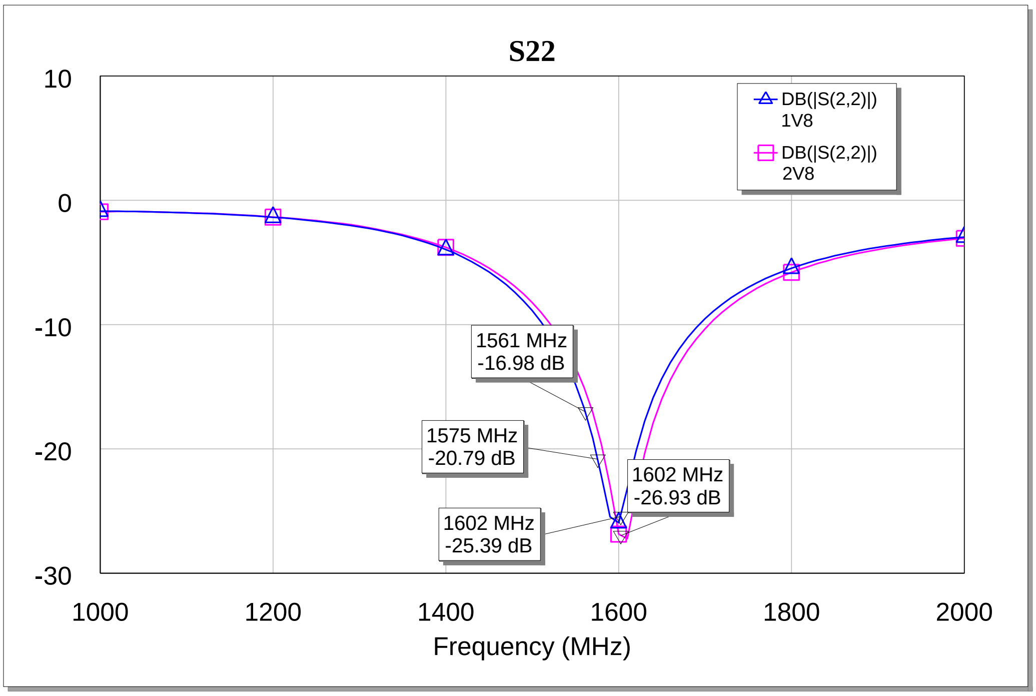

Figure 10 Output matching of the BGA524N6 as LNA for GNSS applications

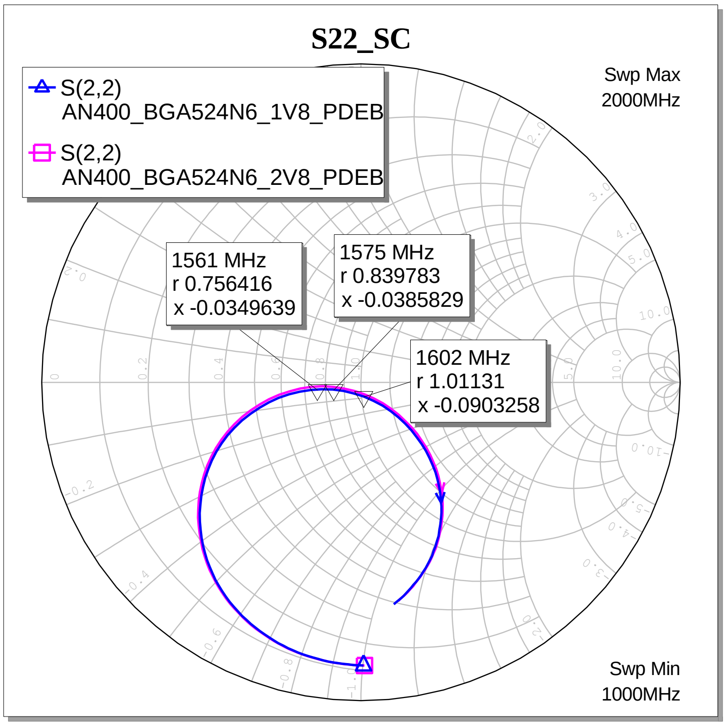

Figure 11 Output matching (Smith chart) of BGA524N6 as LNA for GNSS applications

