BGA123L4 as LNA for GNSS applications with LTE B13 rejection

About this document

Scope and purpose

This application note describes Infineon's GNSS MMIC: BGA123L4 – a low-current low noise amplifier for GNSS applications (1550 to 1615 MHz) including an additional filter to reject the LTE band 13 signal.

The BGA123L4 is a silicon germanium low-noise amplifier supporting 1550 to 1615 MHz.

1. The target application is the GNSS applications in the range of 1550 to 1615 MHz (e.g. GPS L1 band).
2. In this report, the performance of BGA123L4 is measured on a Rogers 4003 board. This device is matched with 0402 size high Q-factor external components. Performance deviation, when matched with 0201 size components, is also presented.
3. Key performance parameters at 1.8 V, 1575 MHz
   Noise Figure (NF) = 0.90 dB (LQW15 inductors for matching)
   Insertion gain = 18.0 dB
   Insertion gain at 787 MHz = -34 dB
   Input return loss = 11 dB
   Output return loss = 15 dB
   Out-of-band Output IM3 = -35.4 dBm

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List of tables

1) The graphs were 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), 1259 to 1299 MHz (E6), 1164 MHz to 1214 MHz (E5)

GLONASS: 1598 to 1609 MHz (G1), 1237 to 1254 MHz (G2), 1189 MHz to 1214 MHz (G3)

BeiDou: 1559 to 1591 MHz (B1), 1193 to 1221 MHz (B2), 1257 to 1281 MHz (B3)

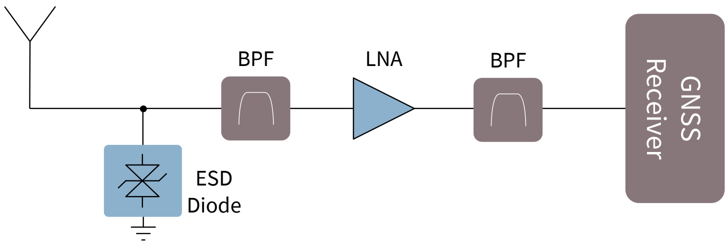

Figure 1 Application diagram for the receiver front-end of the Global Navigation Satellite System

1.1.1 LTE band 13/band 14 interference

The second harmonic of LTE band 13 and band 14 (777 MHz/788 MHz) is located in the GNSS band at 1574 MHz/1576 MHz. Figure 2 depicts the measurement of LTE band 13 second harmonic interference.

Considering a worst-case isolation of 15 dB between the both antennas, jammer frequency fLTE = 787.76 MHz, the power of the LTE band 13 jammer is -32 dBm at the input of GNSS LNA. After inserting a band 13 rejection filter at LNA input with a rejection of 30 dB, the power of the LTE band 13 jammer becomes -62 dBm at the input of GNSS LNA, the second harmonic at fH2 = 1575.52 MHz will be reduced to -110 dBm at the LNA output.

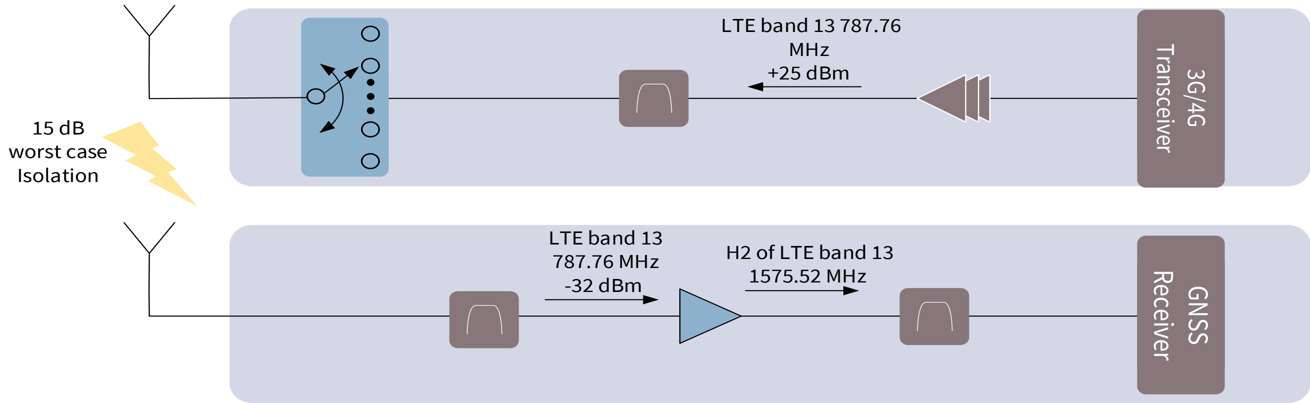

Figure 2 Block diagram for the LTE band 13 second harmonic interference

1.1.2 Out-of-band interference

Because GNSS and cellular systems co-exist in a compact area in a mobile phone, coupling from 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, LTE band 3 signal ($f1_{IN}$) and LTE band 2 signal ($f2_{IN}$) produce third-order intermodulation products at GPS frequencies. This effect desensitizes the GPS receiver and decreases its performance. This may be expressed via the Out-of-Band IM3 LNA output referred (OoB OIM3) and Out-of-Band IM3 LNA input referred (OoB IIM3).

$$\text{OoB } IIM3 = OoB\ OIM3\ at\ GPS - Gain\ at\ GPS \quad \text{------ (1)}$$

When $f1_{IN}$ = 1712.7 MHz and power $P1_{IN}$ = -25 dBm, and $f2_{IN}$ = 1850 MHz and power $P2_{IN}$ = -25 dBm are used, the third-order intermodulation product, $2 \times f1_{IN} - f2_{IN}$, is located at 1575.4 MHz. Considering an OoB IM3 level of -65 dBm at the LNA output, using the equation 1, the OoB IIM3 can be calculated as:

$$OoB\ IIM3 = -65.0 - 17.0 = -82.0 \text{ dBm}$$

(Note: OoB IM3 output referred at GPS, and gain at GPS is from BGA824N6)

1.2 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.

1.3 Key features of GNSS low noise amplifiers

1.3.1 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.

1.3.2 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 intreference, LNAs with high robustness against out-of-band intereference signals are required.

1.3.3 Low current consumption

Power consumption is an important feature in many GNSS systems, 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 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

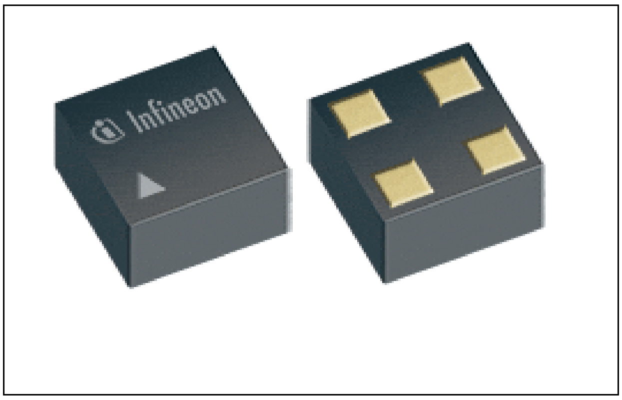

Figure 3 BGA123L4 in TSLP-4-11

RoHS

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 V 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, Galilieo 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

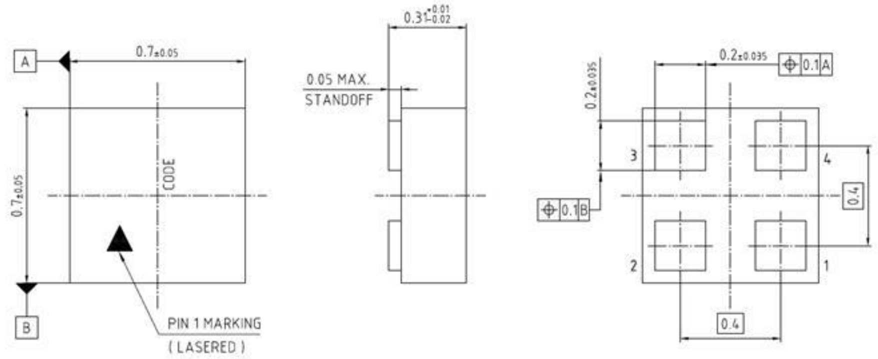

Figure 4 Package and pin connections of BGA123L4

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

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 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.

Table 2 Mode selection of BGA123L4

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 Bill of Materials (BOM) are presented.

