Silicon Germanium Low Noise Amplifier: BGA824N6

Low Noise Amplifier for LTE band-11 (1475.9MHz – 1495.9MHz) and band-21 (1495.9MHz – 1510.9MHz)

Application Note AN403

About this document

Scope and purpose

This application note describes Infineon's GPS/GLONASS/COMPASS MMIC: BGA824N6 used as LNA for LTE band-11 and band-21 applications.

1. This application note documents the design of a LTE band-11 and band-21 LNA with input matching network.
2. The BGA824N6 is used in this documented design.
3. LTE band-11 and band- 21 are the primary application of this document.
4. This design along with AN403 provides a solution to LTE band-11 and band-21 receivers where a single band LNA MMIC is required.
5. Key performance parameter include Gain = 17.3 dB, NF = 0.7 dB, OIP3 = 17.5 dBm and P1dB = -6.8 dBm for 2.8 V.

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

1 Introduction of LNA for LTE Application

1.1 Introduction About 3G and 4G

The mobile technologies for smartphones have seen tremendous growth in recent years. The data rate required from mobile devices has increased significantly over the evolution of modern mobile technologies, starting from the first 3G/3.5G technologies (UMTS & WCDMA, HSPA & HSPA+) to the recently 4G LTE-Advanced (LTE-A). LTE-A can support data rates of up to 1 Gbps.

Advanced technologies such as diversity Multiple Input Multiple Output (MIMO) and Carrier Aggregation (CA) are adopted to achieve such higher data rate requirements. MIMO technology, commonly referred as the diversity path in smartphones, has attracted attention for the significant increasement in data throughput and link range without additional bandwidth or increased transmit power. The technology supports scalable channel bandwidth, between 1.4 and 20 MHz. The ability of 4G LTE to support bandwidths up to 20 MHz and to have more spectral efficiency by using high order modulation methods like QAM-64 is of particular importance as the demand for higher wireless data speeds continues to grow fast. Carrier aggregation used in LTE-Advanced combines up to 5 carriers and widens bandwidths up to 100 MHz to increase the user rates, across FDD and TDD.

Countries all over the world have released various frequencies bands for the 4G applications. **Table 1** shows the band assignment for the LTE bands worldwide.

Table 1 LTE Band Assignment

Band No.	Band Definition	Uplink Frequency Range	Downlink Frequency Range	FDD/TDD System	Comment
1	Mid-Band	1920-1980 MHz	2110-2170 MHz	FDD	
2	Mid-Band	1850-1910 MHz	1930-1990 MHz	FDD	
3	Mid-Band	1710-1785 MHz	1805-1880 MHz	FDD	
4	Mid-Band	1710-1755 MHz	2110-2155 MHz	FDD	
5	Low-Band	824-849 MHz	869-894 MHz	FDD	
6	Low-Band	830-840 MHz	875-885 MHz	FDD	

Table 1 LTE Band Assignment

Band No.	Band Definition	Uplink Frequency Range	Downlink Frequency Range	FDD/TDD System	Comment
7	High-Band	2500-2570 MHz	2620-2690 MHz	FDD	
8	Low-Band	880-915 MHz	925-960 MHz	FDD	
9	Mid-Band	1749.9-1784.9 MHz	1844.9-1879.9 MHz	FDD	
10	Mid-Band	1710-1770 MHz	2110-2170 MHz	FDD	
11		1427.9-1452.9 MHz	1475.9-1500.9 MHz	FDD	
12	Low-Band	698-716 MHz	728-746 MHz	FDD	
13	Low-Band	777-787 MHz	746-756 MHz	FDD	
14	Low-Band	788-798 MHz	758-768 MHz	FDD	
17	Low-Band	704-716 MHz	734-746 MHz	FDD	
18	Low-Band	815-830 MHz	860-875 MHz	FDD	
19	Low-Band	830-845 MHz	875-890 MHz	FDD	
20	Low-Band	832-862 MHz	791-821 MHz	FDD	
21		1447.9-1462.9 MHz	1495.9-1510.9 MHz	FDD	
22		3410-3500 MHz	3510-3600 MHz	FDD	
23	Mid-Band	2000-2020 MHz	2180-2200 MHz	FDD	
24		1626.5-1660.5 MHz	1525-1559 MHz	FDD	
25	Mid-Band	1850-1915 MHz	1930-1995 MHz	FDD	
26	Low-Band	814-849 MHz	859-894 MHz	FDD	
27	Low-Band	807-824 MHz	852-869 MHz	FDD	
28	Low-Band	703-748 MHz	758-803 MHz	FDD	
29	Low-Band	N/A	716-728 MHz	FDD	
33	Mid-Band	1900-1920 MHz		TDD	
34	Mid-Band	2010-2025 MHz		TDD	
35	Mid-Band	1850-1910 MHz		TDD	
36	Mid-Band	1930-1990 MHz		TDD	
37	Mid-Band	1910-1930 MHz		TDD	
38	High-Band	2570-2620 MHz		TDD	
39	Mid-Band	1880-1920 MHz		TDD	
40	High-Band	2300-2400 MHz		TDD	
41	High-Band	2496-2690 MHz		TDD	
42		3400-3600 MHz		TDD	
43		3600-3800 MHz		TDD	
44	Low-Band	703-803 MHz		TDD	

