BGA123L4 as Low Current Low Noise Amplifier for GNSS Applications in L5/E5 bands

About this document

Scope and purpose

This application note describes Infineon's GNSS MMIC: BGA123L4 – a low-current low noise amplifier for GNSS applications in L5/E5 bands (1164 to 1189 MHz).

The BGA123L4 is a silicon germanium low noise amplifier supporting GNSS applications.

1. The target application is GNSS L5/E5 band applications (1164 to 1189 MHz).
2. In this report, the performance of BGA123L4 is measured on a FR4 board. This device is matched with 0402 inch size LQW15 external components. A Noise Figure (NF) measurement with 0201 inch size LQP03T external components is presented. Also, performance at the L2 Band centre frequency (1228 MHz) is also presented.
3. Key performance parameters at 1.8 V, 1176.45 MHz (LQW15 inductors for matching)
   NF with LQP inductor = 1.2 dB
   NF with LQW inductor = 0.90 dB
   Insertion gain = 16.3 dB
   Input return loss = 12.0 dB
   Output return loss = 10.2 dB
   Out-of-band output IM3 at 1169 MHz = -64.3 dBm
   Out-of-band output IM3 at 1207 MHz = -66.3 dBm
4. Key performance parameters at 1.2 V, 1176.45 MHz (LQW15 inductors for matching)
   NF with LQP inductor = 1.25 dB
   NF with LQW inductor = 0.95 dB
   Insertion gain = 16.0 dB
   Input return loss = 11.7 dB
   Output return loss = 10.1dB
   Out-of-band output IM3 at 1169 MHz = -64.6 dBm
   Out-of-band output IM3 at 1207 MHz = -66.5 dBm

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

1 Introduction of Global Navigation Satellite Systems (GNSSs)

1.1 Global Navigation Satellite Systems (GNSSs)

Global Navigation Satellite Systems (GNSSs) are among the fastest growing businesses in the electronic industry. Today, four GNSS systems are in operation: the United States GPS, the Russian GLobal Orbiting Navigation Satellite System (GLONASS), the Chinese BeiDou Navigation Satellite System (BDS) and the European Union Galieo navigation system. Main market segments include the Personal Navigation Devices (PNDs), GNSS-enabled mobile phones and GNSS-enabled portable devices.

The main challenges for the growing GNSS-enabled mobile phone segment are to achieve high sensitivity and high immunity defined by government regulations against interference of cellular signals for safety and emergency reasons. This means GNSS signals must be received at very low power levels (down to less than -130 dBm) in mobile phones in the vicinity of co-existing high-power cellular signals.

The main challenges for the GNSS-enabled portable devices are to obtain a long battery operation time, and low Time-To-First Fix (TTFF) to quickly locate the device.

GPS: 1563 to 1587 MHz (L1), 1215 to 1240 MHz (L2), 1164 to 1189 MHz (L5)
Galileo: 1559 to 1591 MHz (E1), 1260 to 1300 MHz (E6), 1164 MHz to 1214 MHz (E5)
GLONASS: 1593 to 1610 MHz (G1), 1237 to 1254 MHz (G2), 1189 MHz to 1214 MHz (G3)
BeiDou: 1559 to 1591 MHz (B1), 1264 to 1280 MHz (B2), 1193 to 1214 MHz (B3)

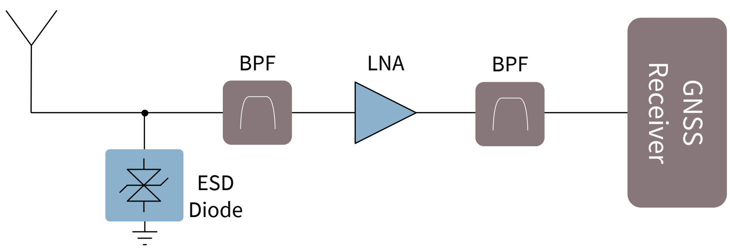

Figure 1 Application diagram: receiver front-end of the GNSS

1.2 Lower L bands

Most existing GNSS systems operate in the upper L band (1559 to 1610 MHz). Recently, GNSS applications in the lower L bands (1164 to 1299 MHz) have started to emerge.

The lower L bands include BDS B3 / Galileo E5 / GLONASS G3 / GPS L5 bands (1164 MHz to 1214 MHz), and BDS B2 / Galileo E6 / GLONASS G2 / GPS L2 bands (1215 MHz to 1300 MHz). The GPS L5 band hosts a civilian safety-of-life signal, and is intended to provide a means of radio navigation secure and robust enough for life-critical applications, such as aircraft precision approach guidance. India's Indian Regional Navigation Satellite System (IRNSS) also operates in the L5 band. The L2 band has been used for high-precision location navigation.

Figure 2 on next page demonstrates an overview of the GNSS lower L band frequency allocation:

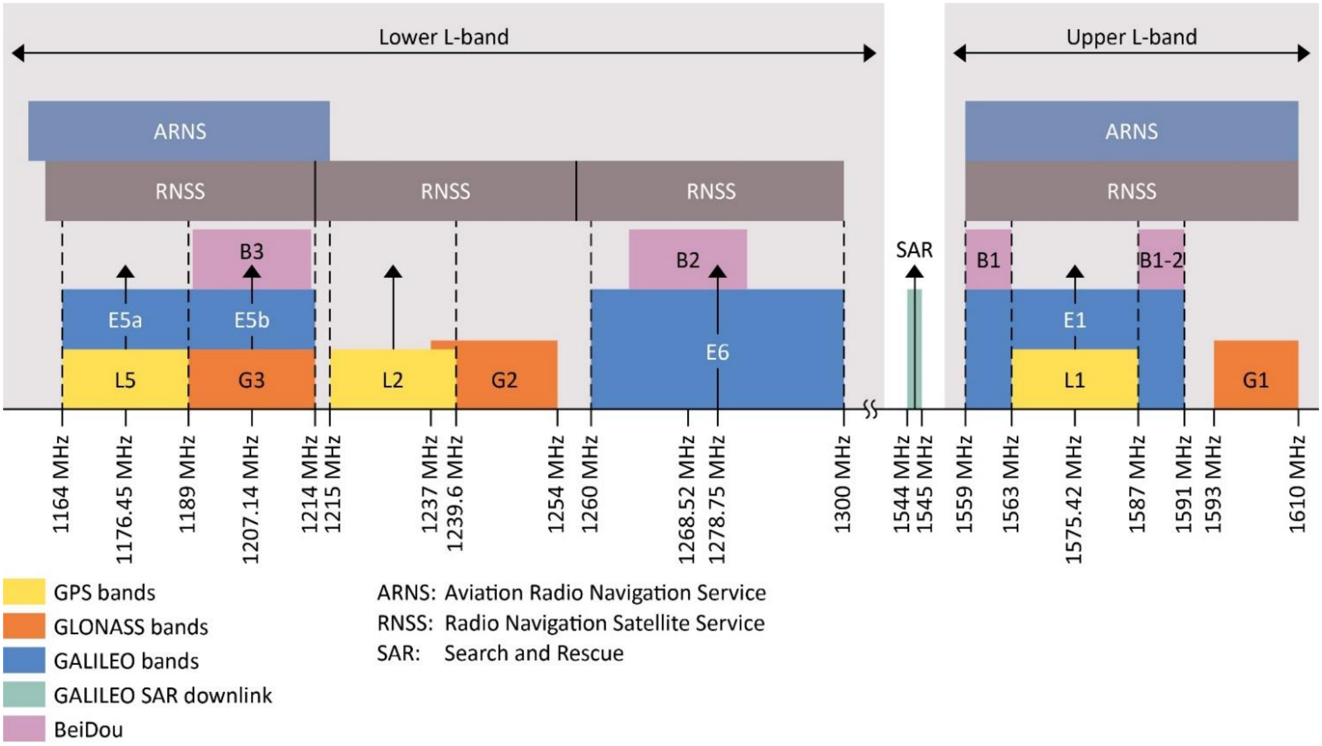

Figure 2 Frequency allocation: GNSS systems, upper L bands and lower L bands

1.2.1 Out-of-band interference

Because GNSS and cellular systems co-exist in a compact area in a mobile phone, coupling from the cellular transmitter to the GNSS receive path results in intermixing of other high-frequency signals in GNSS FE devices; for example, intermodulation between LTE band 2 and band 3 signals, intermodulation between LTE band 5 and WLAN 2.4 GHz signals, etc.

In the example below, the LTE band 3 signal ($f1_{IN}$) and LTE band 40 signal ($f2_{IN}$) produce third-order intermodulation products at GPS frequencies. This effect desensitizes the GPS receiver and decreases its performance. When $f1_{IN}$ = 1785 MHz and power $P1_{IN}$ = -25 dBm, and $f2_{IN}$ = 2401 MHz and power $P2_{IN}$ = -25 dBm are used, the third-order intermodulation product, $2 \times f1_{IN} - f2_{IN}$, is located at 1169 MHz. This signal is referred to as Out-of-Band Output IM3 (OoB OIM3). As to the OoB OIM3 input referred, the OoB Input IM3 (OoB IIM3) can be calculated as:

$$OoB\ IIM3 = OoB\ OIM3 - Gain\ at\ 1169\ MHz$$

As an example, if the OoB OIM3 of the device at 1169 MHz is -61.2 dBm and the gain of the amplifier at 1169 MHz is 16.1 dB, then the OoB IIM3 is calculated as:

$$OoB\ IIM3 = -61.2 - 16.1 = -77.3\ \text{dBm}$$

1.3 Infineon product portfolio for GNSS applications

Infineon Technologies is among the market leaders in GNSS Low Noise Amplifiers (LNAs) for navigation applications. We offer the following product portfolio to all customers designing high-performance flexible RF front-end solutions for all GNSS systems:

- **Low Noise Amplifiers (LNAs):** Infineon offers a wide range of products such as high-performance Monolithic Microwave Integrated Circuits (MMICs) as well as cost-effective and high-end RF transistors.
- **Transient Voltage Suppression (TVS) diodes:** Infineon devices can protect GNSS antennas reliably up to 20 kV.