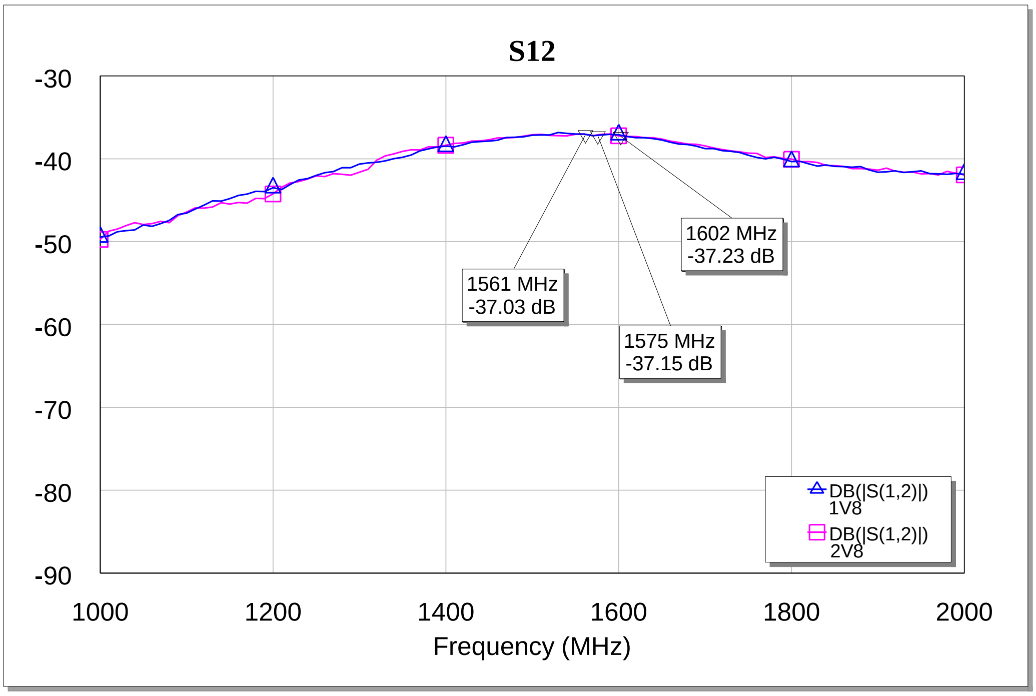

Figure 12 Isolation of BGA524N6 as LNA for GNSS applications

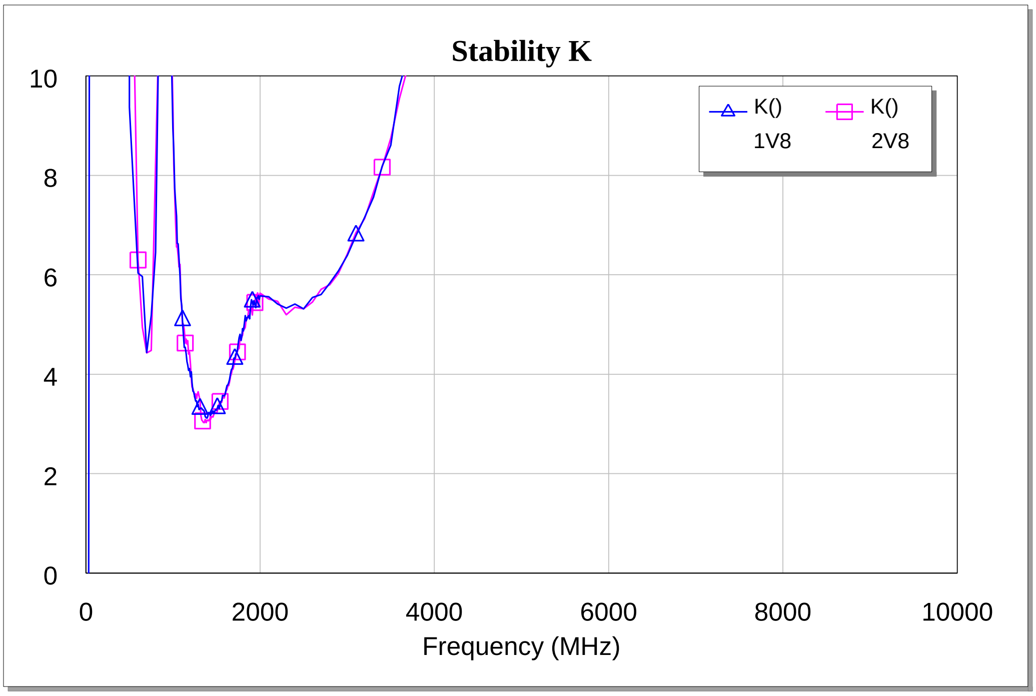

Figure 13 Stability factor k of BGA524N6 as LNA for GNSS applications