Device: BGA123L4

Application: Low-current NA for GNSS applications with LTE band 13 rejection

PCB marking: GL05 V1.0/V1.1

EVB order no.: AN578

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	1550	1575	1615	MHz	
DC voltage	V_{CC}	1.2			V	
DC current	I_{CC}	1.05			mA	
Gain	G	17.6	17.6	17.5	dB	
Gain at 787 MHz	G_B13	-34			dB	
Noise Figure[1)]	NF	0.95	0.95	0.95	dB	LQW15 inductor for matching[1)]
Noise Figure[1)]	NF	1.10	1.10	1.10	dB	LQP03TN inductor for matching[2)]
Input return loss	RL_{in}	11	12	12	dB	
Output return loss	RL_{out}	14	16	15	dB	
Reverse isolation	I_{Rev}	37	38	38	dB	
Input P1dB	IP1dB		-17.0		dBm	
Output P1dB	OP1dB		-0.4		dBm	
LTE band 13 second harmonic input referred	B13 IHD2	-77.2			dBm	Power at input: -25 dBm f = 787.7 MHz, HD2 measured at 1575.4 MHz
LTE band 13 second harmonic output referred	B13 OHD2	-59.6			dBm	
Input IP3	IIP3	-14.2			dBm	Power at input: -30 dBm f1 = 1575 MHz, f2 = 1576 MHz
Output IP3	OIP3	3.4			dBm	
Out-of-Band Input IM3[4)]	OoB_IIM3	-55.3			dBm	Power at input: -25 dBm f1 = 1712.7 MHz, f2 = 1850 MHz OoB_IM3 measured at 1575.4 MHz
Out-of-Band Output IM3	OoB_OIM3	-37.7			dBm	
Stability	K	>1			–	Measured up to 10 GHz

Application circuit and performance overview

Note: 1) Loss of input-line of 0.05 dB is de-embedded

2) OoB_IIM3 calculated as OoB_OIM3 – gain at the measured frequency

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

Parameter	Symbol	Value			Unit	Comment/test condition
Frequency range	Freq	1550	1575	1615	MHz	
DC voltage	Vcc	1.8			V	
DC current	Icc	1.10			mA	
Gain	G	18.0	18.0	18.0	dB	
Gain at 787 MHz	G_B13	-34			dB	
Noise Figure[1]	NF	0.90	0.90	0.90	dB	LQW15 inductor for matching[1]
Noise Figure[2]	NF	1.05	1.05	1.05	dB	LQP03TN inductor for matching[2]
Input return loss	RLin	11	11	12	dB	
Output return loss	RLout	13	15	15	dB	
Reverse isolation	IRev	37	37	39	dB	
Input P1dB	IP1dB		-14.1		dBm	
Output P1dB	OP1dB		2.9		dBm	
LTE band 13 second harmonic input referred	B13 IHD2	-77.3			dBm	Power at input: -25 dBm f = 787.7 MHz, measure HD2 at 1575.4 MHz
LTE band 13 second harmonic output referred	B13 OHD2	-59.3			dBm	
Input IP3	IIP3	-14.0			dBm	Power at input: -30 dBm f1 = 1575 MHz, f2 = 1576 MHz
Output IP3	OIP3	4.0			dBm	
Out-of-Band Input IM3	Oob_IIM3	-53.4			dBm	Power at input: -25 dBm f1 = 1712.7 MHz, f2 = 1850 MHz OoB_IM3 measured at 1575.4 MHz
Out-of-Band Output IM3	Oob_OIM3	-35.4			dBm	
Stability	K	>1			–	Measured up to 10 GHz

Note: 1) Loss of input-line of 0.05 dB is de-embedded

2) OoB_IIM3 calculated as OoB_OIM3 – gain at the measured frequency

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

Parameter	Symbol	Value			Unit	Comment/test condition
Frequency range	Freq	1550	1575	1615	MHz	
DC voltage	V_{CC}	2.8			V	
DC current	I_{CC}	1.15			mA	
Gain	G	18.3	18.3	18.3	dB	
Gain at 787 MHz	G_B13	-34			dB	
Noise Figure[1)]	NF	0.90	0.90	0.90	dB	LQW15 inductor for matching[1)]
Noise Figure[2)]	NF	1.05	1.05	1.05	dB	LQP03TN inductor for matching[2)]
Input return loss	RL_{in}	11	12	12	dB	
Output return loss	RL_{out}	12	14	15	dB	
Reverse isolation	I_{Rev}	37	37	38	dB	
Input P1dB	IP1dB		-13.4		dBm	
Output P1dB	OP1dB		3.9		dBm	
LTE band 13 second harmonic input referred	B13 IHD2	-77.3			dBm	Power at input: -25 dBm f = 787.7 MHz, measure HD2 at 1575.4 MHz
LTE band 13 second harmonic output referred	B13 OHD2	-59.0			dBm	
Input IP3	IIP3	-13.5			dBm	Power at input: -30 dBm f1 = 1575 MHz, f2 = 1576 MHz
Output IP3	OIP3	4.8			dBm	
Out-of-Band Input IM3	OoB_IIM3	-54.0			dBm	Power at input: -25 dBm f1 = 1712.7 MHz, f2 = 1850 MHz OoB_IP3 measured at 1575.4 MHz
Out-of-Band Output IM3	OoB_OIM3	-35.7			dBm	
Stability	K	>1			–	Measured up to 10 GHz

Note: 1) Loss of input-line of 0.05 dB is de-embedded

2) OoB_IIM3 calculated as OoB_OIM3 – gain at the measured frequency

3.2 Schematic and Bill-of-Materials

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

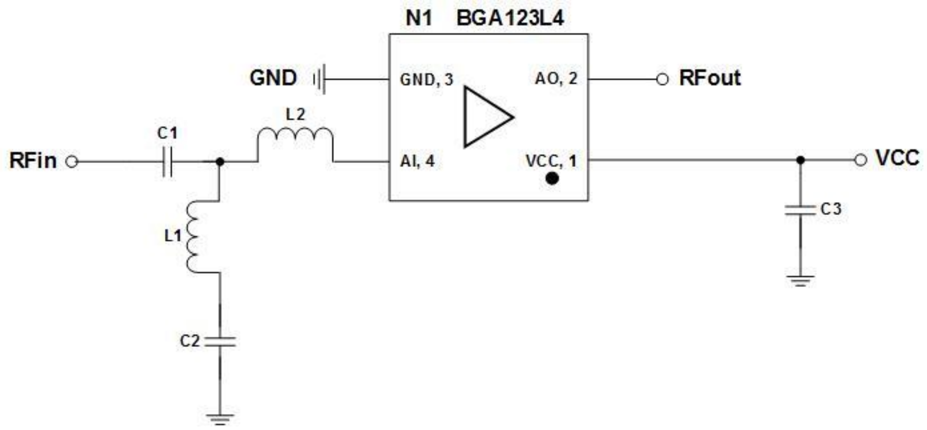

Figure 5 Schematic of the BGA123L4 application circuit

Table 6 Bill-of-Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
C1	1	nF	0402	Various	DC block (optional)
C2	3.3	pF	0402	Various	B13/B14 rejection filter
C3	Greater than or equal to 1	nF	0402	Various	RF bypass (optional)
L1	12	nH	0402	Murata LQW15	B13/B14 rejection filter
L2	7.5	nH	0402	Murata LQW15	Input 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