In order to cover all the bands from different countries in a unique device, mobile phones and data cards are usually equipped more bands and band combinations. Some typical examples are quad-band combinations of band 1/2/5/8, 1/3/5/7 and 3/7/5/17. The frequency bands used by TD-LTE are 3.4–3.6 GHz in Australia and UK, 2.57−2.62 GHz in the US and China, 2.545-2.575 GHz in Japan, and 2.3–2.4 GHz in India and Australia.

1.2 Applications

Figure 1 shows an example of the block diagram of the front-end of a 4G modem. A SPnT switch connects one side the antenna and several duplexers for different 4G bands on the other side. Every duplexer is connected to the transmitting (TX) and receiving (RX) paths of each band. The external LNA, here for example Infineon single-band LNA BGA824N6 is placed on the RX path between the duplex and the bandpass SAW filter. The output of the SAW filter is connected to the receiver input of the transceiver IC.

Depending on the number of bands designed in a device, various numbers of LNAs are required in a system. Recently, even mobile devices with 5 modes 13 bands are under discussion. Not only for the main pathes, but also for the diversity pathes, the external LNAs are widely used to boost end user experience while using mobile devices for video and audio streaming.

Besides low noise amplifiers, Infineon Technologies also offers solutions for high power highly linear antenna switches, band switches as well as power detection diodes for power amplifiers.

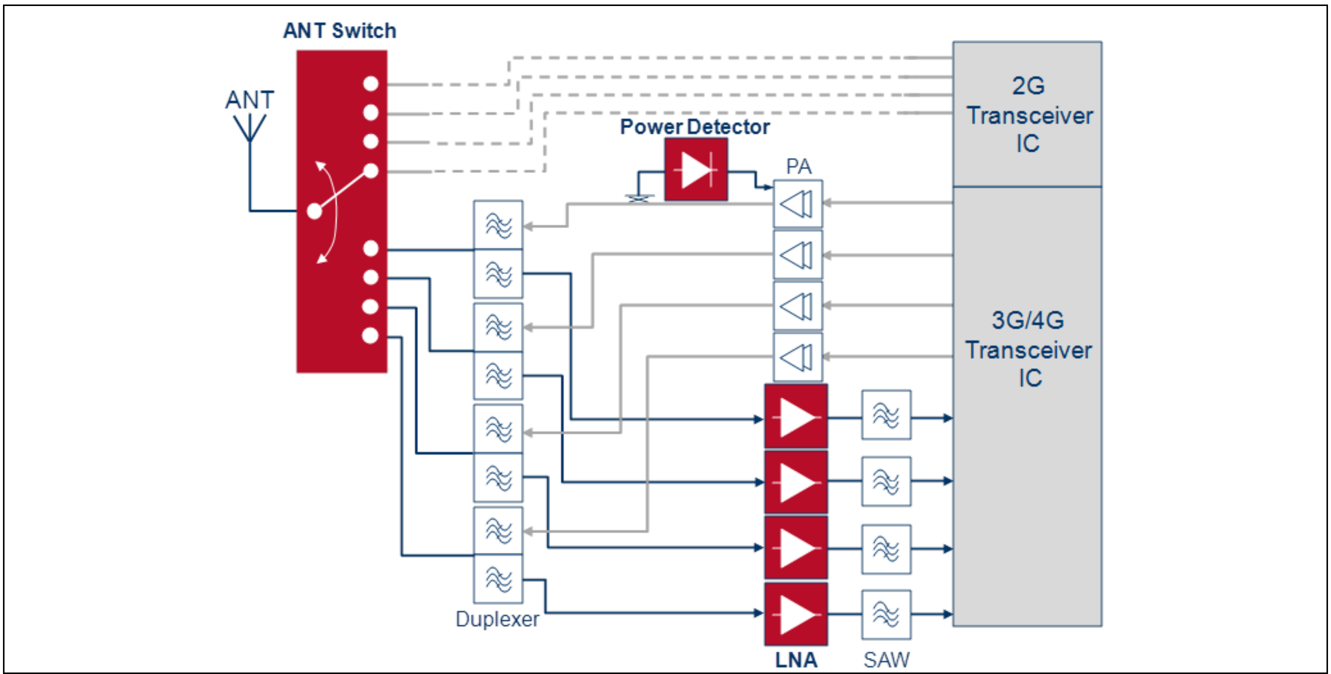

Figure 1 Example of Application Diagram of RF Front-End for 3G and 4G Systems.