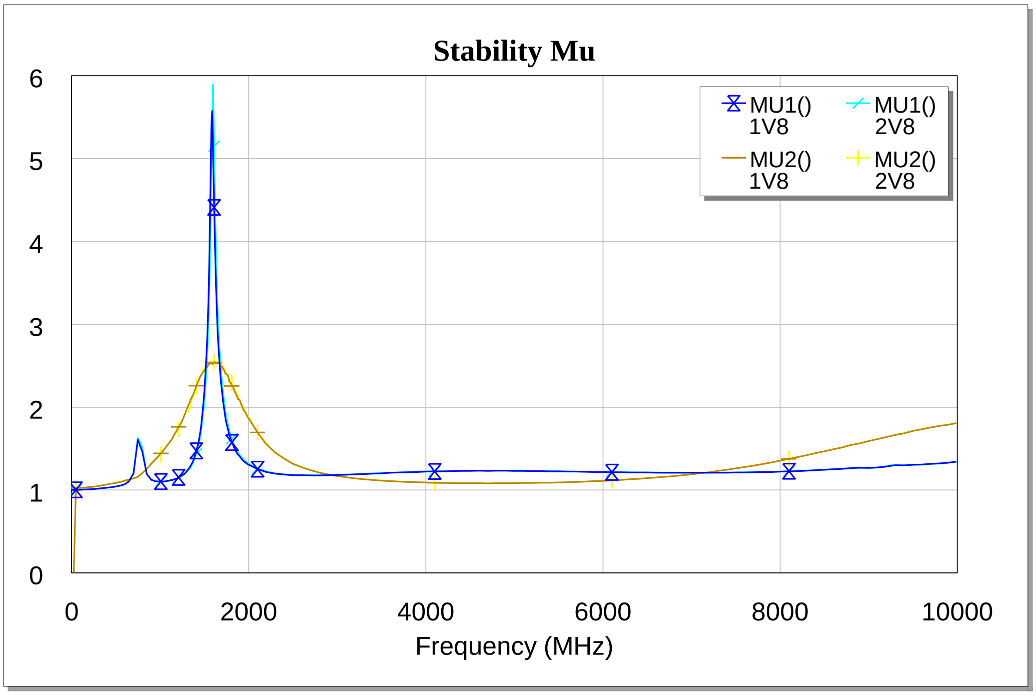

Figure 14 Stability factors µ1, µ2 of the BGA524N6 as LNA for GNSS applications

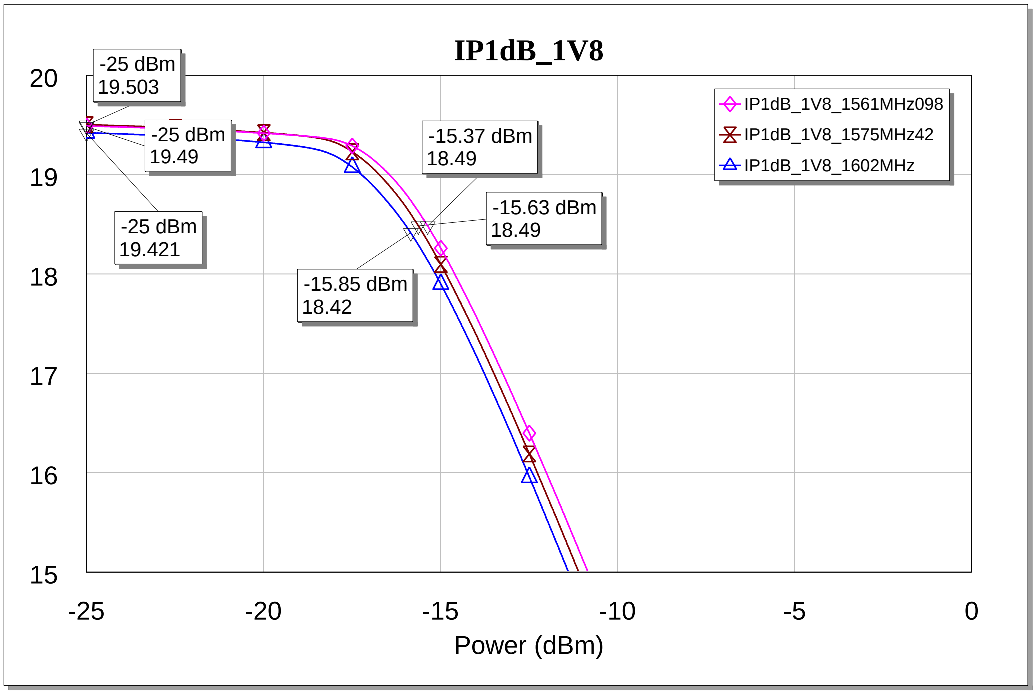

Figure 15 IP1dB of the BGA524N6 as LNA for GNSS applications (1.8V)