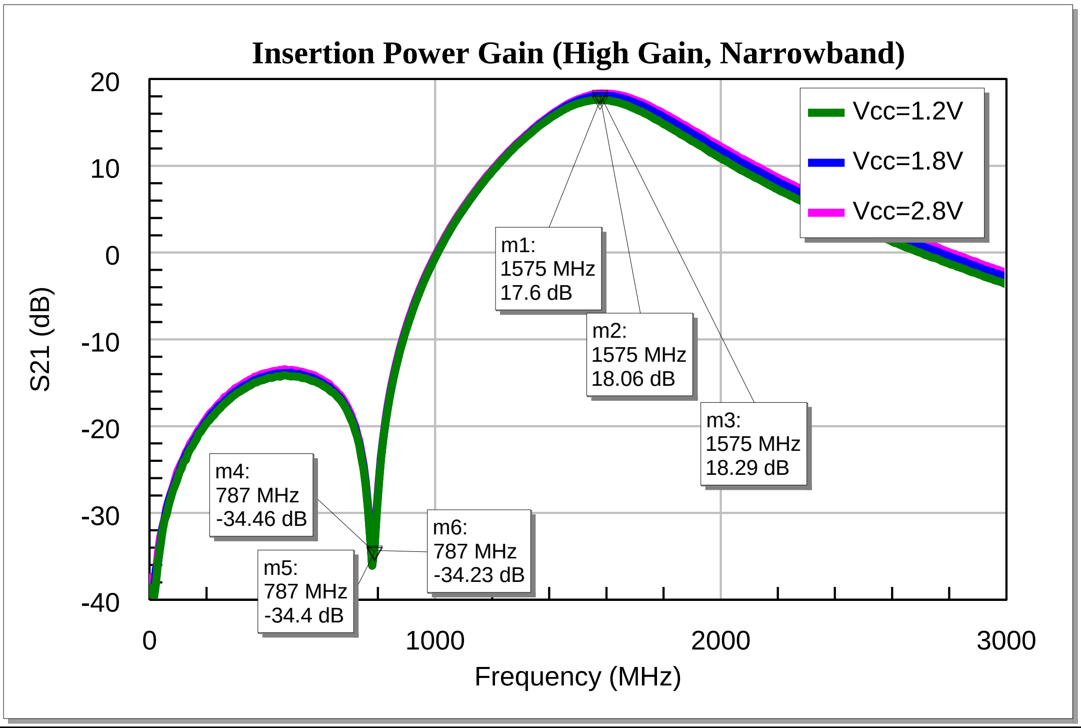

Figure 6 Insertion power gain (narrowband) of BGA123L4 for GNSS applications

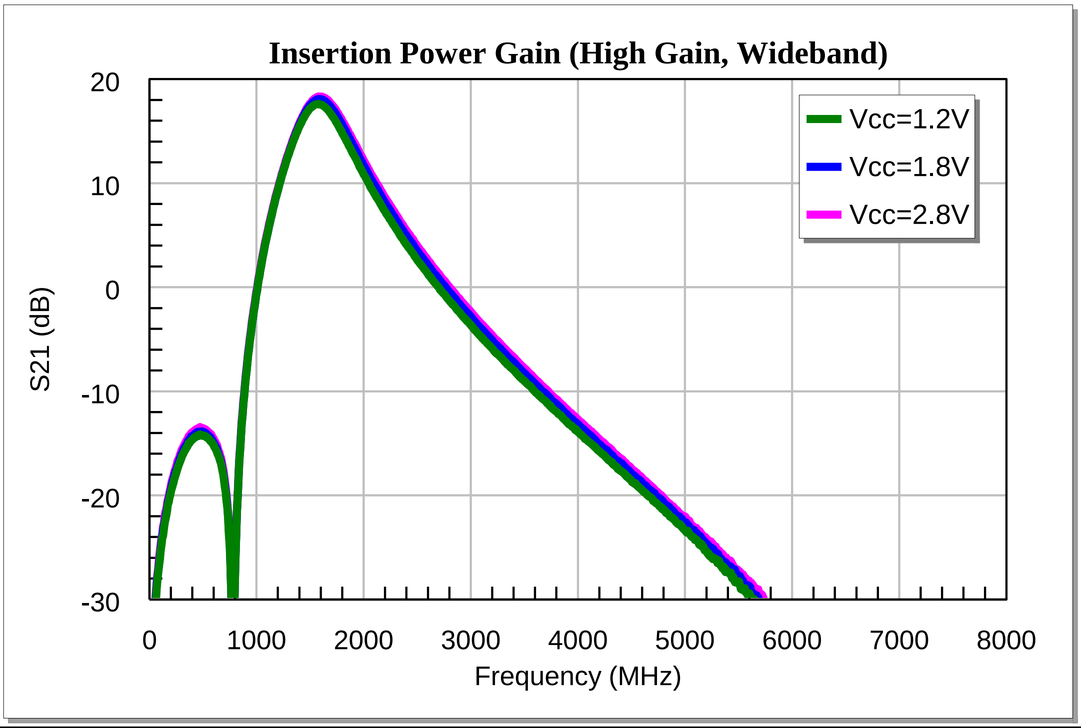

Figure 7 Insertion power gain (wideband) of BGA123L4 for GNSS applications

Measurement graphs

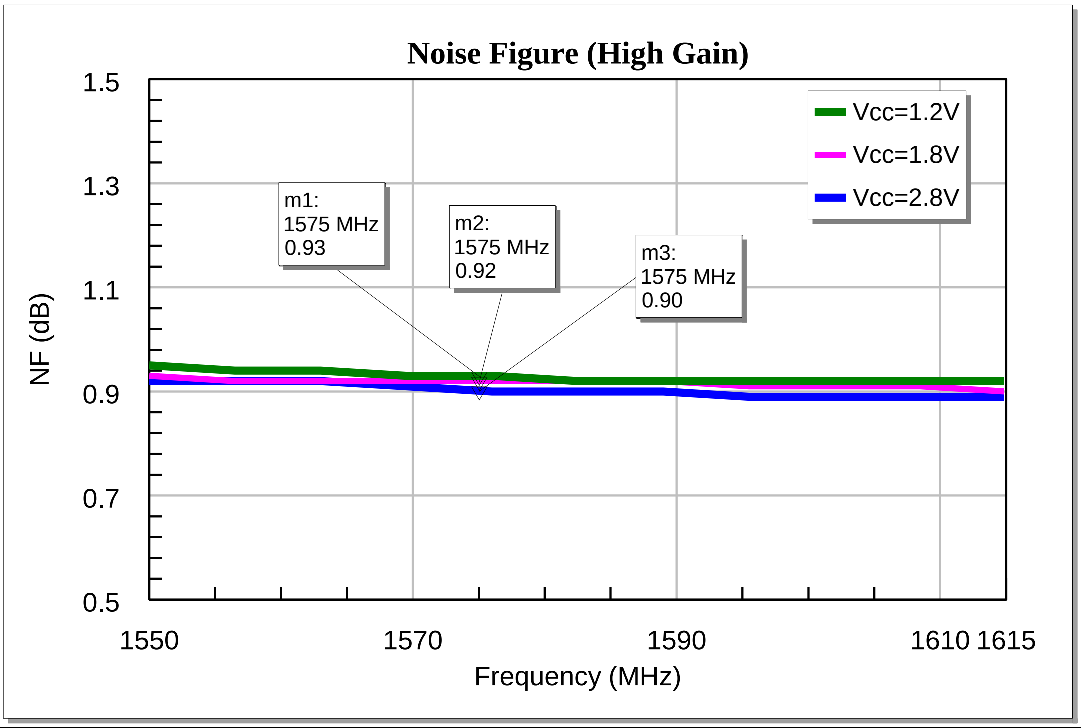

Figure 8 NF of BGA123L4 for GNSS applications (SMA and connector losses de-embedded, LQW15 inductors for matching)

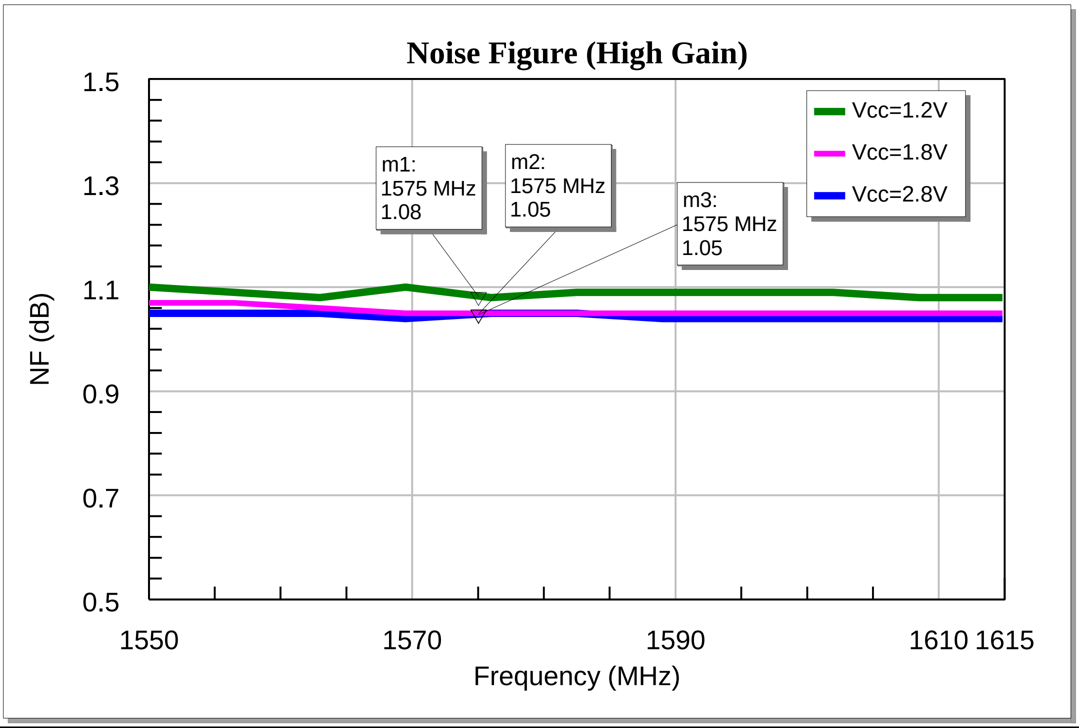

Figure 9 NF of BGA123L4 for GNSS applications (SMA and connector losses de-embedded, LQP03TN inductors for matching)