1.4 Key features of GNSS low-noise amplifiers

Infineon is among the leading suppliers for GNSS Low Noise Amplifiers (LNAs) for navigation applications. The GNSS MMIC LNAs are designed with below features:

1.4.1 Low noise figure and high gain

The power levels of satellite signals received by a GNSS receiver are as low as -130 dBm. An external LNA with exceptionally low NF and good gain helps to boost the sensitivity of the system. The portfolio includes devices with various gain levels to tailor to the customer's RF systems.

1.4.2 High robustness against coexistence of out-of-band jammer signals

In the presence of very weak GNSS satellite signals, there is no inband intereference signal in the GNSS receiver frontends.

In case of mobile phone systems, GNSS signals coexist with strong jammer signals from other RF applications, e.g. 3G/4G, wireless LAN, etc. The above out-of-band jammer signals can mix to produce intermodulation products in the GNSS receiver frequency band. Compared with the receveid signal level from GNSS satellites, the resulted intermodulation products are significant interference, LNAs with high robustness against out-of-band intereference signals are required.

1.4.3 Low current consumption

Power consumption is an important feature in many GNSS systems that 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 recent development has focused on low current (e.g. 1.1 mA) and low supply voltage (1.2 V), making the LNAs suitable for portable devices such as GNSS enabled wearables and connected IoT devices.

Please visit www.infineon.com for more details on LNA products for navigation in mobile phones and portable devices.

2 BGA123L4 overview

2.1 Features

- Operating frequencies: 1550 to 1615 MHz
- Ultra-low current consumption: 1.1 mA
- Wide supply voltage range: 1.1 to 3.6 V
- High insertion power gain: 18.2 dB
- Low NF: 0.75 dB
- 2 kV HBM ESD protection (including AI pin)
- Ultra-small TSLP-4-11 leadless package (footprint: 0.7 x 0.7 x 0.31 mm^3)
- RF output internally matched to 50 Ω
- Only one external SMD component necessary
- Pb-free (RoHS compliant) package
- B7HF silicon germanium technology

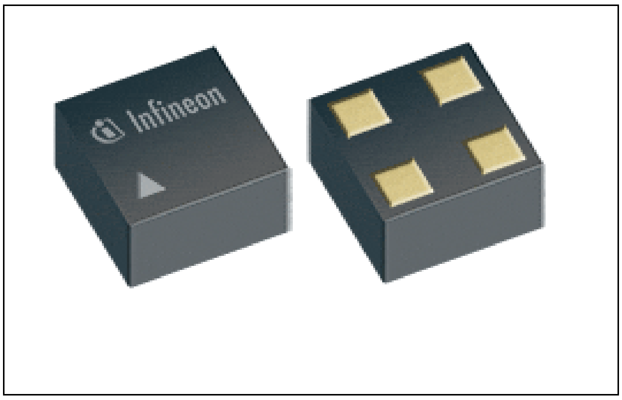

Figure 3 BGA123L4 in TSLP-4-11

2.2 Key applications of BGA123L4

BGA123L4 is designed to enhance GNSS signal sensitivity especially in wearables and mobile cellular IoT devices. With 18.2 dB gain and only 0.75 dB NF it ensures high system sensitivity. The current needed is only 1.1 mA, which means just 1.3 mW power consumption, which is critical to help to conserve batteries. The wide supply voltage range of 1.1 to 3.6 V ensures flexible design and high compatibility. It supports all GNSS systems including GPS, GLONASS, BeiDou and Galileo.

2.3 Description

The BGA123L4 is an ultra-low noise amplifier for Global Navigation Satellite Systems (GNSS) which covers all GNSS frequency bands from 1550 to 1615 MHz, such as GPS, GLONASS, BeiDou, Galileo and others. The LNA provides 18.2 dB gain and 0.75 dB NF at a current consumption of only 1.1 mA in the application configuration described in Figure 4. The BGA123L4 is based on Infineon Technologies' B7HF silicon germanium technology. It operates from 1.1 to 3.6 V supply voltage.

BGA123L4 overview

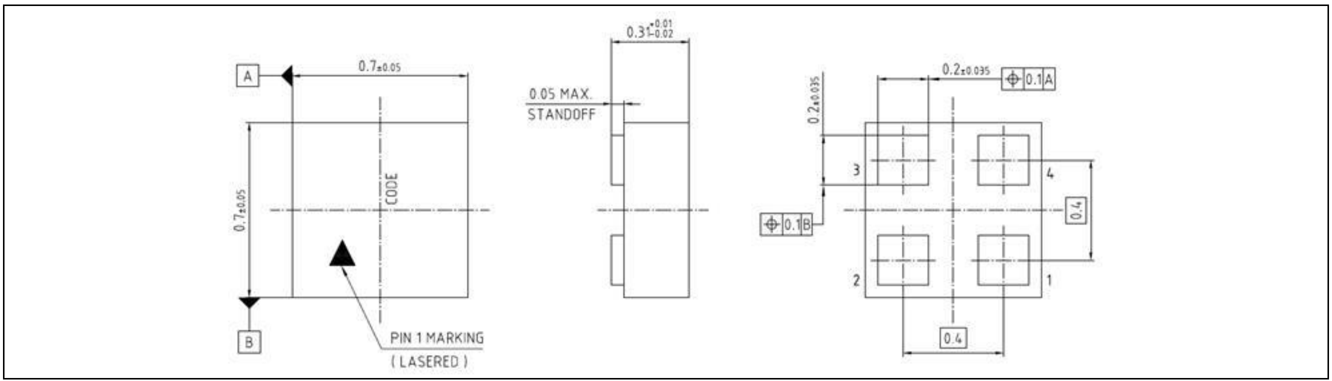

Figure 4 Package and pin connections of BGA123L4

Table 1 Pin assignment of BGA123L4

Pin no.	Symbol	Function
1	V_{CC}	DC supply
2	AO	LNA output
3	GND	Ground
4	AI	LNA input

Table 2 Mode selection of BGA123L4

To select the mode for BGA123L4, one option is to control the mode directly via the V_{CC} pin; an alternative option is to connect the the V_{CC} pin to the GPIO port. The table below provides the voltage range required at the V_{CC} pin to set the device to on or off mode.

LNA mode	On/off control voltage at V_{CC} pin	
	Min.	Max.
ON	1.1 V	3.6 V
OFF	0 V	0.4 V

Please visit the product page of BGA123L4 for more information.

3 Application circuit and performance overview

In this chapter the performance of the application circuit, the schematic and the Bill of Materials (BOM) are presented.

Device: **BGA123L4**

Application: **Low-noise amplifier for GNSS applications in L5/E5 bands**

PCB marking: **GL05 V 1.2 A**

EVB order no.: **AN552**

3.1 Summary of measurement results

The performance of BGA123L4 for GNSS applications is summarized in the following table.

Table 3 Electrical characteristics at 1.2 V (at room temperature)

Parameter	Symbol	Value				Unit	Comment/test condition
Frequency range	Freq	1164	1176	1189	1228	MHz	E5/L5 Band and L2 Band center frequency
DC voltage	V_{CC}	1.2				V	
DC current	I_{CC}	1.1				mA	
Gain	G	16.0	16.0	16.1	15.8	dB	
Noise Figure	NF	1.25	1.25	1.25	1.25	dB	LQP03T inductor for matching, loss of input line of 0.1 dB is de-embedded
Noise Figure	NF	0.90	0.95	0.95	0.90	dB	LQW15 inductor for matching, loss of input line of 0.1 dB is de-embedded
Input return loss	RL_{in}	11.4	11.7	11.9	11.3	dB	
Output return loss	RL_{out}	11.3	10.1	9.0	6.6	dB	
Reverse isolation	I_{Rev}	34.5	34.6	34.7	35.1	dB	
Input P1dB	IP1dB		-19		-18	dBm	Measured at 1176 / 1228 MHz
Output P1dB	OP1dB		-3.0		-2.2	dBm	
Input IP3	IIP3	-17.0				dBm	Power at input: -30 dBm f1 = 1176.5 MHz, f2 = 1177.5 MHz
Output IP3	OIP3	-1.0				dBm	
Out-of-Band Input IM3[1)]	OoB_IIM3	-80.6				dBm	Power at input: -25 dBm f1 = 1785 MHz, f2 = 2401 MHz OoB_OIM3 measured at 1169 MHz
Out-of-Band Output IM3	OoB_OIM3	-64.6				dBm	
Out-of-Band Input IM3[1)]	OoB_IIM3	-82.5				dBm	Power at input: -25 dBm f1 = 1850 MHz, f2 = 2493 MHz OoB_OIM3 measured at 1207 MHz
Out-of-Band Output IM3	OoB_OIM3	-66.5				dBm	
Stability	K	More than 1				–	Measured up to 10 GHz

1) Out-of-band Input IMx = IM level output referred – Gain @ the measured frequency

Table 4 Electrical characteristics at 1.8 V (at room temperature)

Parameter	Symbol	Value				Unit	Comment/test condition
Frequency range	Freq	1164	1176	1189	1228	MHz	E5/L5 Band and L2 Band center frequency
DC voltage	V_{CC}	1.8				V	
DC current	I_{CC}	1.1				mA	
Gain	G	16.2	16.3	16.3	16.1	dB	
Noise Figure	NF	1.20	1.20	1.25	1.25	dB	LQP03T inductor for matching, loss of input line of 0.1 dB is de-embedded
Noise Figure	NF	0.90	0.90	0.90	0.90	dB	LQW15 inductor for matching, loss of input line of 0.1 dB is de-embedded
Input return loss	RL_{in}	11.6	12.0	12.3	11.7	dB	
Output return loss	RL_{out}	11.4	10.2	9.0	6.6	dB	
Reverse isolation	I_{Rev}	34.6	34.7	34.6	35.1	dB	
Input P1dB	IP1dB		-18		-17.5	dBm	Measured at 1176 / 1228 MHz
Output P1dB	OP1dB		-3.2		-1.4	dBm	
Input IP3	IIP3	-17.0				dBm	Power at input: -30 dBm f1 = 1176.5 MHz, f2 = 1177.5 MHz
Output IP3	OIP3	-0.7				dBm	
Out-of-Band Input IM3[1)]	OoB_IIM3	-80.6				dBm	Power at input: -25 dBm f1 = 1785 MHz, f2 = 2401 MHz OoB_OIM3 measured at 1169 MHz
Out-of-Band Output IM3	OoB_OIM3	-64.3				dBm	
Out-of-Band Input IM3[1)]	OoB_IIM3	-82.6				dBm	Power at input: -25 dBm f1 = 1850 MHz, f2 = 2493 MHz OoB_OIM3 measured at 1207 MHz
Out-of-Band Output IM3	OoB_OIM3	-66.3				dBm	
Stability	K	More than 1				–	Measured up to 10 GHz