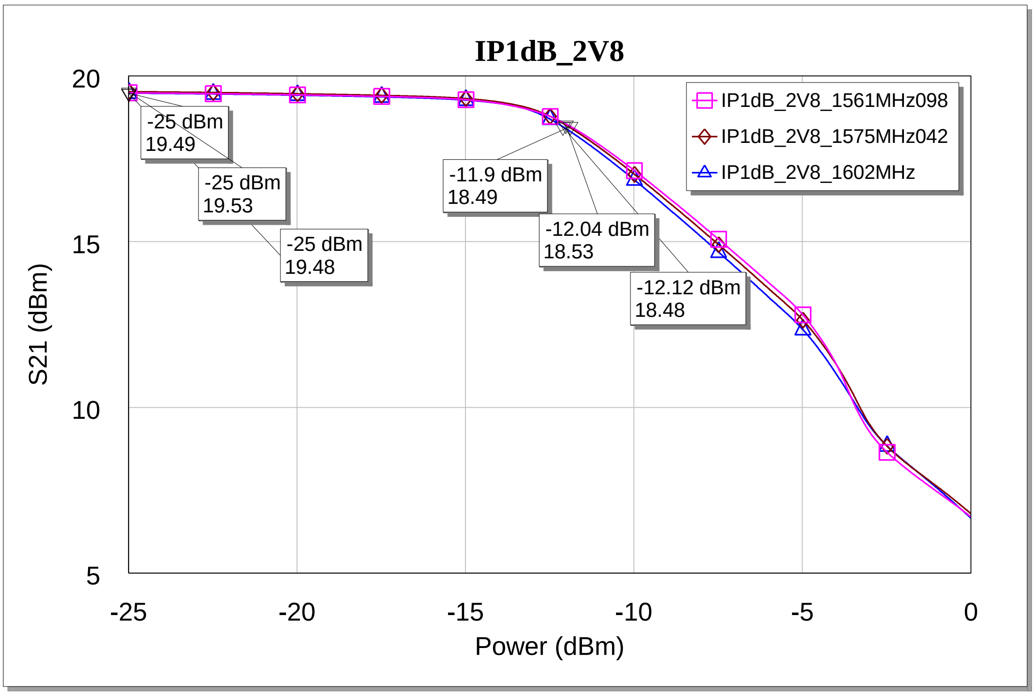

Figure 16 IP1dB of the BGA524N6 as LNA for GNSS applications (2.8V)