Measurement graphs

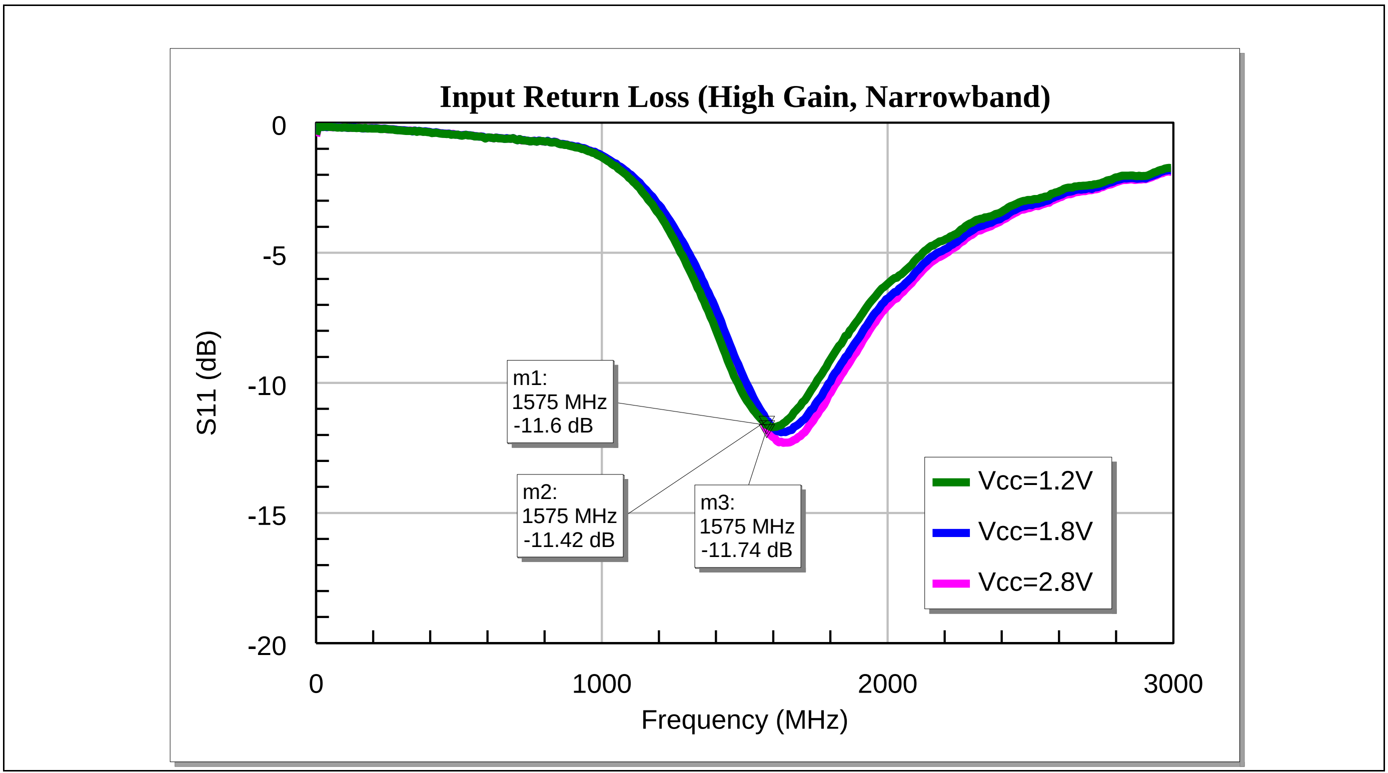

Figure 10 Input return loss of BGA123L4 for GNSS applications

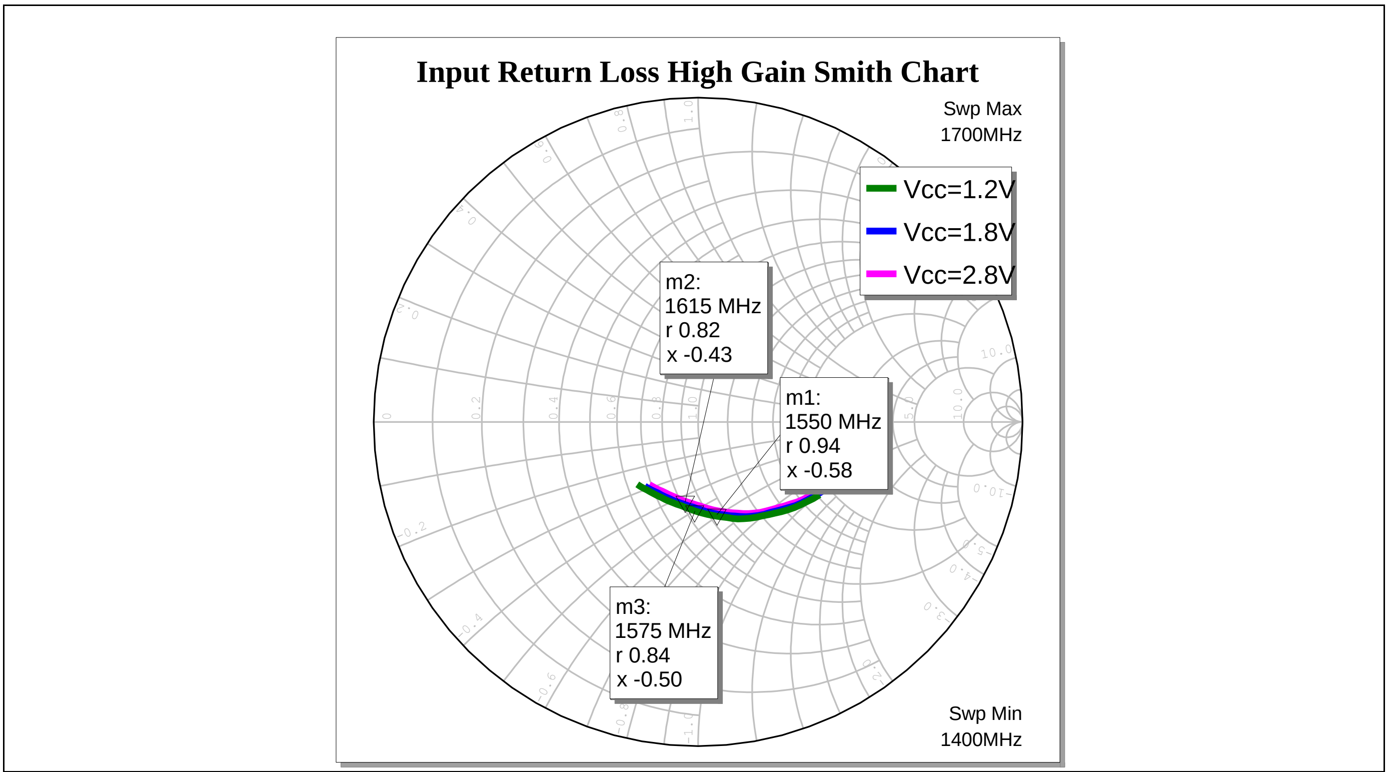

Figure 11 Input return loss (Smith chart) of BGA123L4 for GNSS applications (port de-embedded)