1) Out-of-band Input IMx = IM level output referred – Gain @ the measured frequency

Table 5 Electrical characteristics at 2.8 V (at room temperature)

Parameter	Symbol	Value				Unit	Comment/test condition
Frequency range	Freq	1164	1176	1189	1228	MHz	E5/L5 Band and L2 Band center frequency
DC voltage	V_{CC}	2.8				V	
DC current	I_{CC}	1.2				mA	
Gain	G	16.5	16.5	16.5	16.4	dB	
Noise Figure	NF	1.20	1.20	1.25	1.20	dB	LQP03TN inductor for matching, loss of input line of 0.1 dB is de-embedded
Noise Figure	NF	0.90	0.90	0.90	0.90	dB	LQW15 inductor for matching, loss of input line of 0.1 dB is de-embedded
Input return loss	RL_{in}	11.8	12.3	12.6	12.4	dB	
Output return loss	RL_{out}	11.2	10.1	9.0	6.6	dB	
Reverse isolation	I_{Rev}	34.7	34.6	34.7	35.1	dB	
Input P1dB	IP1dB		-19		-17	dBm	Measured at 1176 / 1228 MHz
Output P1dB	OP1dB		-2.5		-0.6	dBm	
Input IP3	IIP3	-17.0				dBm	Power at input: -30 dBm f1 = 1176.5 MHz, f2 = 1177.5 MHz
Output IP3	OIP3	-0.5				dBm	
Out-of-Band input IM3[1)]	OoB_IIM3	-81.6				dBm	Power at input: -25 dBm f1 = 1785 MHz, f2 = 2401 MHz OoB_OIM3 measured at 1169 MHz
Out-of-Band output IM3	OoB_OIM3	-65.1				dBm	
Out-of-Band input IM3[1)]	OoB_IIM3	-83.0				dBm	Power at input: -25 dBm f1 = 1850 MHz, f2 = 2493 MHz OoB_OIM3 measured at 1207 MHz
Out-of-Band output IM3	OoB_OIM3	-66.5				dBm	
Stability	K	More than 1				–	Measured up to 10 GHz

1) Out-of-band Input IMx = IM level output referred – Gain @ the measured frequency

3.2 Schematic and Bill of Materials (BOM)

The schematic of BGA123L4 for GNSS applications is presented in Figure 5 and its bill-of-materials is shown in Table 6.

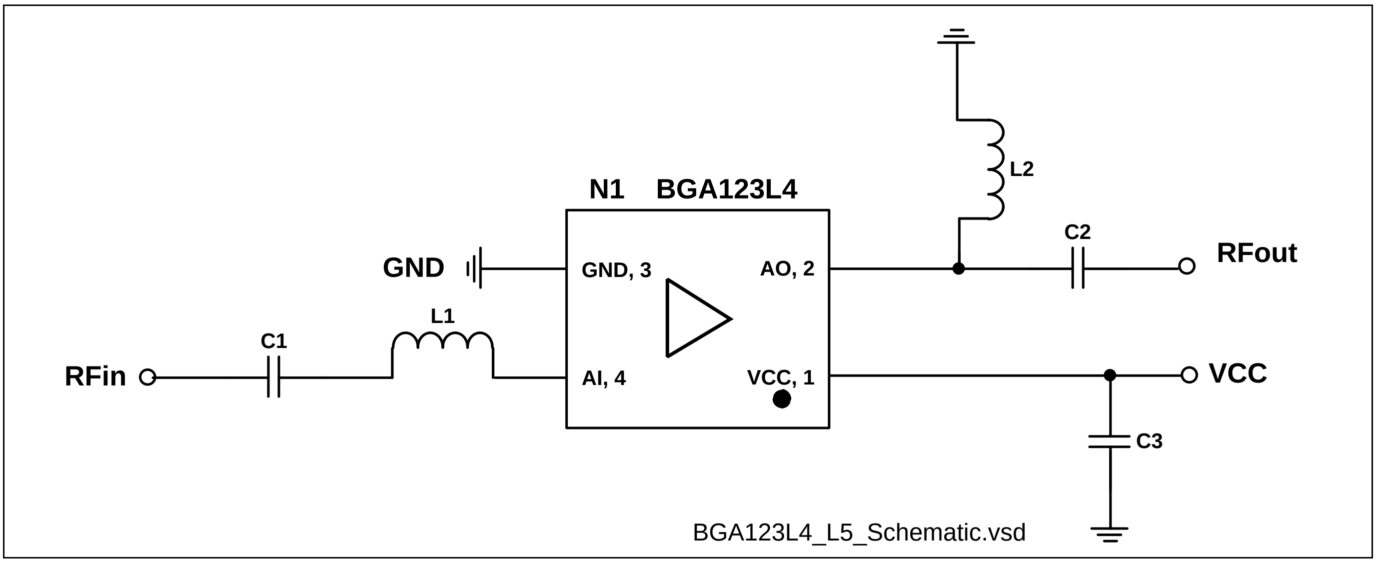

Figure 5 Schematic of the BGA123L4 application circuit

Table 6 Bill Of Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
C1	1	nF	0402/0201	Various	DC block (optional)
C2	3.0	pF	0402/0201	Various	Output matching
C3	1	nF	0402/0201	Various	RF bypass (optional)
L1	18	nH	0402/0201	Murata LQW15/LQP03TN	Input matching
L2	3.6	nH	0402/0201	Murata LQW15/LQP03TN	Output matching
N1	BGA123L4	TSLP-4-11		Infineon Technologies	SiGe LNA

Note: DC block function is NOT integrated at the input of BGA123L4. The DC block might be realized with pre-filter in GNSS applications.

Note: The RF bypass capacitor C3 at the DC power supply pin filters out the power supply noise and stabilizes the DC supply. The C3 is not necessary if a clean and stable DC supply can be ensured.

4 Measurement graphs

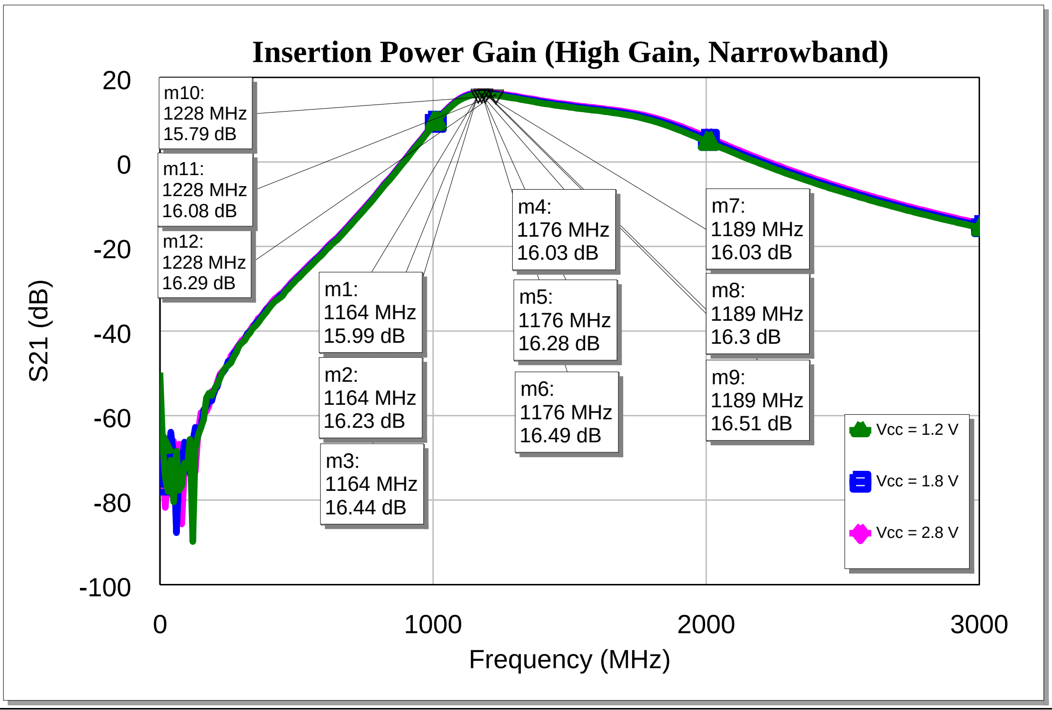

Figure 6 **Insertion power gain (narrowband) of BGA123L4 for GNSS applications including L2 band (center frequency)**