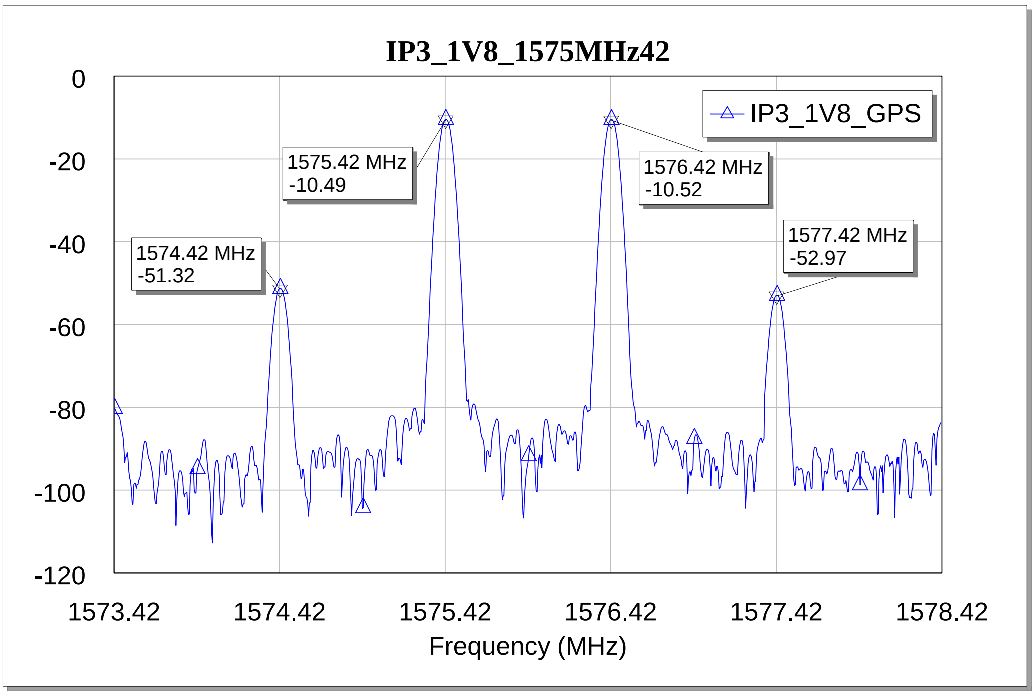

Figure 17 Output IP3 of the BGA524N6 as LNA for GNSS applications (1.8V)

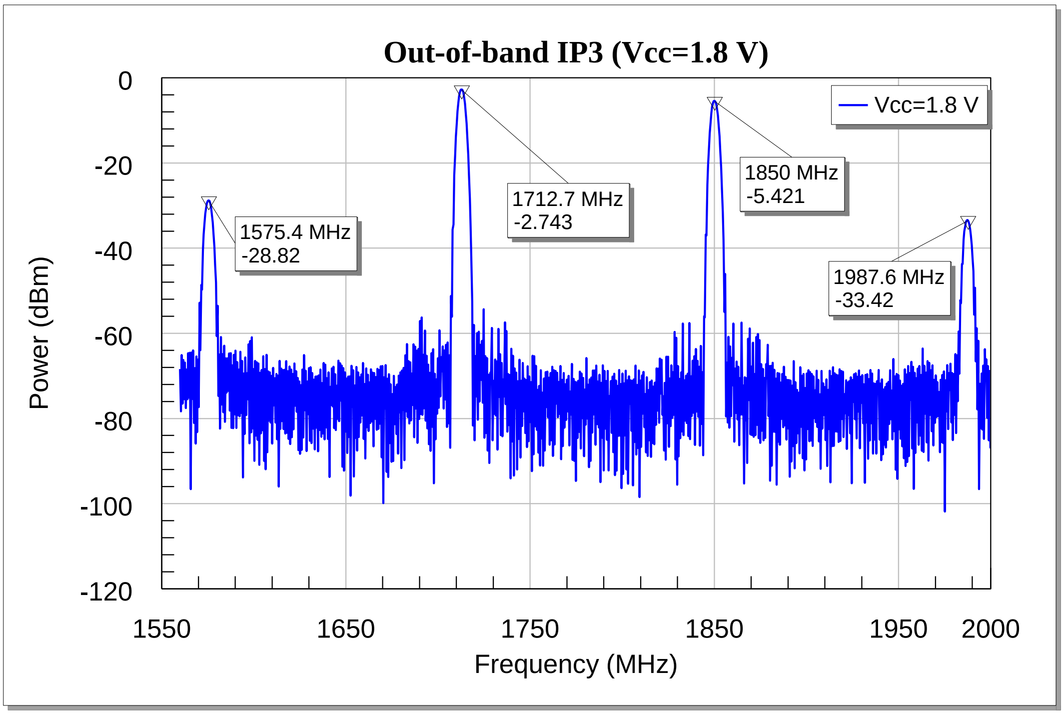

Figure 18 Out-of-band IP3 of the BGA524N6 as LNA for GNSS applications (1.8V)