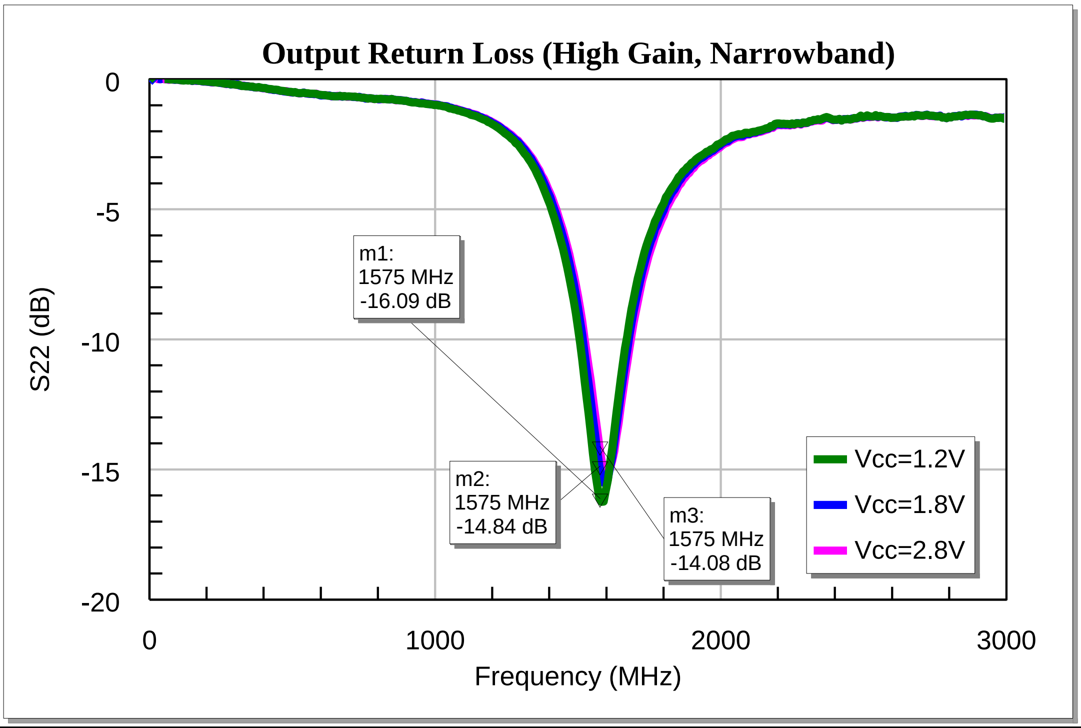

Figure 12 Output return loss of BGA123L4 for GNSS applications

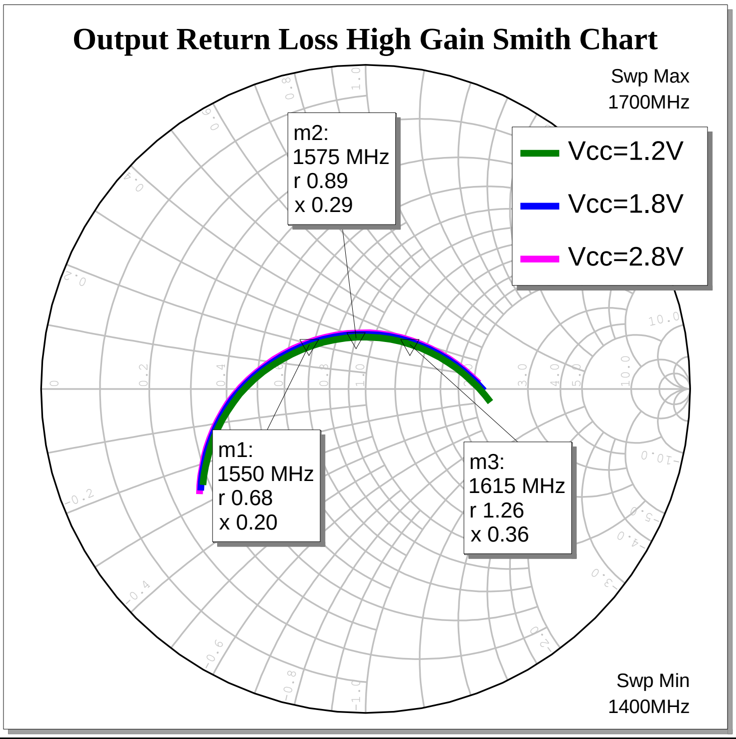

Figure 13 Output return loss (Smith chart) of BGA123L4 for GNSS applications (port de-embedded)