1.3 Infineon LNAs for 3G, 4G LTE and LTE-A Applications

With the increasing wireless data speed and with the extended link distance of mobile phones and 4G data cards, the requirements on the sensitivity are much higher. Infineon offers different kind of low noise amplifiers (LNAs) to support the customers for mobile phones and data cards of 4G LTE and LTE-A to improve their system performance to meet the requirements coming from the networks/service providers.

The benefits to use external LNAs in equipment for 4G LTE and LTE-A applications are:

- Flexible design to place the front-end components: due to the size constraint, the modem antenna and the front-end can not be always put close to the transceiver IC. The path loss in front of the integrated LNA on the transceiver IC increases the system noise figure noticeably. An external LNA physically close to the antenna can help to eliminate the path loss and reduce the system noise figure. Therefore the sensitivity can be improved by several dB.
- Support RX carrier aggregation where two LNAs can be tuned on at the same time.
- Boost the sensitivity by reducing the system noise figure: external LNA has lower noise figure than the integrated LNA on the transceiver IC.
- Bug fix to help the transceiver ICs to fulfill the system requirements.
- Increase the dynamic range of the power handling.

Infineon Technologies is the leading company with broad product portfolio to offer high performance SiGe:C bipolar transistor LNAs and MMIC LNAs for various wireless applications by using the industrial standard silicon process. The MMIC LNA portfolio includes:

- New generation single band LTE LNAs like BGA7H1N6 for high-band (HB, 2300-2700 MHz), BGA7M1N6 for mid-band (MB, 1805-2200 MHz) and BGA7L1N6 for low-band (LB, 728-960 MHz) are available.

- New generation LTE LNA Banks are quad-band. Currently there are six different types of these new LTE LNAs which are shown in **Table 2**. Each LNA bank combines four various bands LNA from the high-band (HB, 2300-2700 MHz), mid-band (MB, 1805-2200 MHz) and low-band (LB, 728-960 MHz). Two of the four LNAs in one LNA bank can be turned on at the same time to support carrier aggregassion.

The broad product portfolio with highest integration and best features in noise figure and flexible band selection helps designers to design mobile phones and data cards with outstanding performance. Therefore Infineon LNAs and LNA banks are widely used by mobile phone vendors.

Table 2 Infineon Product Portfolio of LNAs for 4G LTE and LTE-A Applications

Frequency Range	728 MHz–960 MHz	1805MHz–2200MHz	2300 MHz–2690 MHz	Comment
Single-Band LNA				
BGA7L1N6	1X			
BGA7M1N6		1X		
BGA7L1N6			1X	
Quad-Band LNA bank				
BGM7MLLH4L12	1X	2X	1X	
BGM7LMHM4L12	1X	2X	1X	
BGM7HHMH4L12		1X	3X	
BGM7MLLM4L12	2X	2X		
BGM7LLHM4L12	2X	1X	1X	
BGM7LLMM4L12	2X	2X		

In addition, the older generation of LTE LNAs is featured with gain switching functions which is often helpful for the cases when string or weak signal environment could happen in the field causing. Below the possible combinations of available bands are shown:

- Single-band LNAs like BGA777L7 / BGA777N7 for high-band (2300-2700 MHz), BGA711L7 / BGA711N7 for mid-band (MB, 1700-2300 MHz) and BGA751L7 / BGA751N7, BGA728L7/BGA728N7, BGA713L7/BGA713N7 for low-band (LB, 700-1000 MHz) are available.

- Dual-band LNA BGA771L16 supports 1x mid-band (MB, 1700-2300 MHz) and 1x low-band (LB, 700-1000 MHz).

- Triple-band LNAs BGA734N16, BGA735N16 and BGA736N16 are available to cover the most bands. All of the three triple-band LNAs can support designs covering 2x high-bands and 1x low-band.

- Both BGA748N16 and BGA749N16 are quad-band LNAs. BGA748N16 can cover 2x high-and 2x low-bands and BGA749N16 can cover 1x high-band and 3x low-bands.