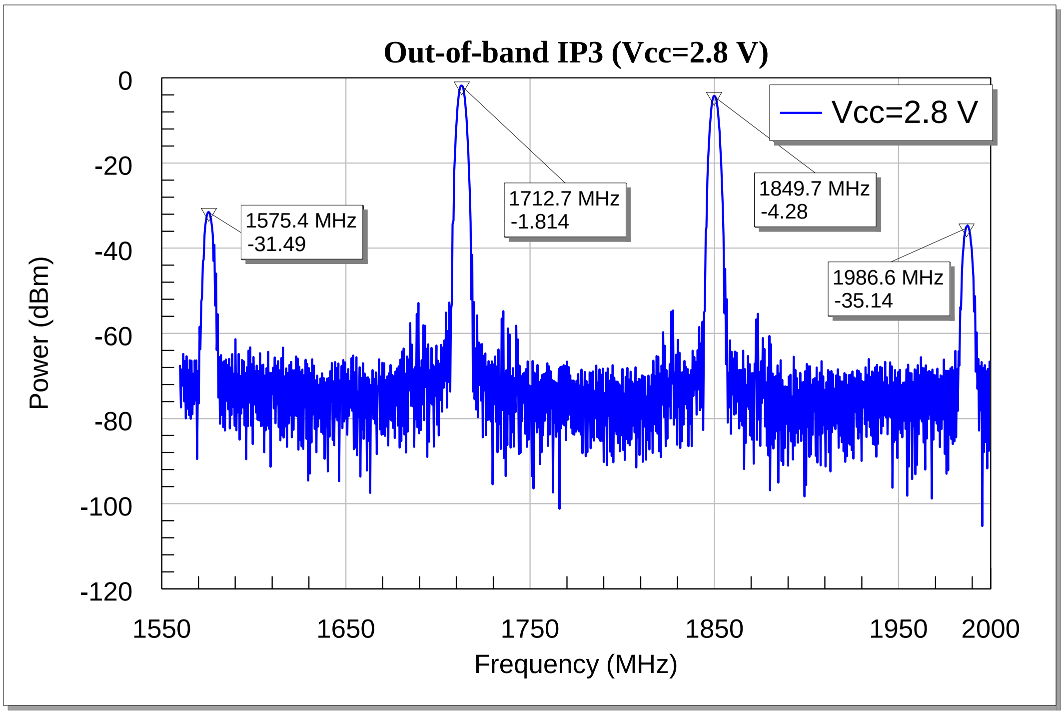

Figure 19 Out-of-band IP3 of the BGA524N6 as LNA for GNSS applications (2.8V)

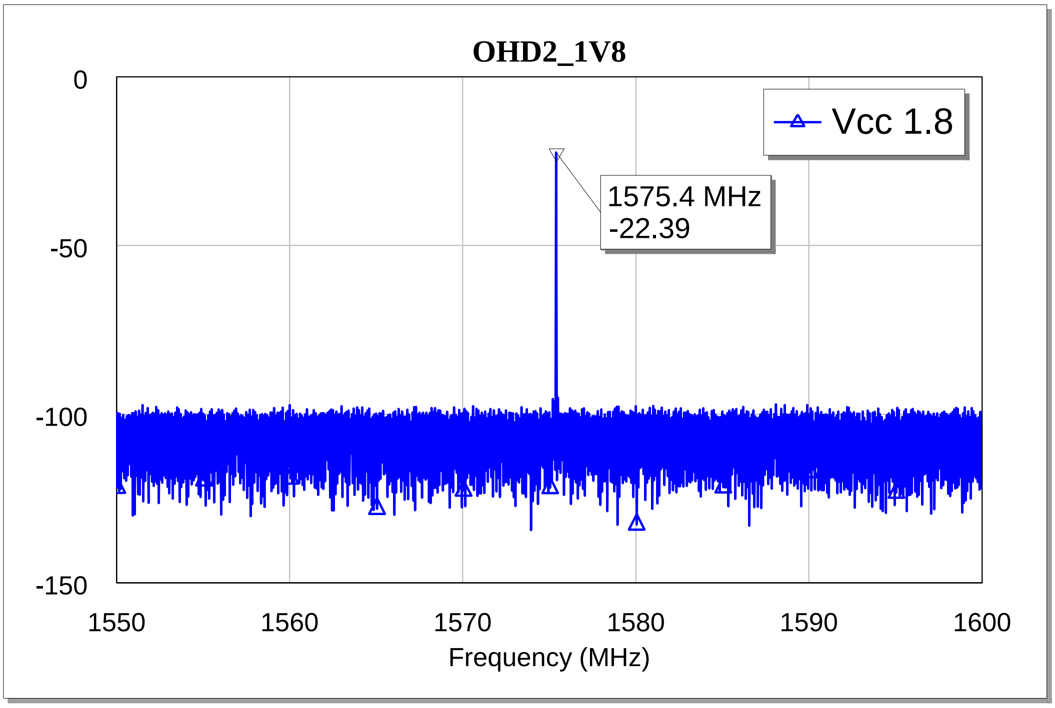

Figure 20 LTE Band 13 Second Harmonic Interference of the BGA524N6 as LNA for GNSS applications (1.8V, output referred)