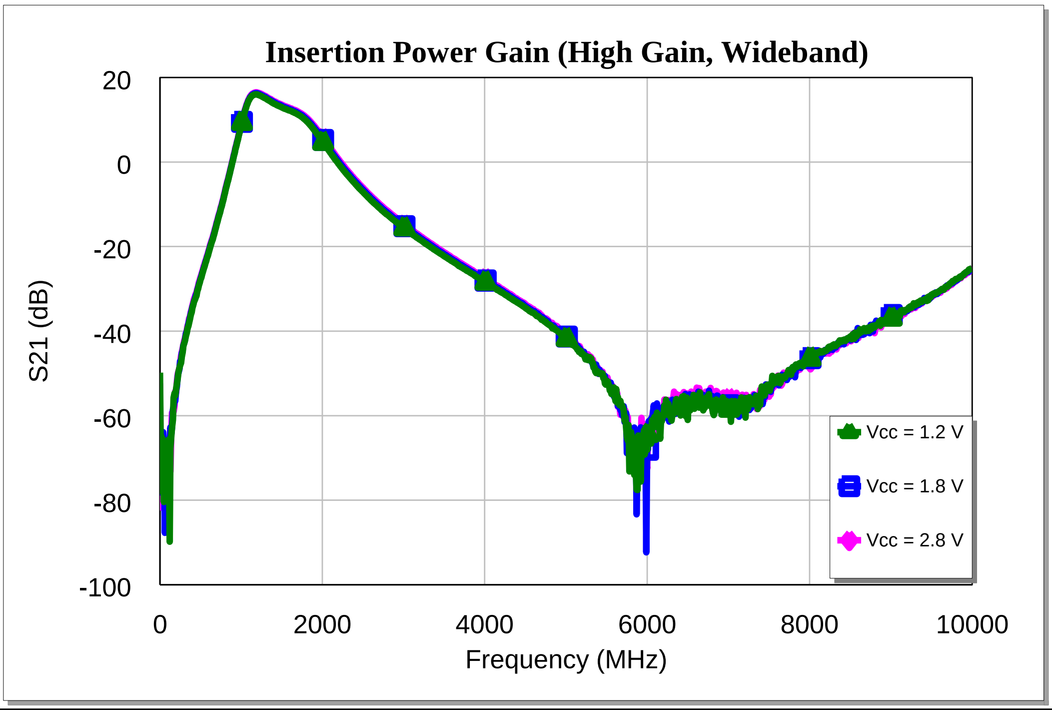

Figure 7 **Insertion power gain (wideband) of BGA123L4 for GNSS applications**

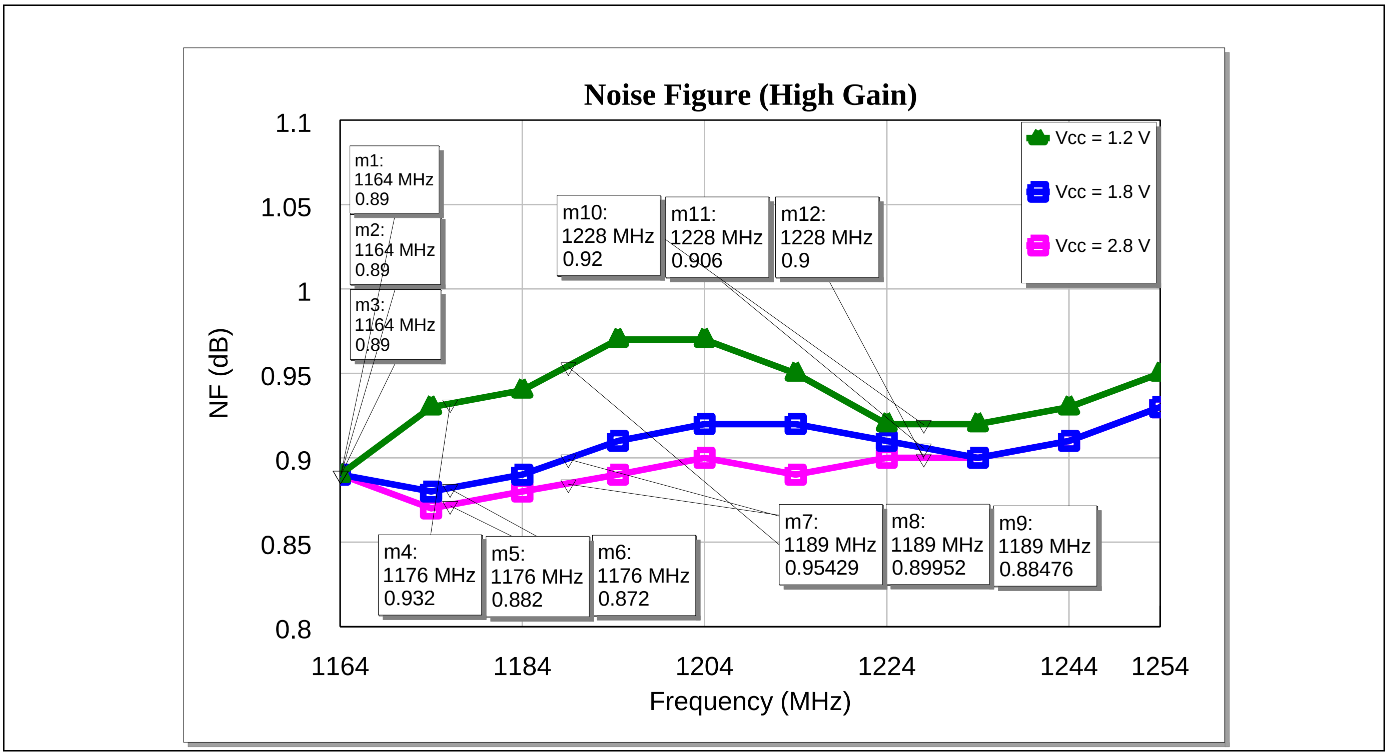

Figure 8 NF of BGA123L4 for GNSS applications (SMA and connector losses de-embedded, LQW15 inductors for matching)

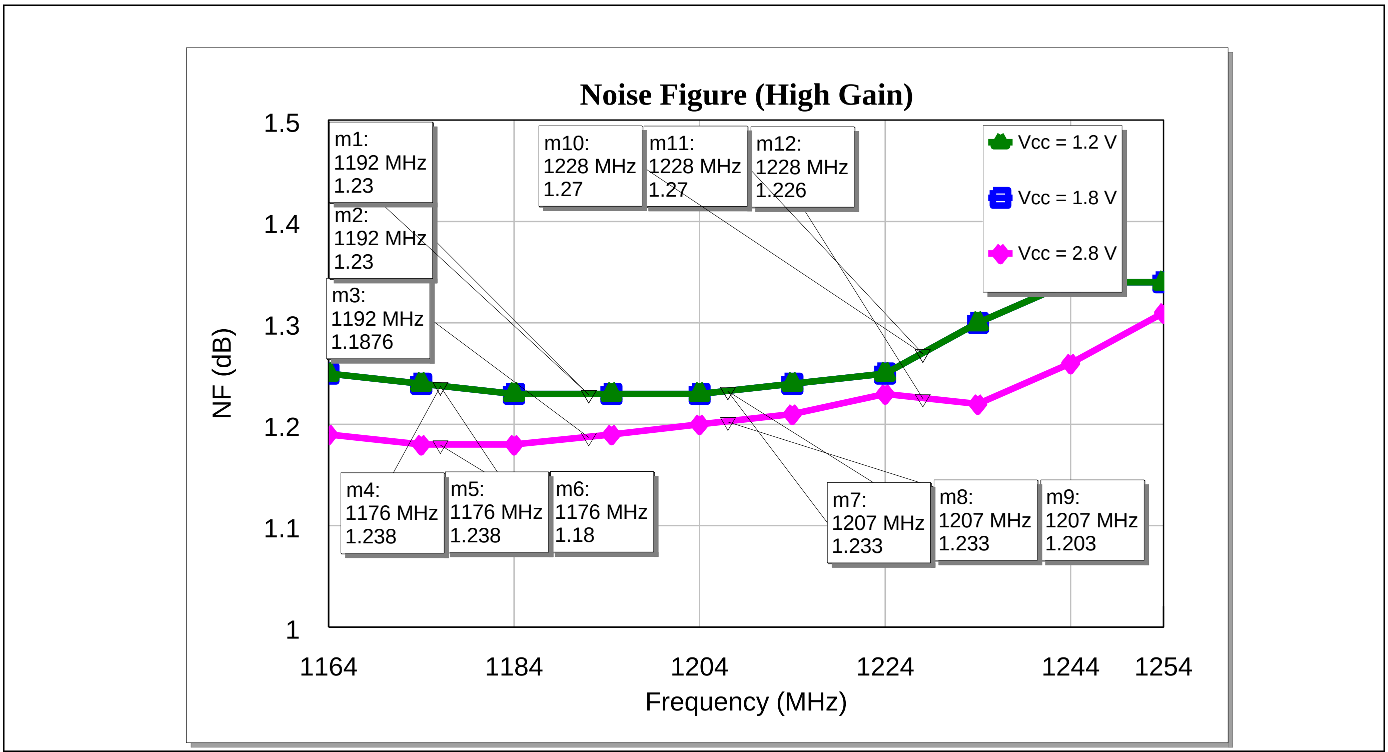

Figure 9 NF of BGA123L4 for GNSS applications (SMA and connector losses de-embedded, LQP03TN inductors for matching)