Table 3 Infineon Product Portfolio of LNAs for 3G and 4G Applications

Frequency Range	700 MHz – 1 GHz	1700MHz – 2200MHz	2100 MHz – 2700 MHz	Comment
Single-Band LNA				
BGA711N7		1X		
BGA713N7	1X			
BGA751N7	1X			
BGA777N7			1X	
BGA728L7	1X	1X		
Dual Band LNA				
BGA771N16	1X	1X		
Triple Band LNA				
BGA735N16	1X	1X	1X	
BGA736L16	1X	1X	1X	
Quad-band LNA				
BGA748L16	2X		2X	
BGA749N16	3X		1X	

2 BGA824N6 Overview

2.1 Features

- High insertion power gain: 17.0 dB
- Out-of-band input 3rd order intercept point: +7 dBm
- Input 1 dB compression point: -6 dBm
- Low noise figure: 0.55 dB
- Low current consumption: 3.8 mA
- Operating frequencies: 1550 - 1615 MHz
- Supply voltage: 1.5 V to 3.6 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 Ω
- Only 1 external SMD component necessary
- 2 kV HBM ESD protection (including AI-pin)
- Pb-free (RoHS compliant) package

Figure 2 BGA824N6 in TSNP-6-2

2.2 Key Applications of BGA824N6

- Ideal for the 4G and LTE-A applications for the band-11 and band-21
- Ideal for all Global Navigation Satellite Systems (GNSS) like
  - GPS (Global Positioning System) working in the L1 band at 1575.42 MHz
  - GLONASS (Russian GNSS) working in the L1 band from 1598.06 MHz to 1605.38 MHz
  - Galileo (European GNSS) working in the E2-L1-E1 band from 1559 MHz to 1592 MHz
  - COMPASS (Chinese Beidou Navigation System) working in E2 band at 1561.10 MHz and E1 band at 1589.74 MHz

2.3 Description

The BGA824N6 is a front-end low noise amplifier for Global Navigation Satellite Systems (GNSS) from 1550 MHz to 1615 MHz like GPS, GLONASS, Beidou, Galileo and others. The LNA provides 17.0

dB gain and 0.55 dB noise figure at a current consumption of 3.8 mA in the application configuration described in **Chapter 3**. The BGA824N6 is based upon Infineon Technologies B7HF Silicon Germanium technology. It operates from 1.5 V to 3.6 V supply voltage.

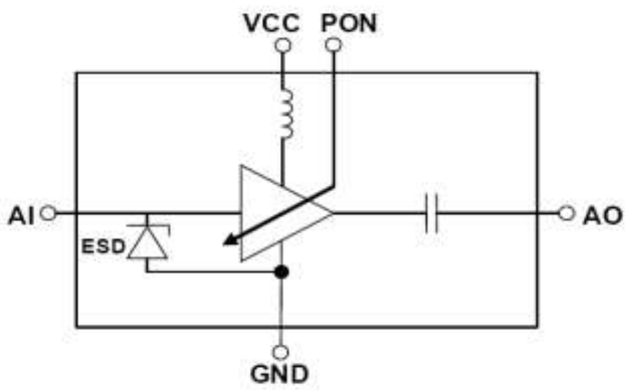

Figure 3 Equivalent Circuit Block diagram of BGA824N6

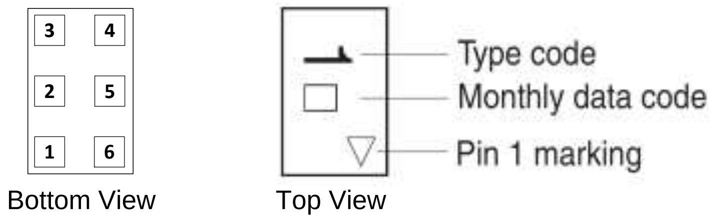

Figure 4 Package and pin connections of BGA824N6

Table 4 Pin Assignment of BGA824N6

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 5 Pin Assignment of BGA824N6

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

3 Application Circuit and Performance Overview

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

Device: **BGA824N6**
Application: **LTE LNA**
PCB Marking: **BGA824N6**
EVB Order No.: **AN403**

3.1 Summary of Measurement Results

Ther performance of BGA824N6 for LTE LNA band-11 (1486 MHz) and band-21 (1503 MHz) is summarized in the **Table 6**.

Table 6 Electrical Characteristics of the BGA824N6 (at room temperature)

Parameter	Symbol	Value	Value	Value	Value	Unit	Comment/Test Condition
Frequency Range	Freq	1486	1486	1503	1503	GHz	
DC Voltage	Vcc	1.8	2.8	1.8	2.8	V	
DC Current	Icc	4	4	4	4	mA	
Gain	G	17.3	17.3	17.4	17.4	dB	Loss of input/output line of 0.1 dB are included
Noise Figure	NF	0.7	0.7	0.7	0.7	dB	Loss of input line of 0.1 dB is deembeded
Input Return Loss	RLin	11.2	11.2	12.3	12.3	dB	
Output Return Loss	RLout	20.7	20.7	23.5	23.5	dB	
Reverse Isolation	IRev	23.7	23.7	23.1	23.1	dB	
Input P1dB	IP1dB	-9.9	-6.6	-9.8	-6.6	dBm	
Output P1dB	OP1dB	6.4	9.7	6.6	9.8	dBm	
Input IP3	IIP3	-1.9	-0.7	-1.2	0.1	dBm	Δf=1 MHz and P_{in} -30 dBm
Output IP3	OIP3	15.4	16.6	16.2	17.5	dBm	
Stability	k	>1	>1	>1	>1	--	Unconditionally Stable from 0 to 12 GHz