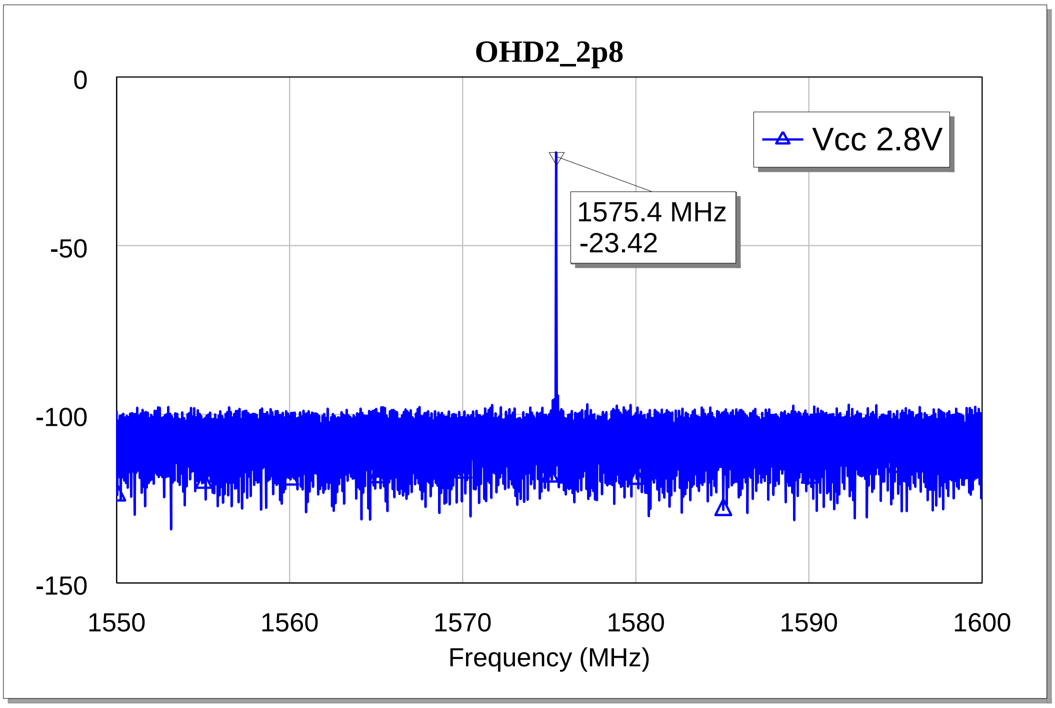

Figure 21 LTE Band 13 Second Harmonic Interference of the BGA524N6 as LNA for GNSS applications (1.8V, output referred)

5 Evaluation Board and Layout Information

In this application note, the following PCB is used:

PCB Marking: **M260814 V3.1**

PCB material: **FR4**

ε_r of PCB material: **4.8**

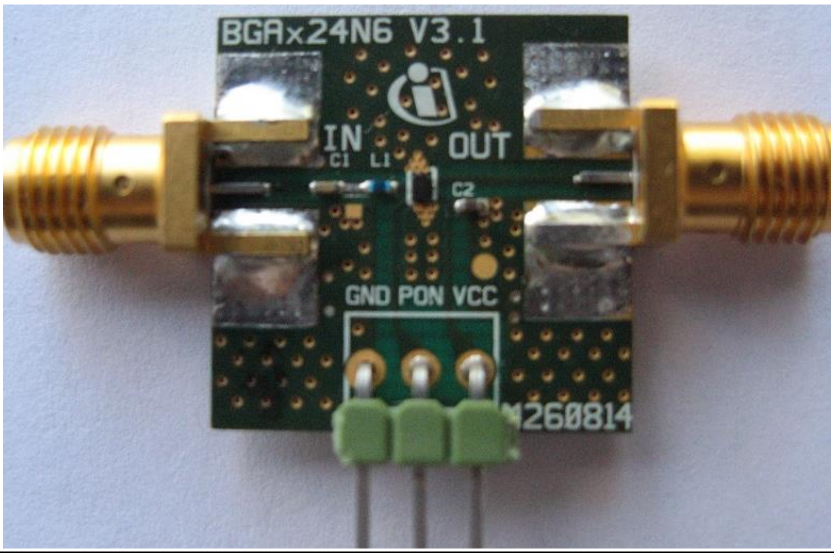

Figure 22 Photo Picture of Evaluation Board (overview) <PCB Marking M260814 V 3.1>