Measurement graphs

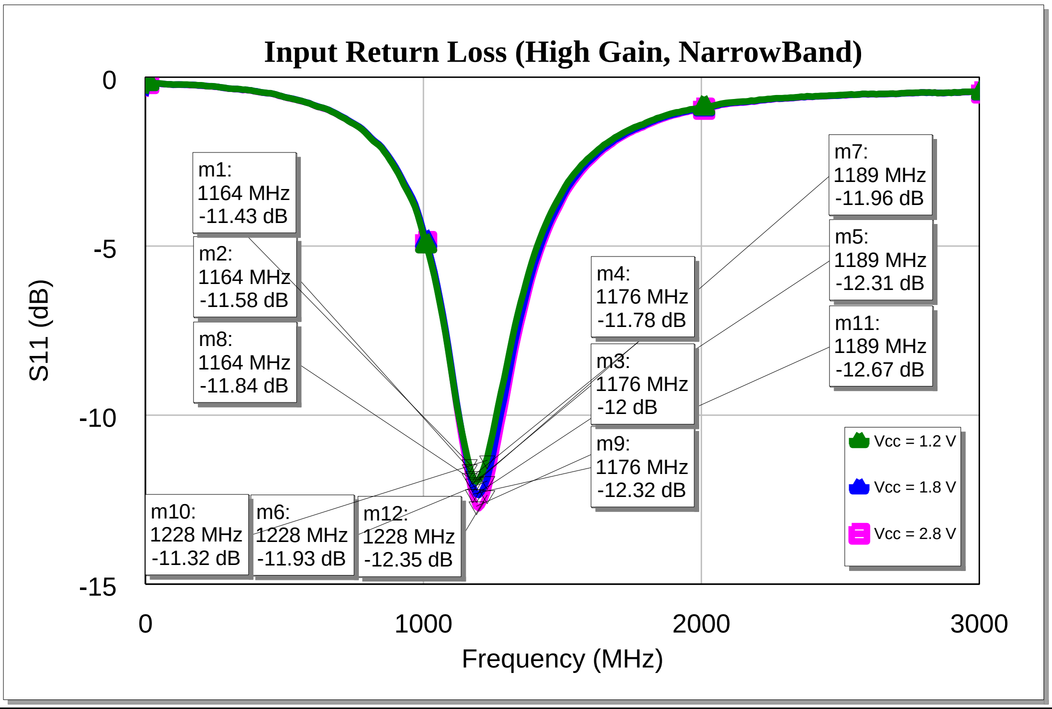

Figure 10 **Input return loss of BGA123L4 for GNSS applications including L2 band (center frequency)**

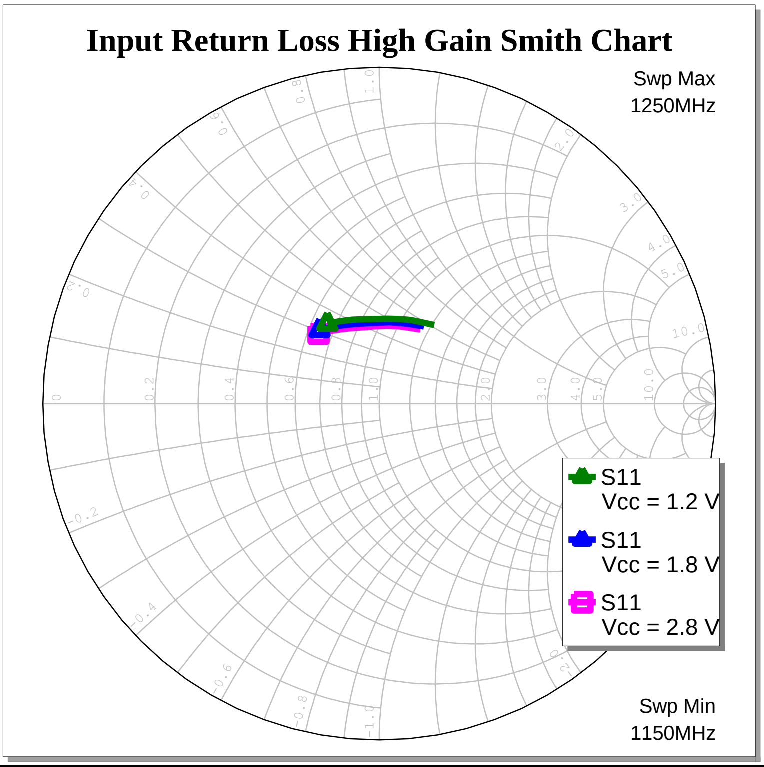

Figure 11 **Input return loss (Smith chart) of BGA123L4 for GNSS applications**

Measurement graphs

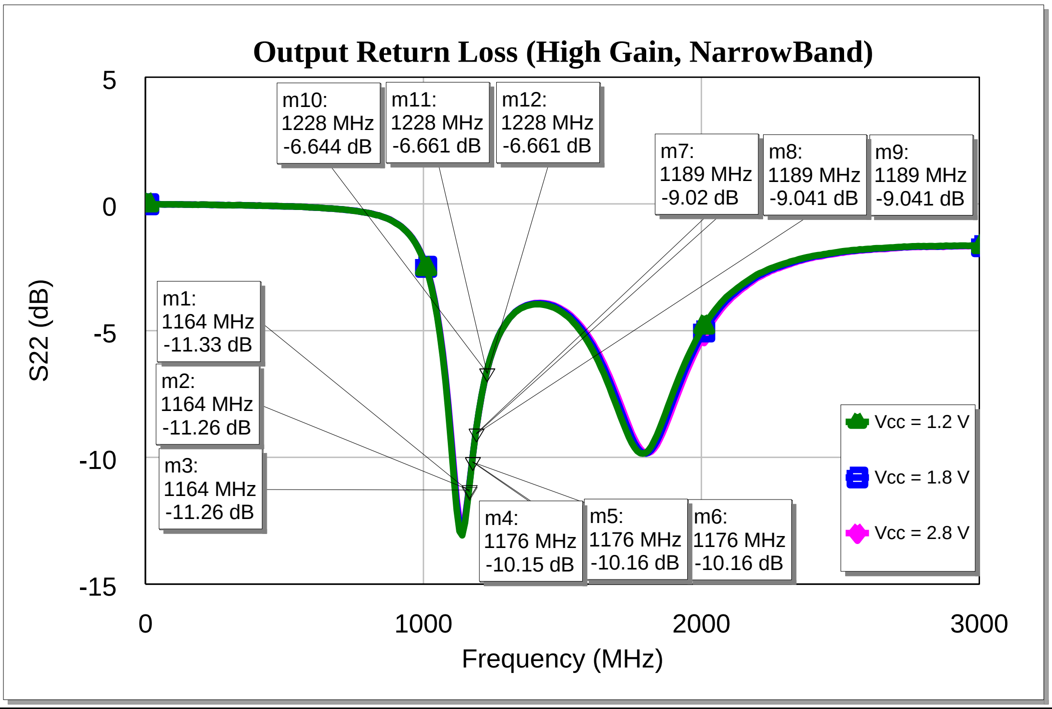

Figure 12 **Output return loss of BGA123L4 for GNSS applications including L2 band (center frequency)**

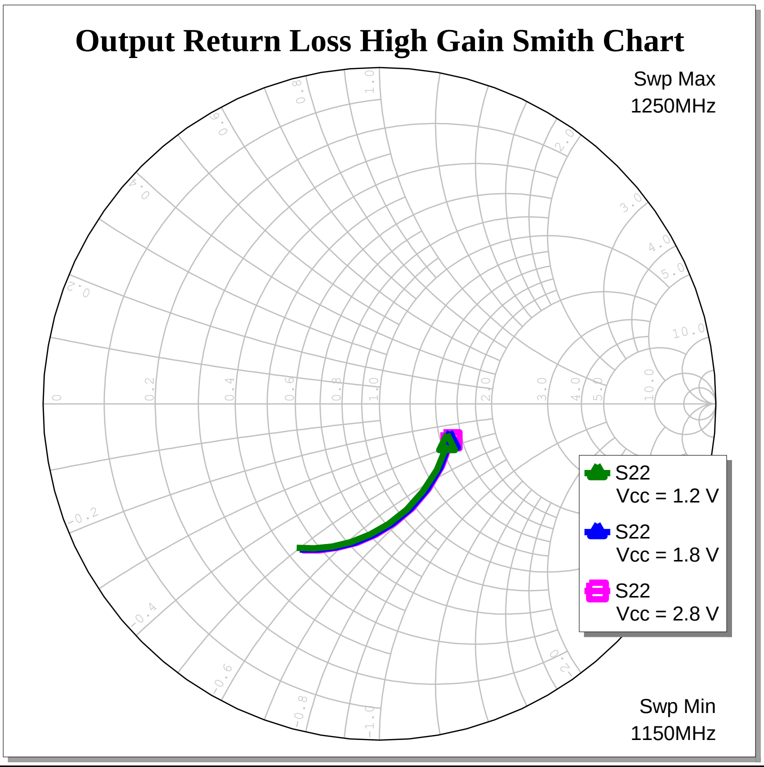

Figure 13 **Output return loss (Smith chart) of BGA123L4 for GNSS applications**

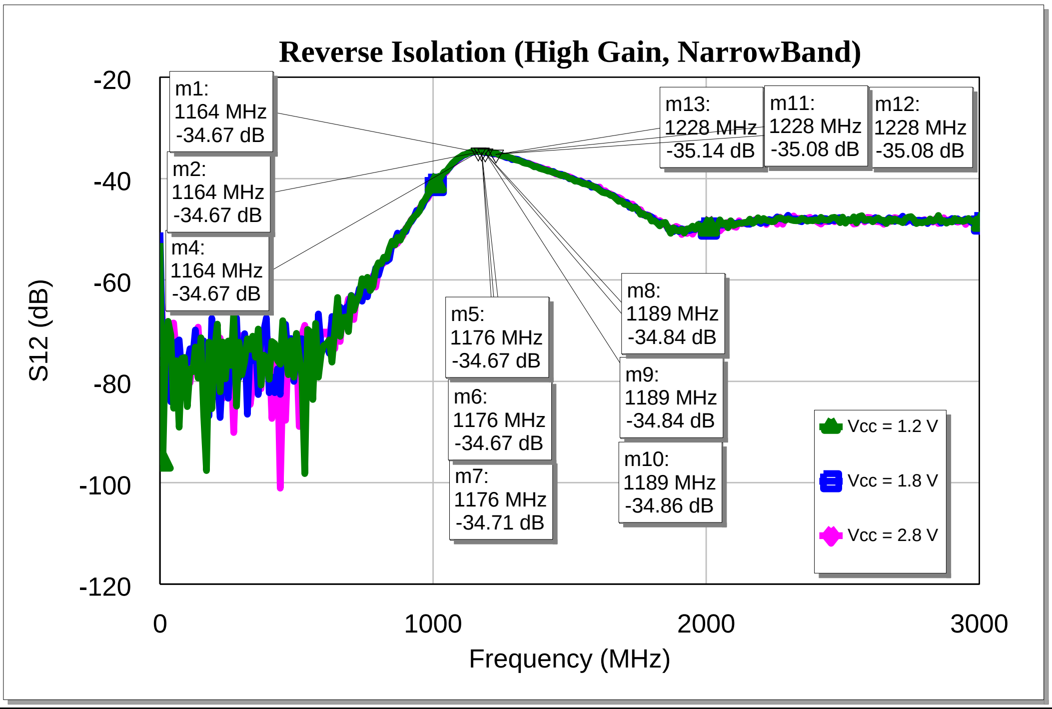

Figure 14 Reverse isolation of BGA123L4 for GNSS applications including L2 band (center frequency)