3.2 Summary BGA824N6 as 1475.9 – 1510.9 MHz LNA for LTE band-11 and band-21

This application note describes the LNA performance of LTE Band-11 (1475.9 – 1495.9 MHz) and Band-21 (1495.9 – 1510.9 MHz).

The LNA is fine tuned to provide the lowest possible Noise Figure and having optimal input/output matching. The circuit requires only one 0402 passive component for matching purposes and one optinal capacitor which can be omitted when DC-Blocking is already provided in the previous stages of a circiut.

The application circuit has in band gain of 17.4 dB. It achives input return loss better than 11 dB, as well as output return loss better than 20 dB. At room temperature the noise figure is 0.7 dB (SMA and PCB losses are subtracted) for the LTE Bands 11/22 frequency. Furthermore, the circuit is unconditionally stable till 10 GHz.

At LTE Band-11 frequency (1486 MHz), using two tones spacing of 1 MHz, the output third order intercept point OIP3 reaches 16.6 dBm for 2.8 V. At LTE Band-21 frequency (1503 MHz), using two tones spacing of 1 MHz, the output third order intercept point OIP3 reaches 17.5 dBm for 2.8 V.

The linearity of the LNA is also best in its class. Input P1dB at LTE Band-11 frequency (1486 MHz) of the LNA is about -6.6 dBm and -6.6 dBm at LTE Band-21 frequency (1503 MHz).

3.3 Schematics and Bill-of-Materials

The schematic of BGA824N6 for LTE band-11 and band- 22 is presented in **Figure 5** and its bill-of-materials is shown in **Table 7**.