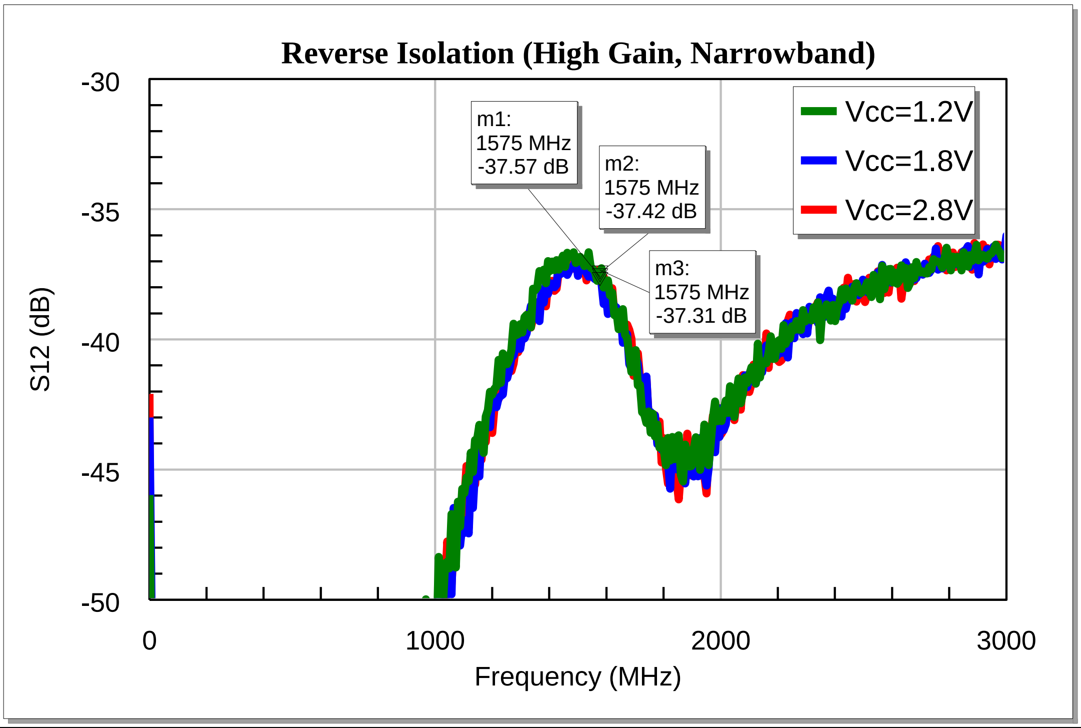

Figure 14 **Reverse isolation of BGA123L4 for GNSS applications**

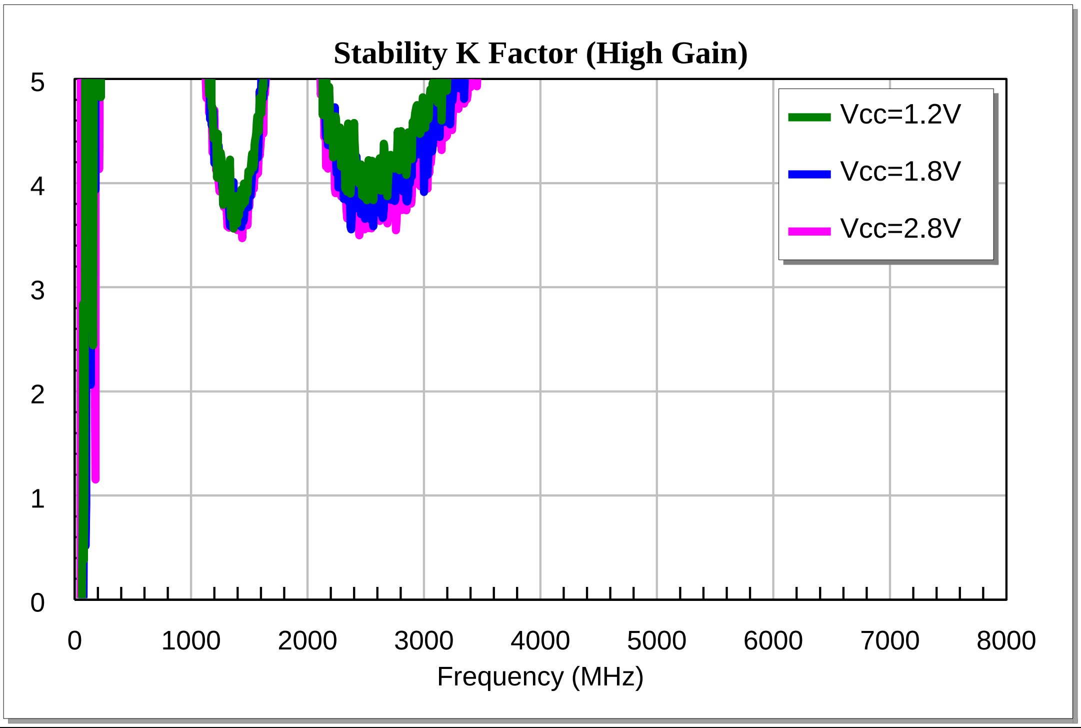

Figure 15 **Stability K-factor of BGA123L4 for GNSS applications**

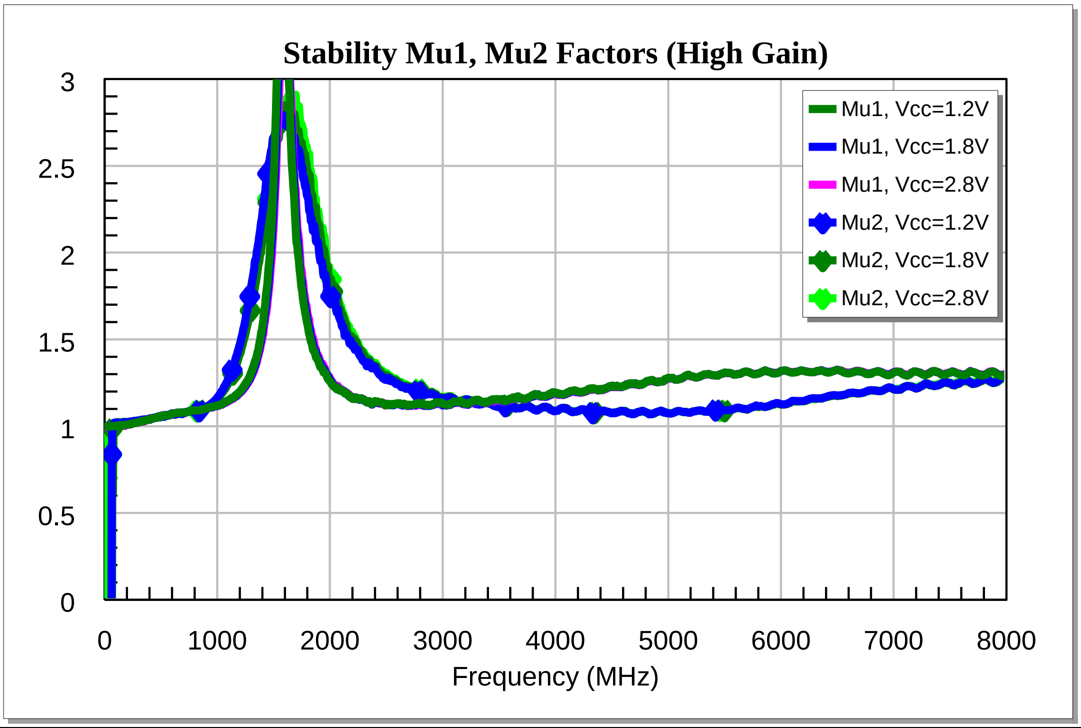

Figure 16 Stability Mu1-factor, Mu2-factor of BGA123L4 for GNSS applications

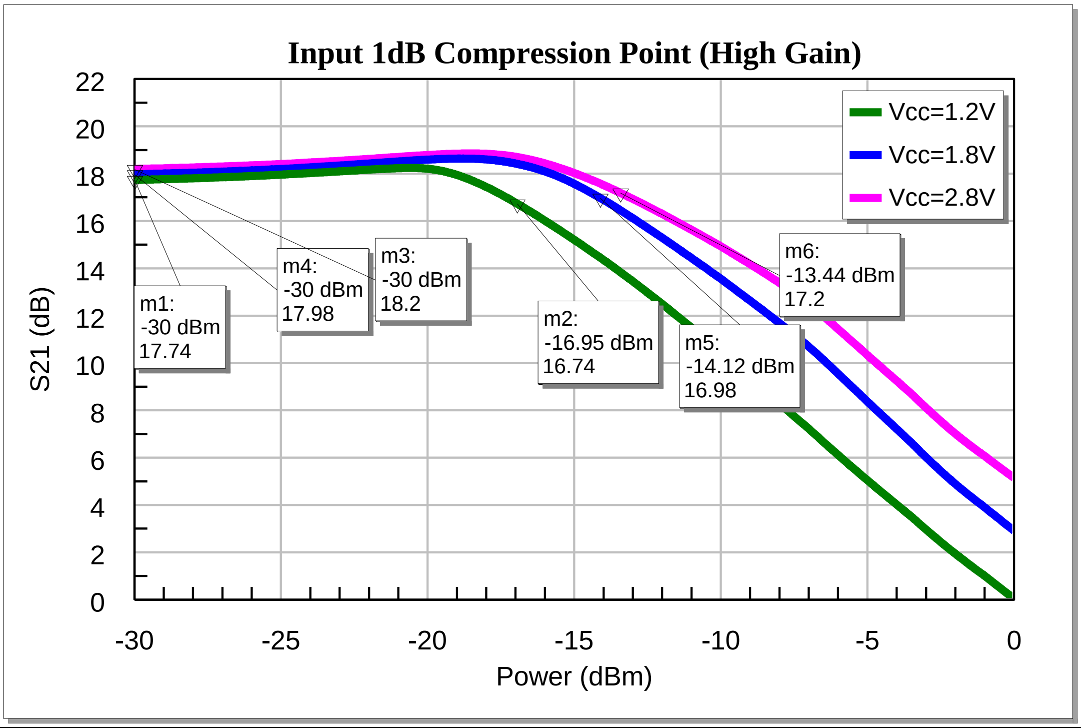

Figure 17 Input 1dB compression point of BGA123L4 for GNSS applications

Measurement graphs

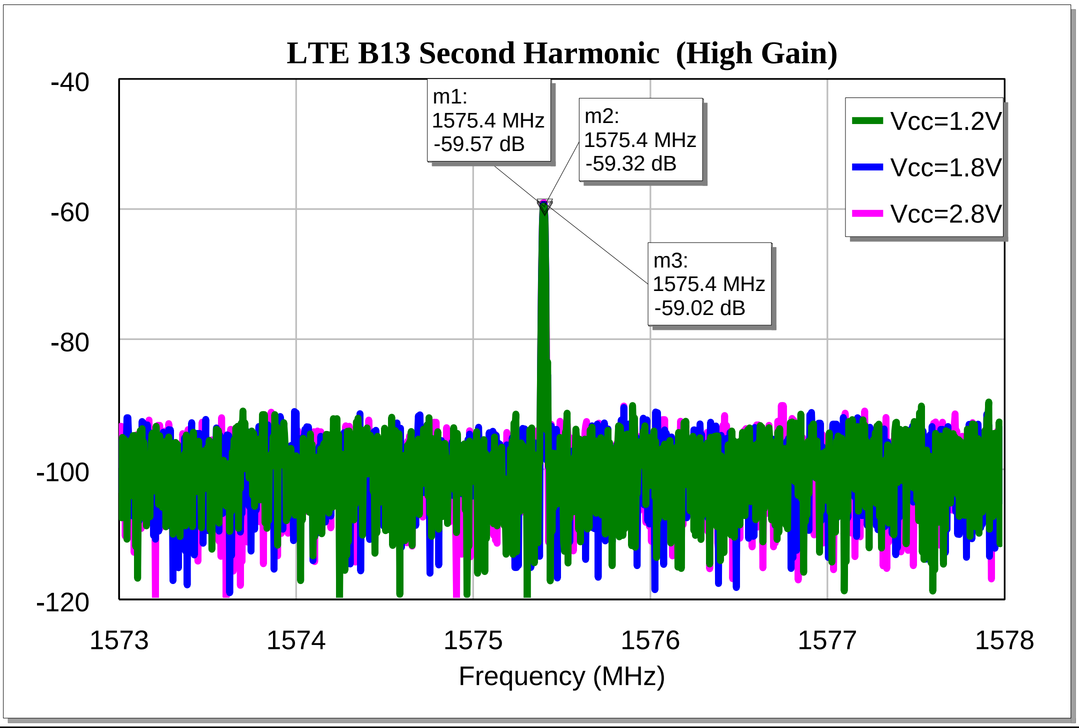

Figure 18 Second harmonic of LTE band 13 of BGA123L4 for GNSS applications (output referred)

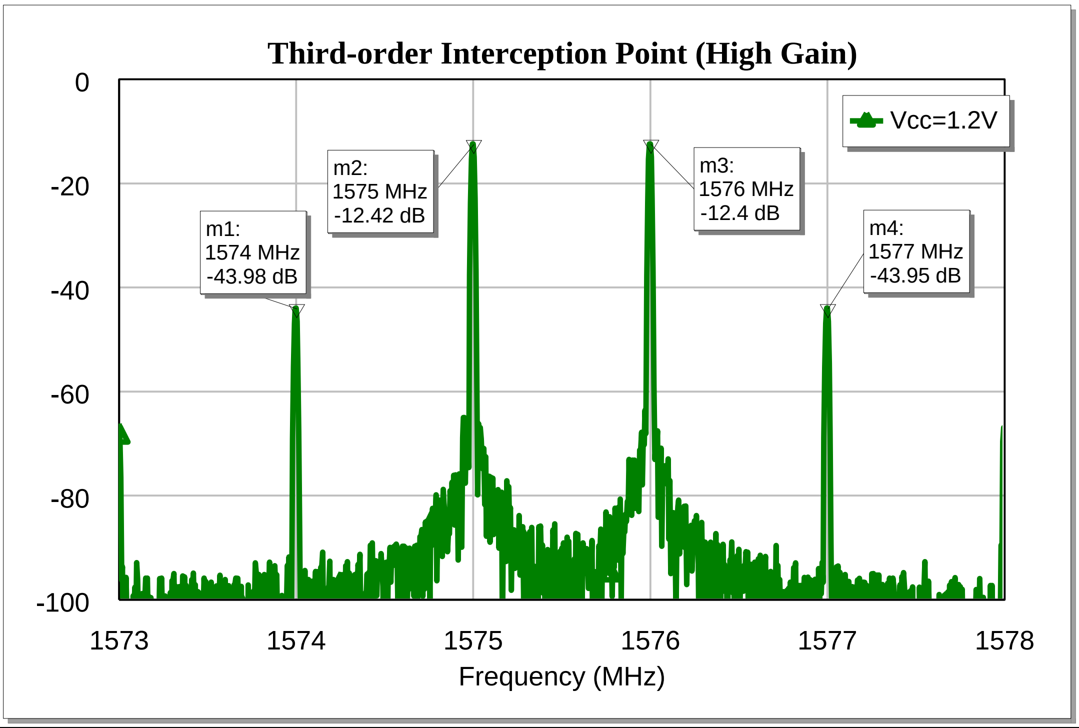

Figure 19 Third-order interception point (1.2 V) of BGA123L4 for GNSS applications (output referred)