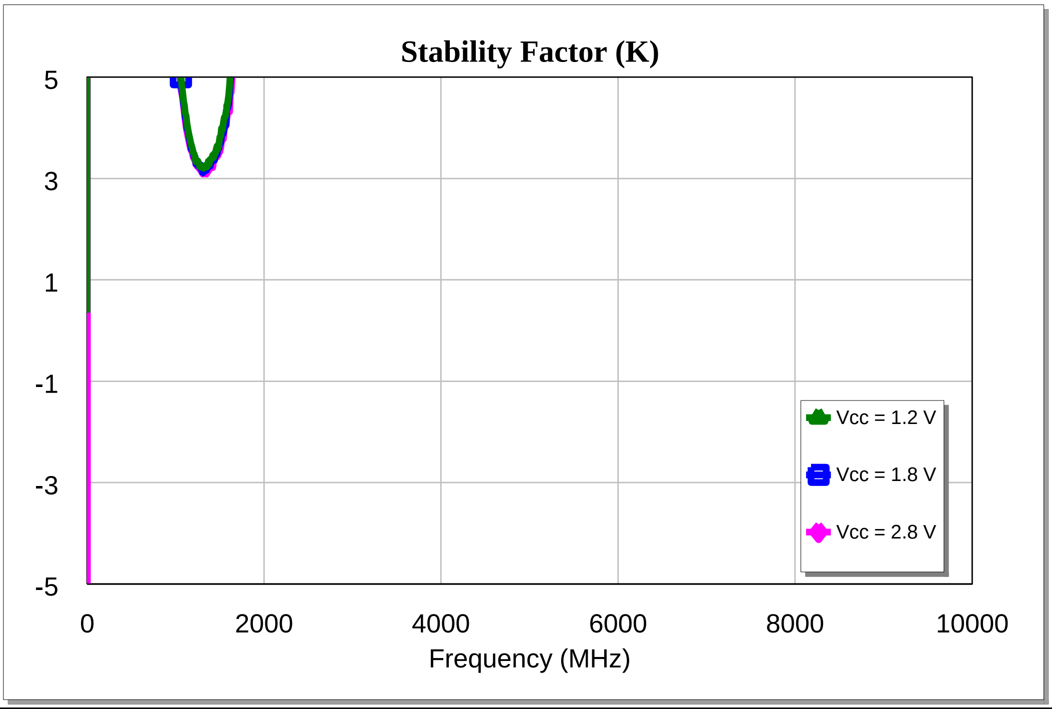

Figure 15 Stability K-factor of BGA123L4 for GNSS applications

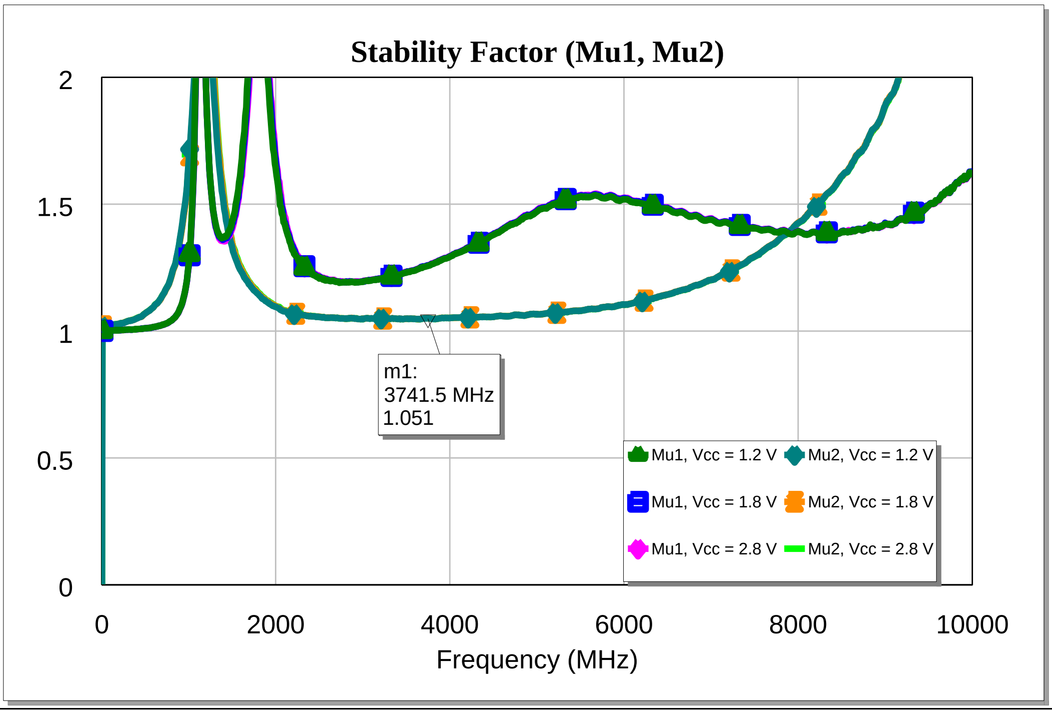

Figure 16 Stability Mu1-factor, Mu2-factor of BGA123L4 for GNSS applications

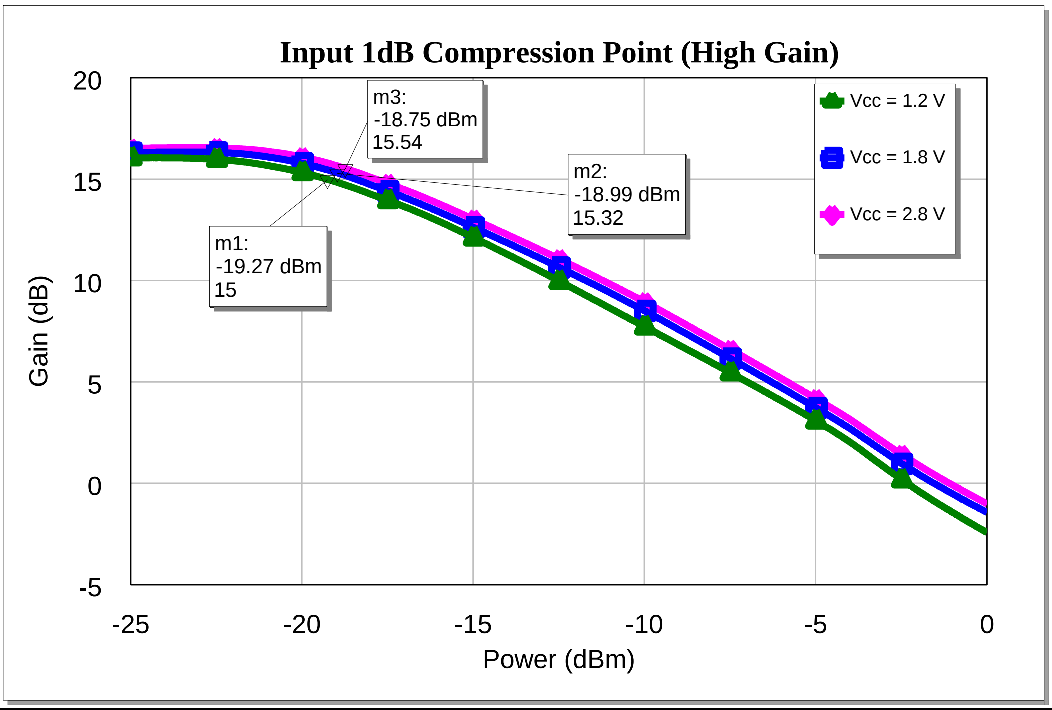

Figure 17 Input 1 dB compression point of BGA123L4 for GNSS applications at L5 Centre frequency

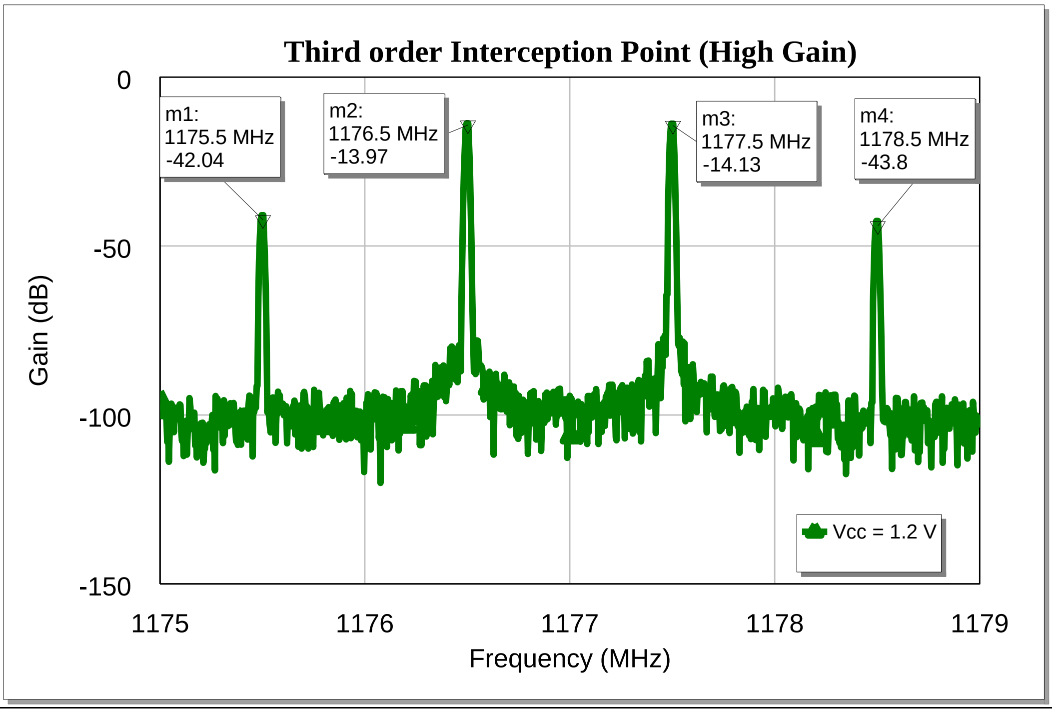

Figure 18 Third-order interception point (1.2 V) of BGA123L4 for GNSS applications (output referred)