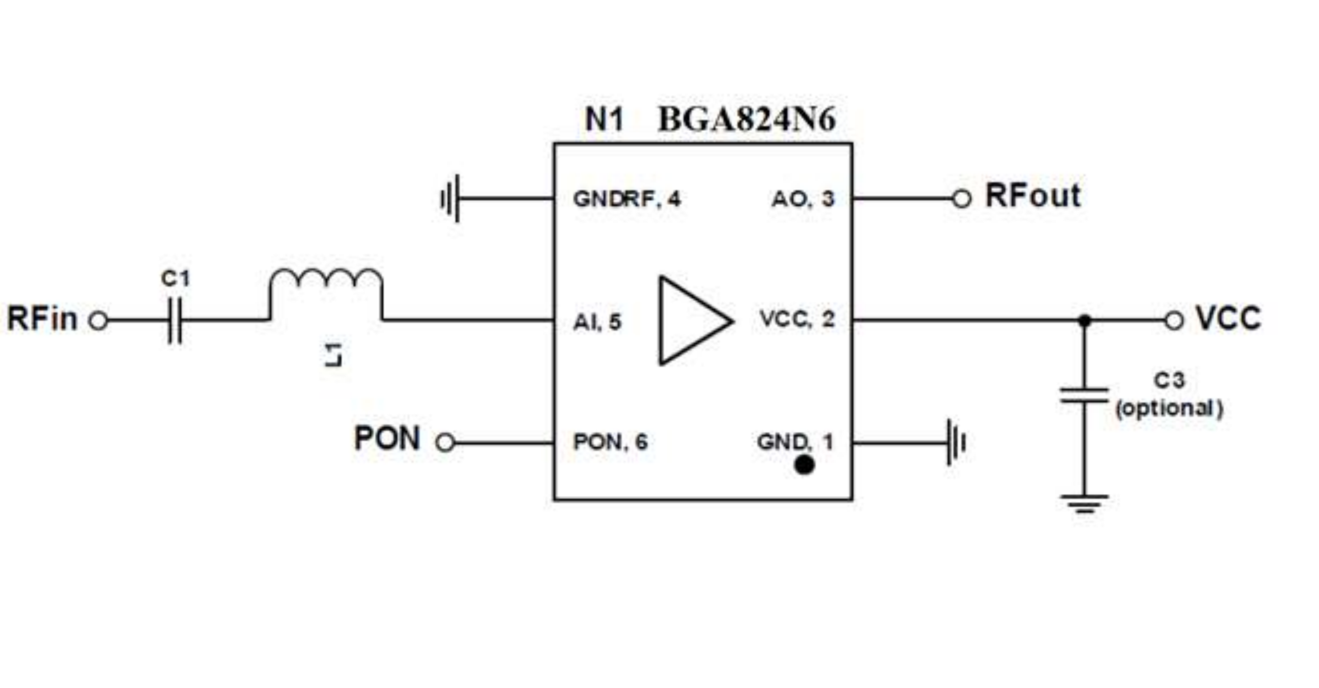

Figure 5 Schematics of the BGA824N6 Application Circuit

Table 7 Bill-of-Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
C1	1	nF	0402	Various	DC block
L1	7.5	nH	0402	Murata LQW15 Type	Input matching 1490/1510 MHz
C3 (optional)	1	nF	0402	Various	RF bypass
N1	BGA826N6		TSNP-6-2	Infineon	SiGe LNA

Note: DC block function is NOT integrated at input of BGA824N6. 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 C3 at the DC power supply pin filters out the power supply noise and stabilizes the DC supply. The RF bypass capacitor C3 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.

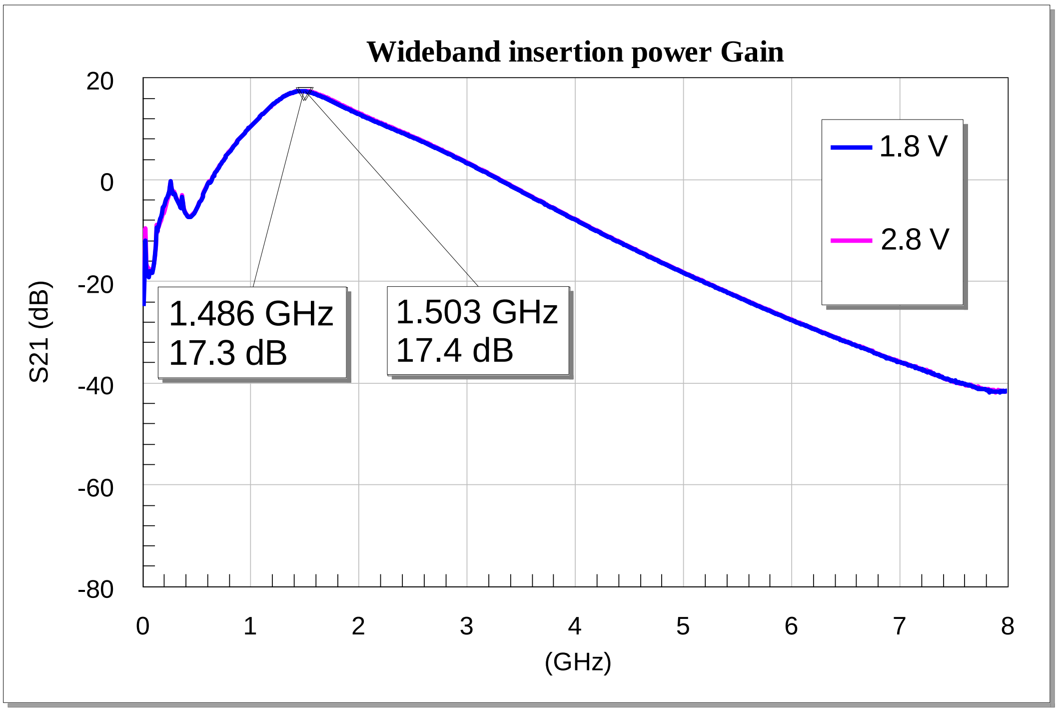

Figure 6 Wideband Insertion Power Gain of the BGA824N6 for LTE band-11 and band-21