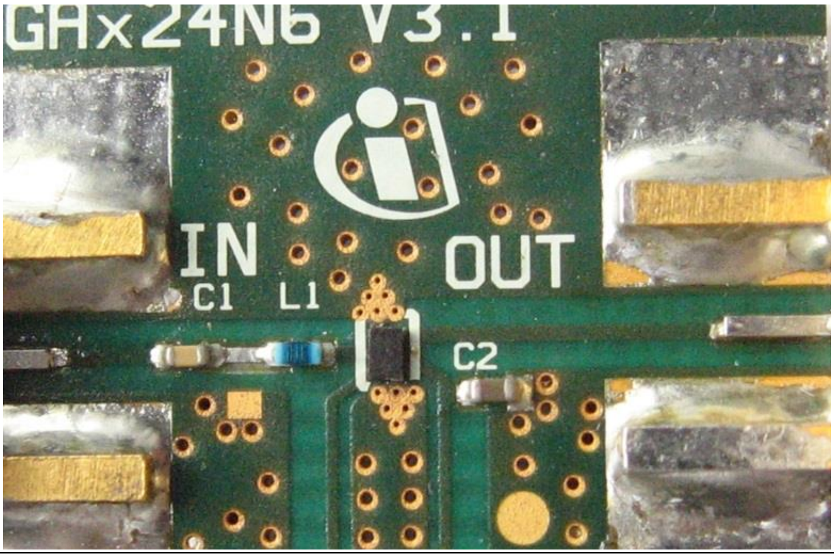

Figure 23 Photo Picture of Evaluation Board (detailed view)

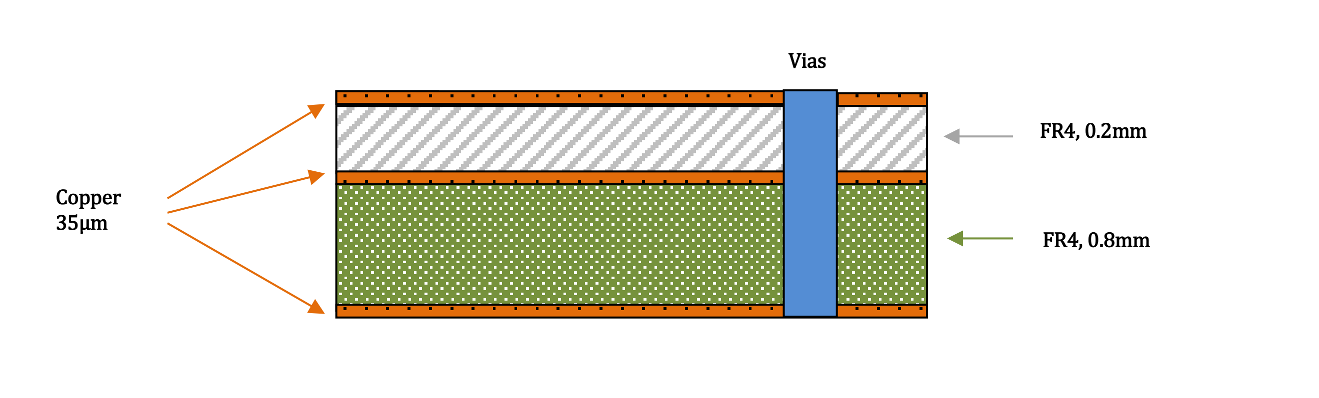

Figure 24 PCB Layer Information

6 Authors

Xiang Li, Application Engineer of Business Unit “Radio Frequency and Sensors”
Islam Moakhkhrul, Application Engineer of Business Unit “Radio Frequency and Sensors”

7 Reference

[1] Application Guide ‘Mobile Communication, Edition 2014’, Business Unit ‘’Radio Frequency and Sensors’’, Infineon Technologies www.infineon.com

[2] Application Note AN346: ‘Low Noise Amplifier for Global Navigat ion Satel l i te Systems GPS/GLONASS/Gal i leo/COMPASS f rom 1550 MHz to 1615 MHz Appl icat ions, Low Q inductor’. Revision 1.1, Infineon Technologies

Revision History

Major changes since the last revision

Page or Reference	Description of change
all	V1.0 First release of document (2015-03-06)
5	Inserted description of the LTE B13 H2 measurment setup
9 - 11	Added output referred values for Oob_OIP3 and LTE B13 H2
9 - 11	Updated LTE band-13 2^{nd} Harmonic Results (LTE B13 H2)
18 - 21	Added and updated Figures for Oob_IP3 and LTE B13 H2

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