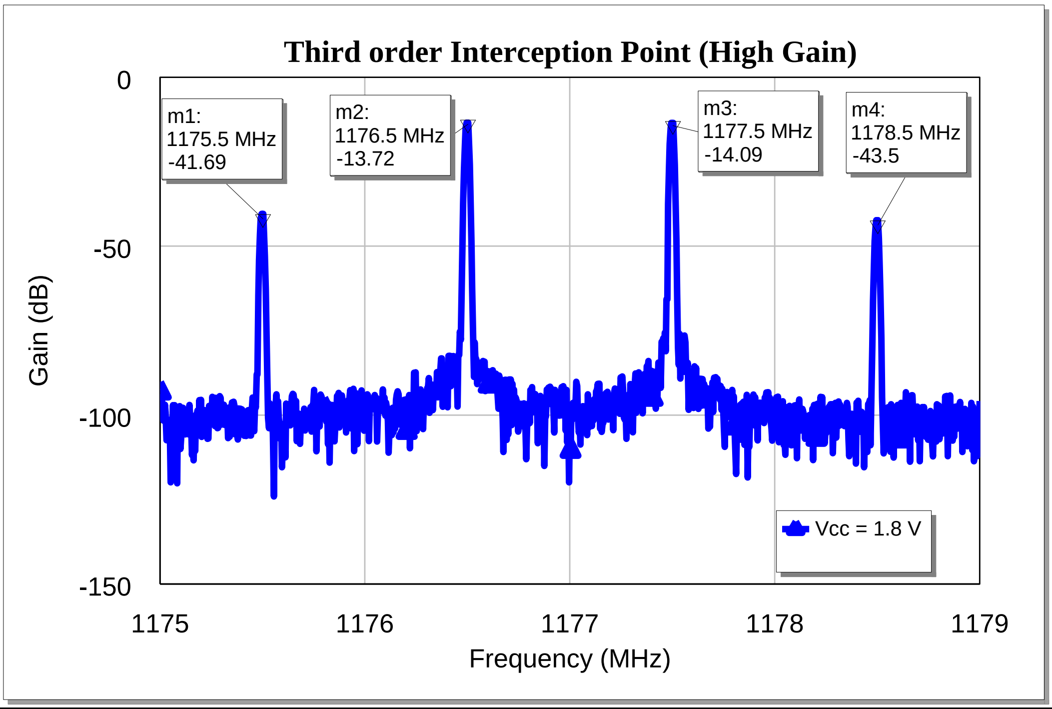

Figure 19 Third-order interception point (1.8 V) of BGA123L4 for GNSS applications (output referred)

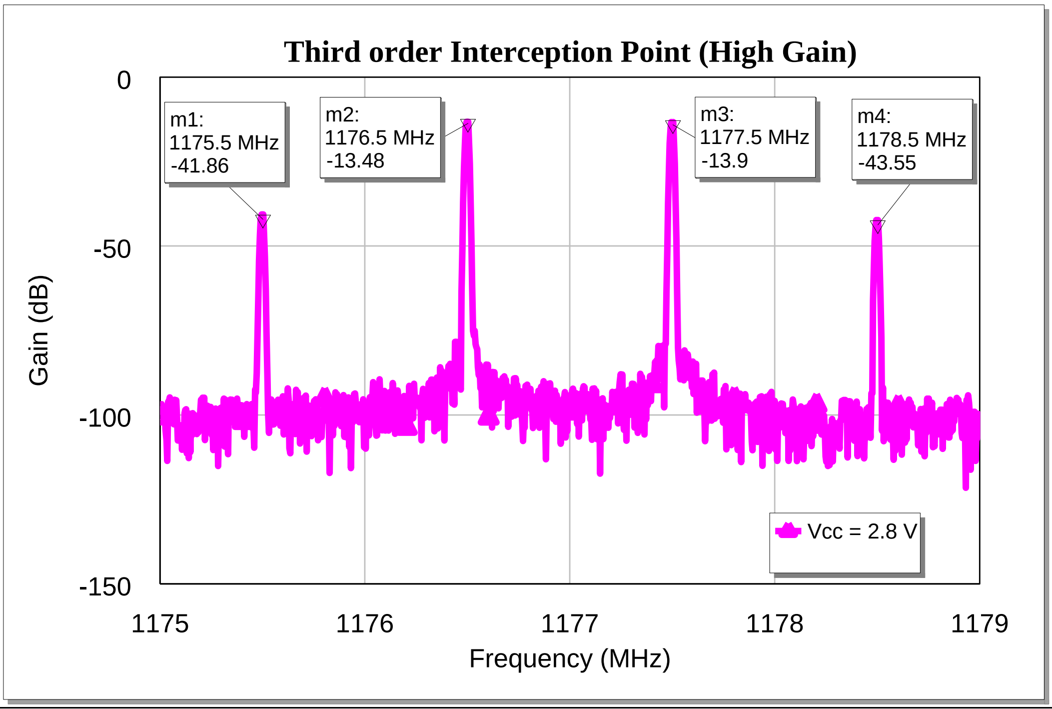

Figure 20 **Third-order interception point (2.8 V) of BGA123L4 for GNSS applications (output referred)**

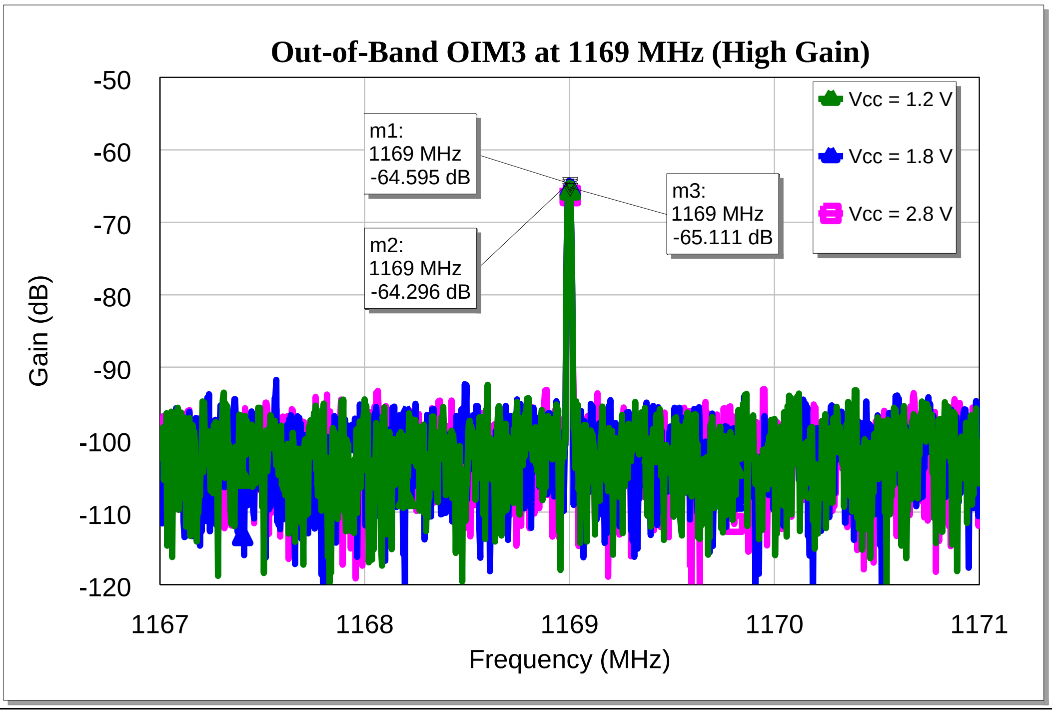

Figure 21 **Out-of-band third-order intermodulation point of BGA123L4 for GNSS applications at 1169 MHz (output referred)**

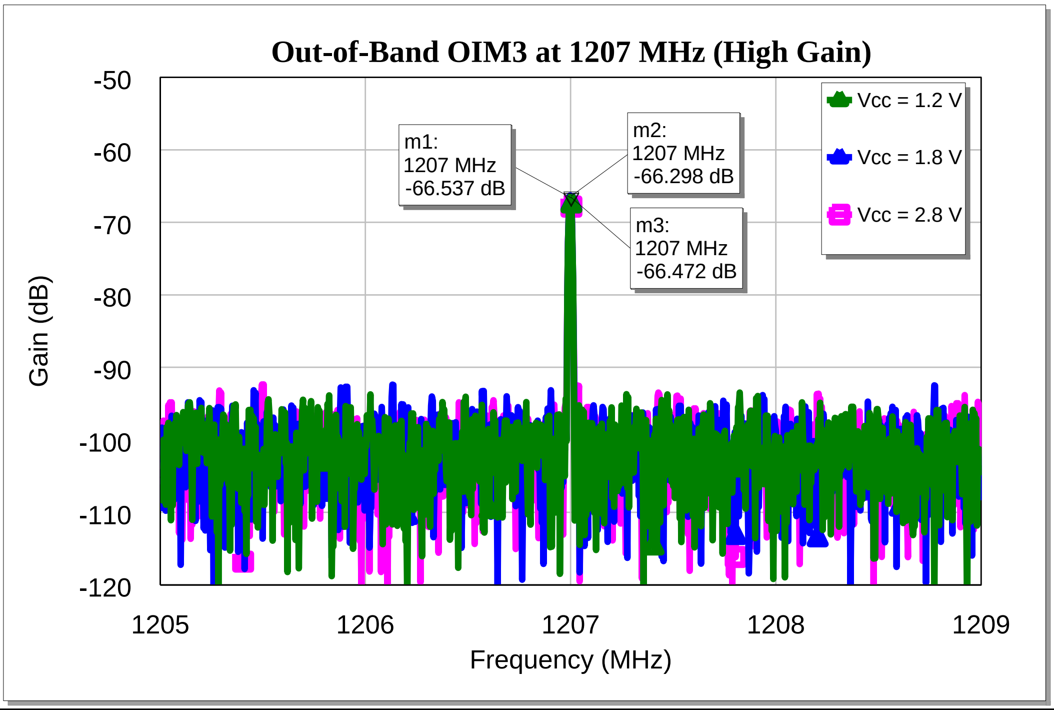

Figure 22 **Out-of-band third-order intermodulation point of BGA123L4 for GNSS applications at 1207 MHz (output referred)**