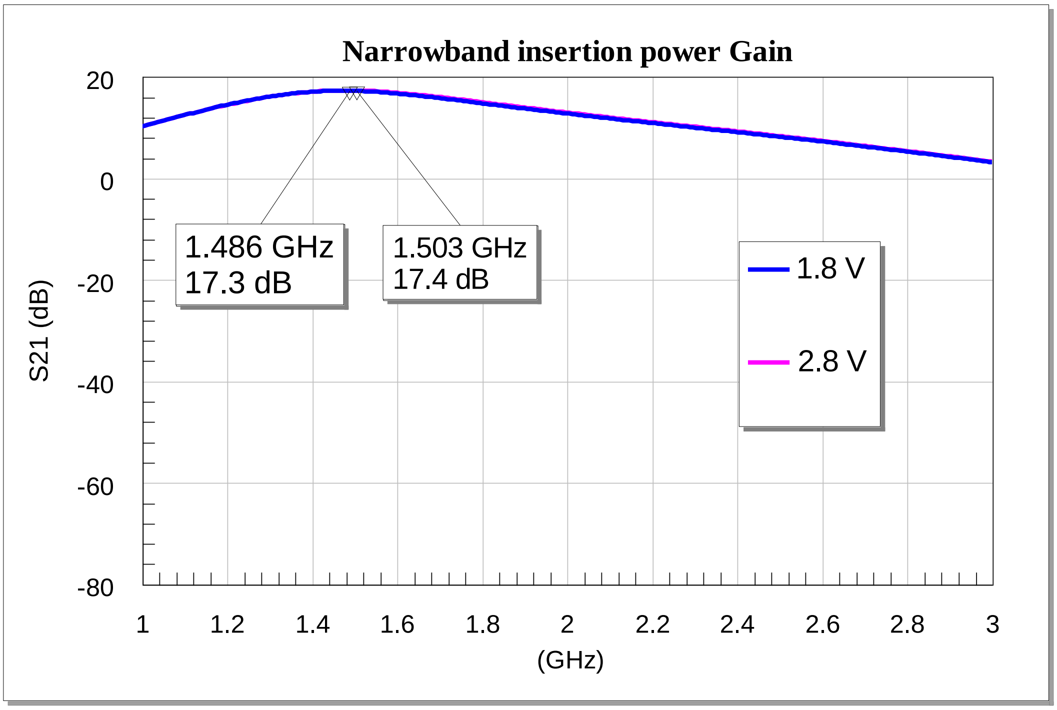

Figure 7 Narrowband Insertion Power Gain of the BGA824N6 for LTE band-11 and band-21