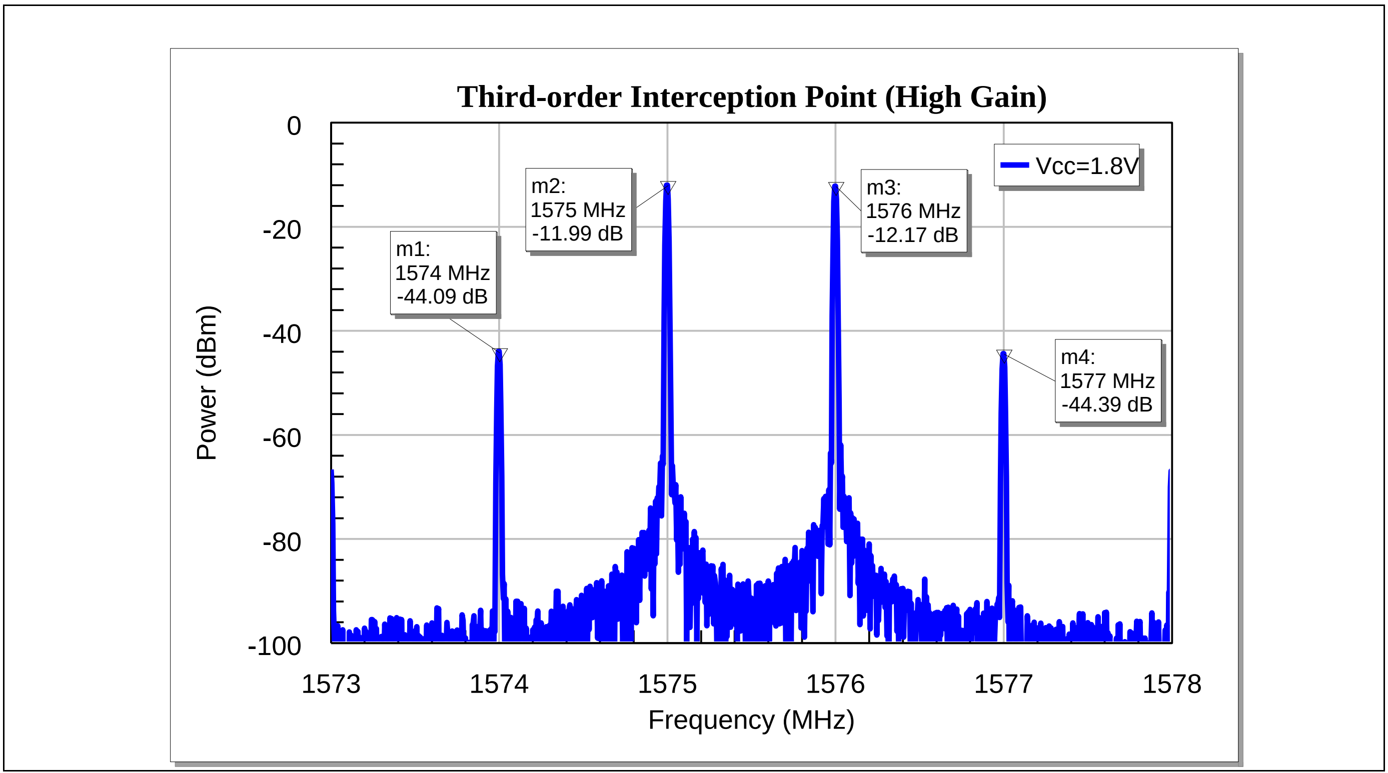

Figure 20 Third-order interception point (1.8 V) of BGA123L4 for GNSS applications (output referred)

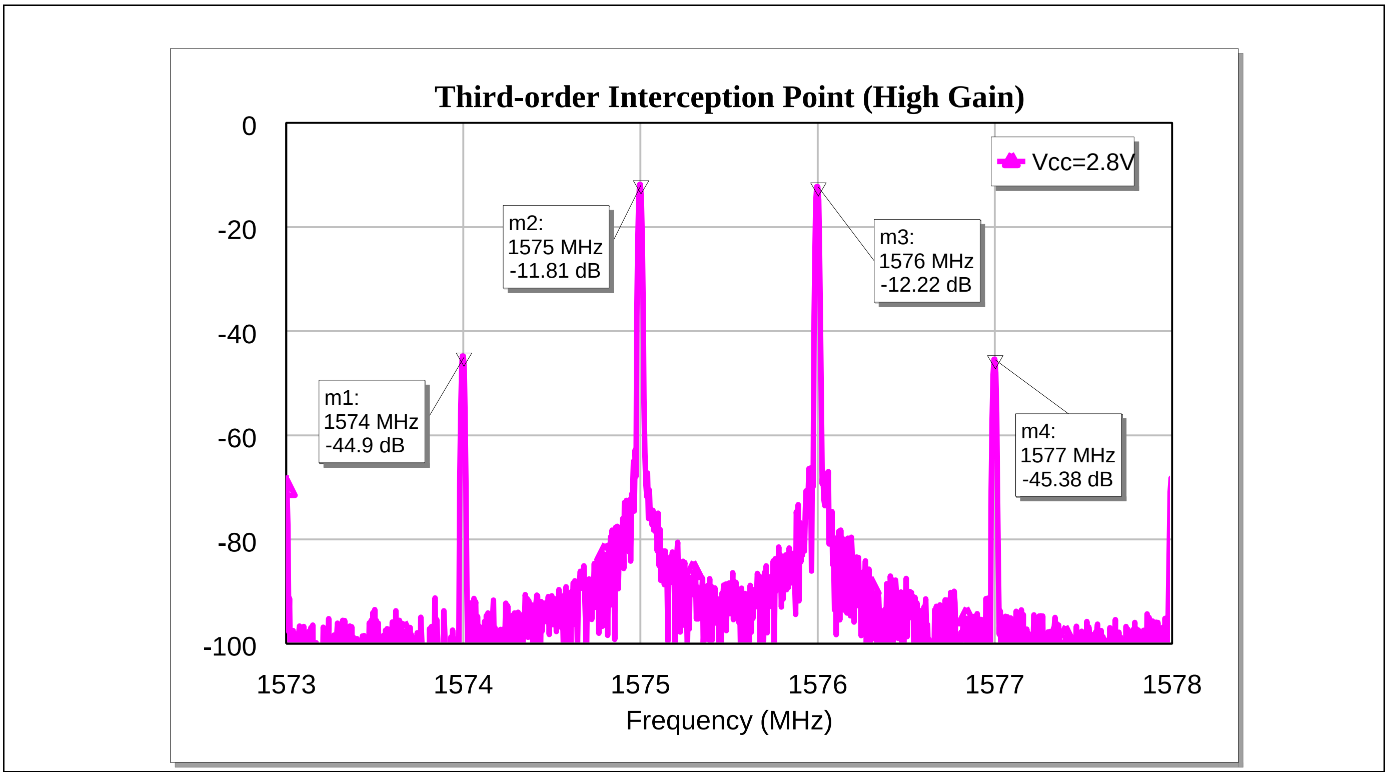

Figure 21 Third-order interception point (2.8 V) of BGA123L4 for GNSS applications (output referred)

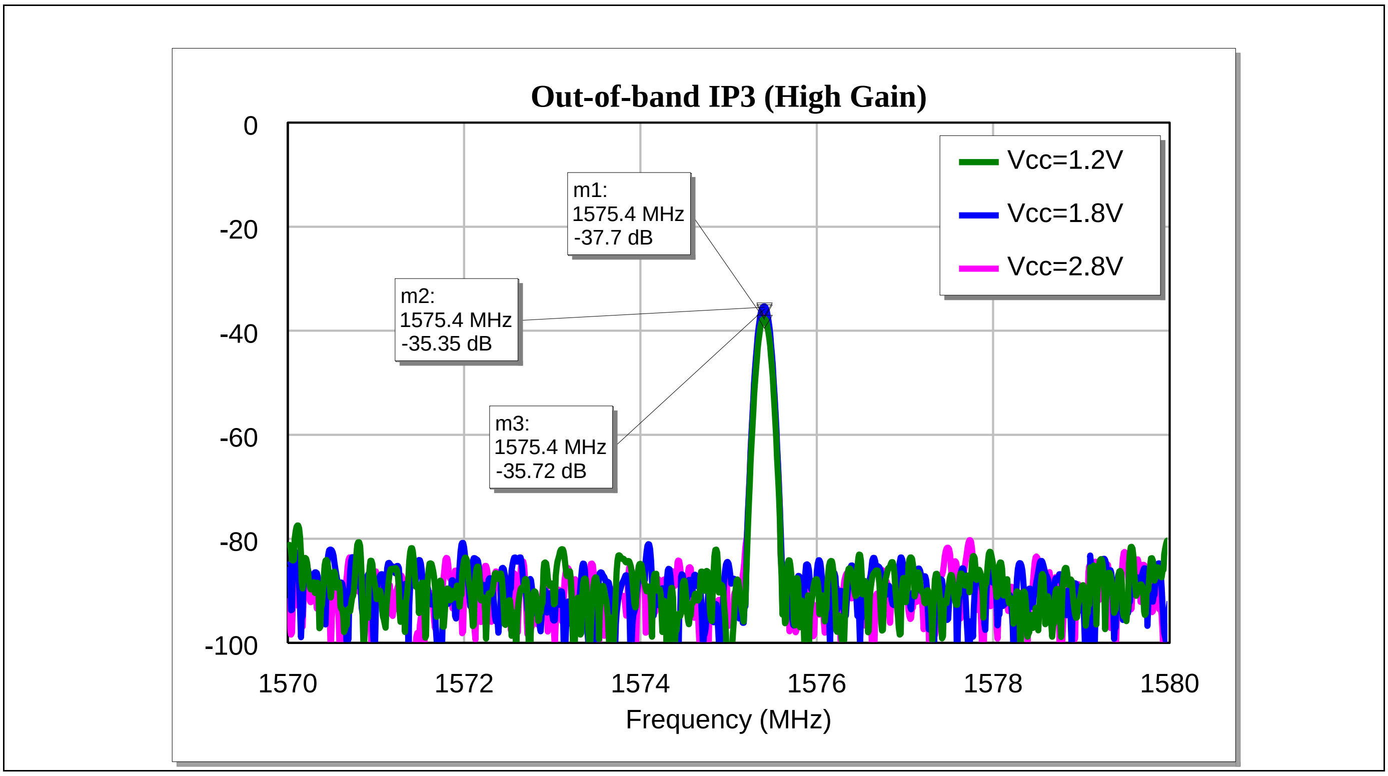

Figure 22 Out-of-band third-order interception point of BGA123L4 for GNSS applications (output referred)