5 Evaluation board and layout information

In this application note, the following PCB is used:

PCB marking: **GL05 V1.2A**

PCB material: **FR 4**

ε_r of PCB material: **4.3**

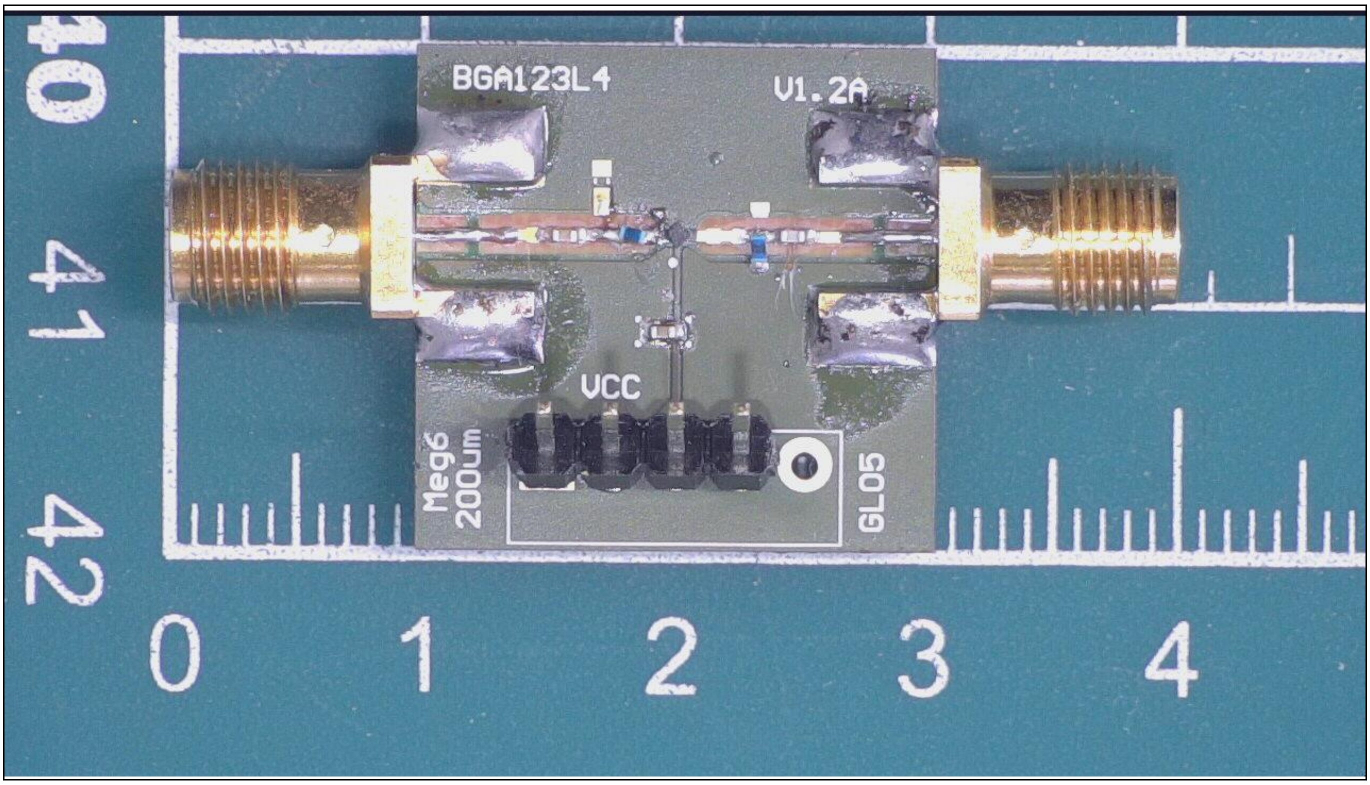

Figure 23 Photo of evaluation board (overview)

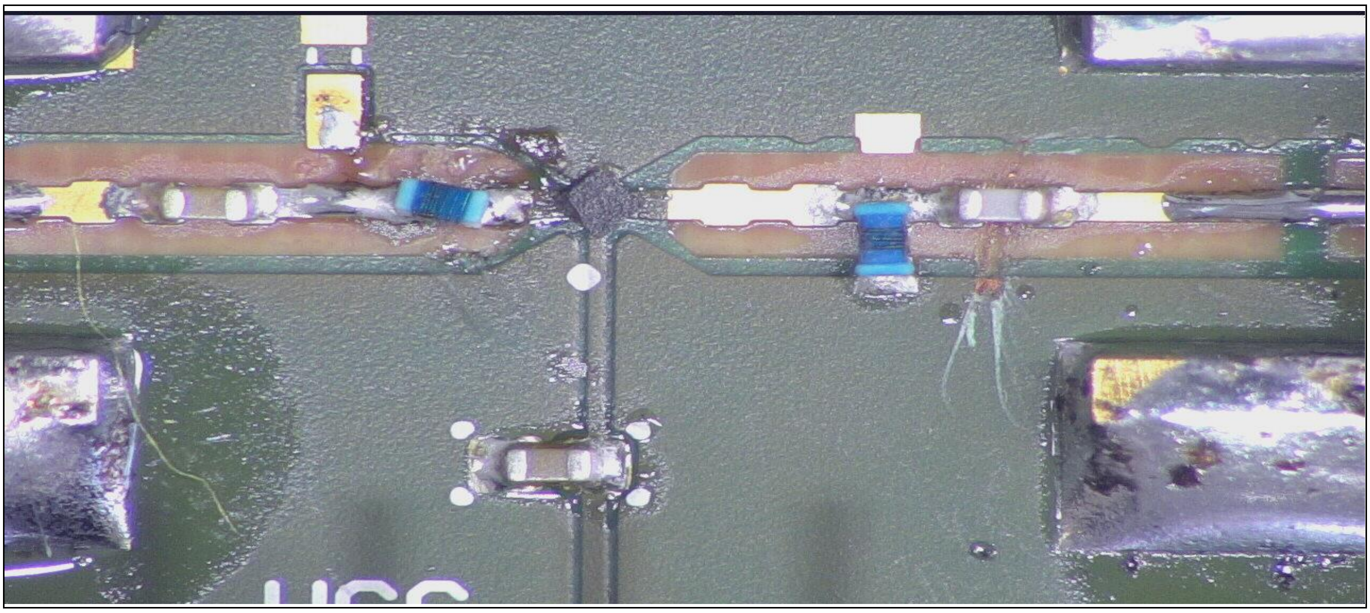

Figure 24 Photo of evaluation board (detailed view)

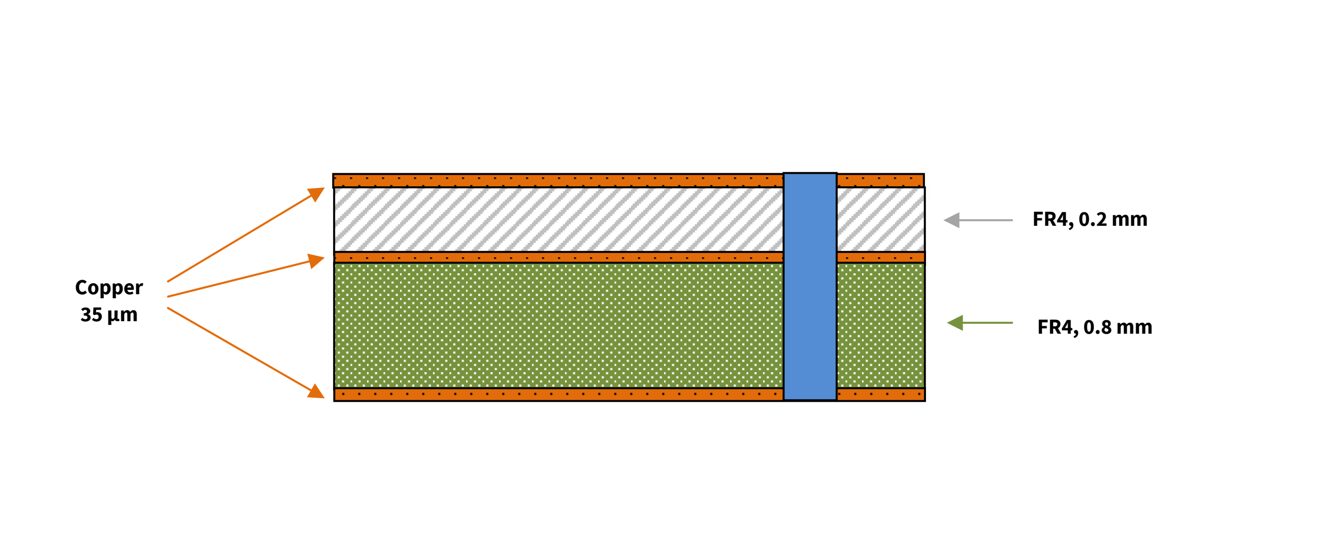

Figure 25 PCB layer information

6 Authors

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7 References

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[2] http://galileognss.eu/wp-content/uploads/2013/09/Galileo-Frequency-bands.jpg

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Revision history

Major changes since the last revision

Page or reference	Description of change

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