5 Evaluation board and layout information

In this application note, the following PCB is used:

PCB marking: **GL05 V1.0/V1.1**

PCB material: **Rogers 4003**

ε_r of PCB material: **3.6**

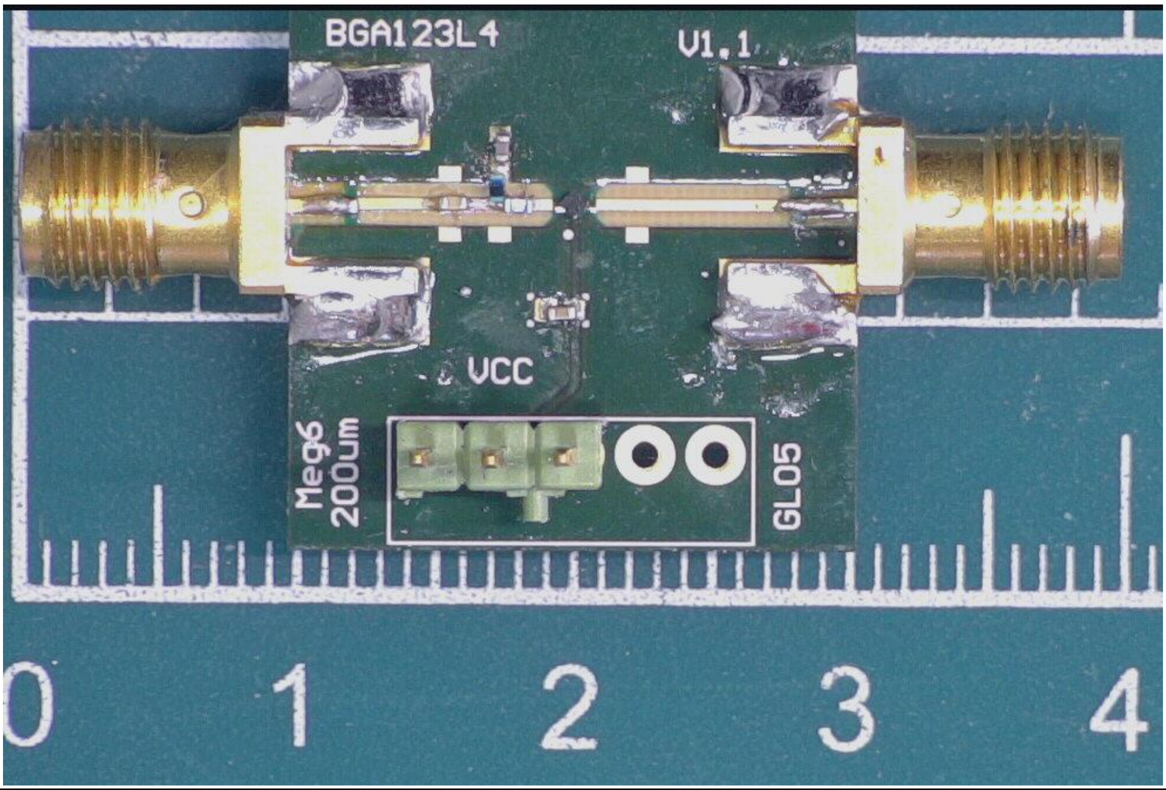

Figure 23 Photo of evaluation board (overview)

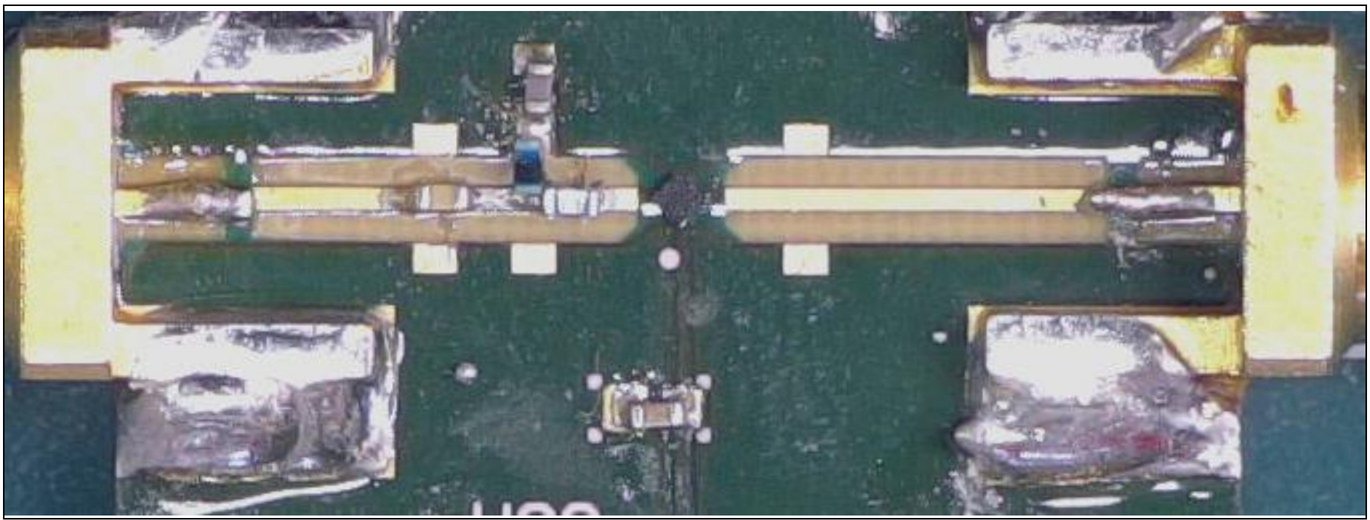

Figure 24 Photo of evaluation board (detailed view)

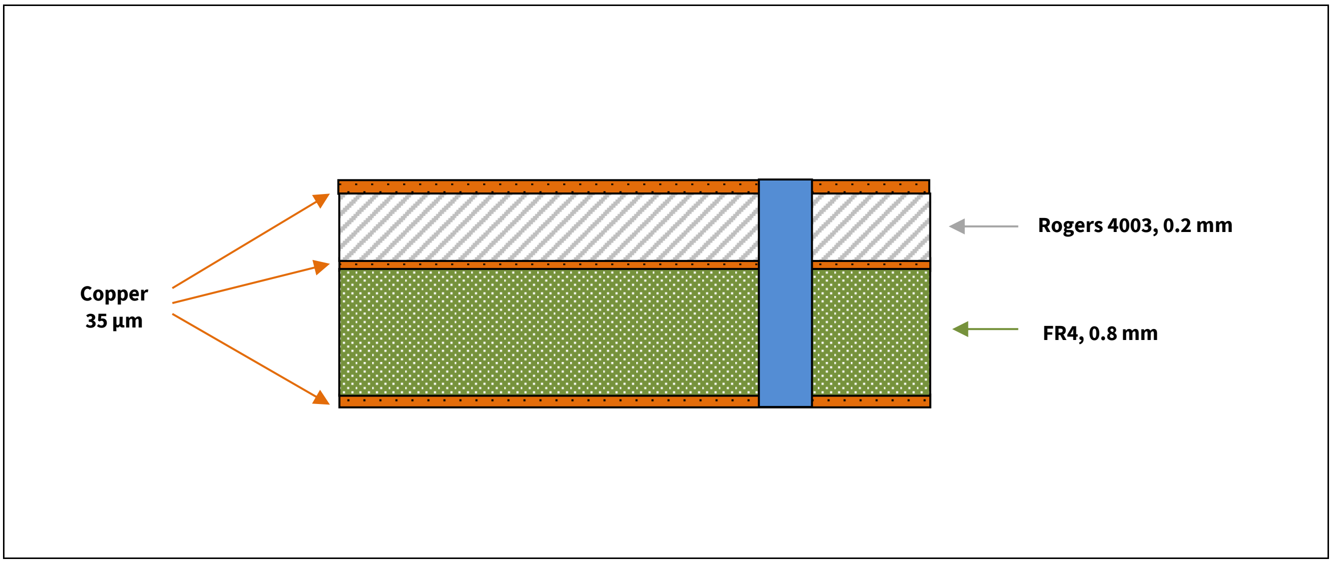

Figure 25 PCB layer information

6 Authors

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

7 References

[1] https://en.wikipedia.org/wiki/GPS_signals

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

[3] http://www.navipedia.net/index.php/GNSS_signal

Revision history

Major changes since the last revision

Page or reference	Description of change

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