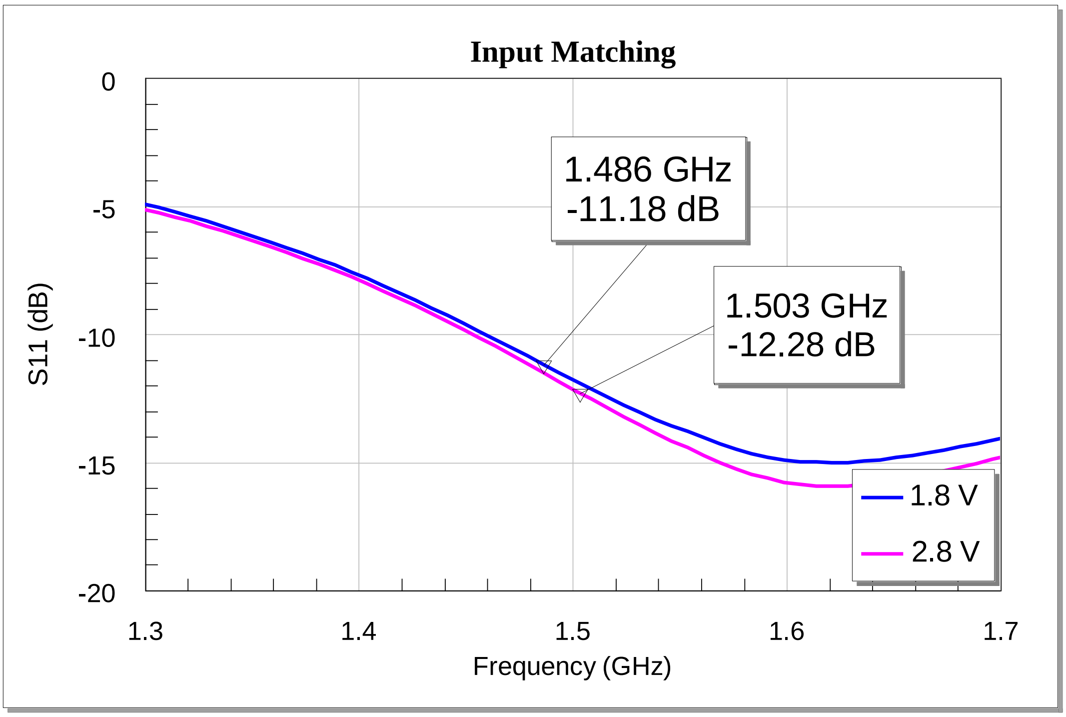

Figure 8 Input Matching of the BGA824N6 for LTE band-11 and band-21

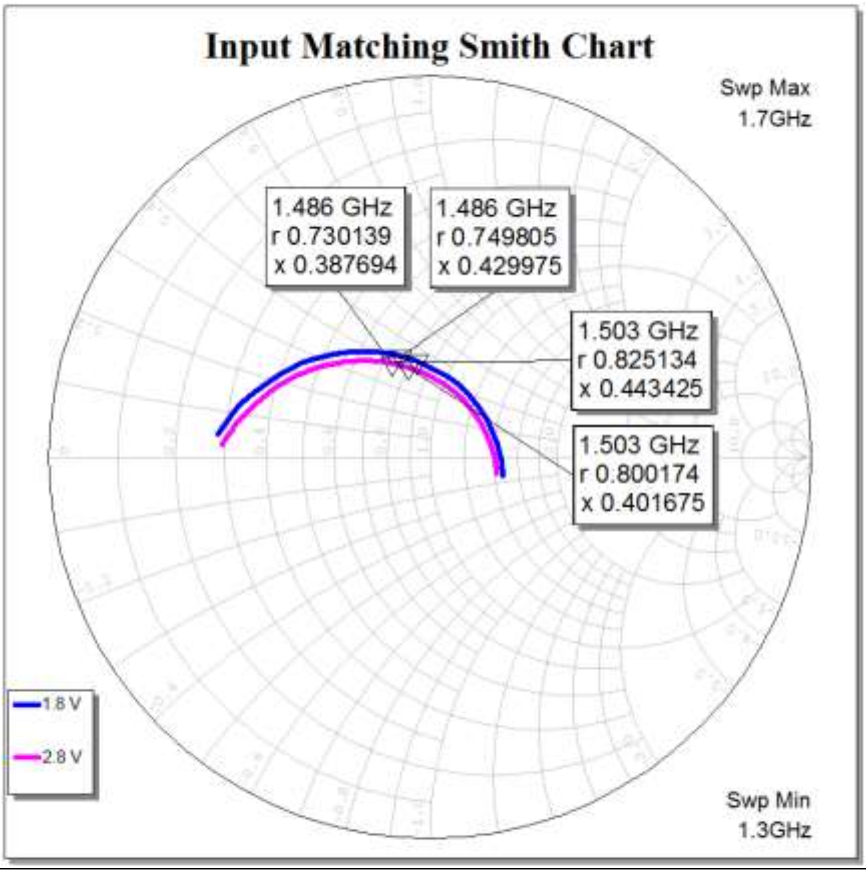

Figure 9 Input Matching (Smith Cahrt) of the BGA824N6 for LTE band-11 and band-21

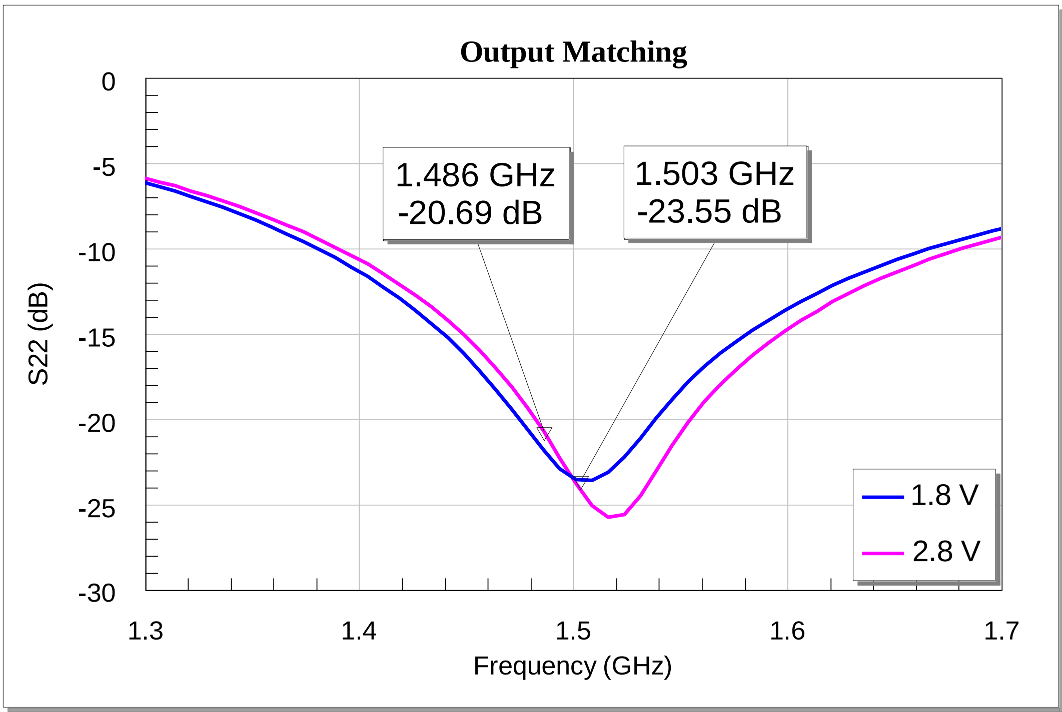

Figure 10 Input Matching of the BGA824N6 for LTE band-11 and band-21

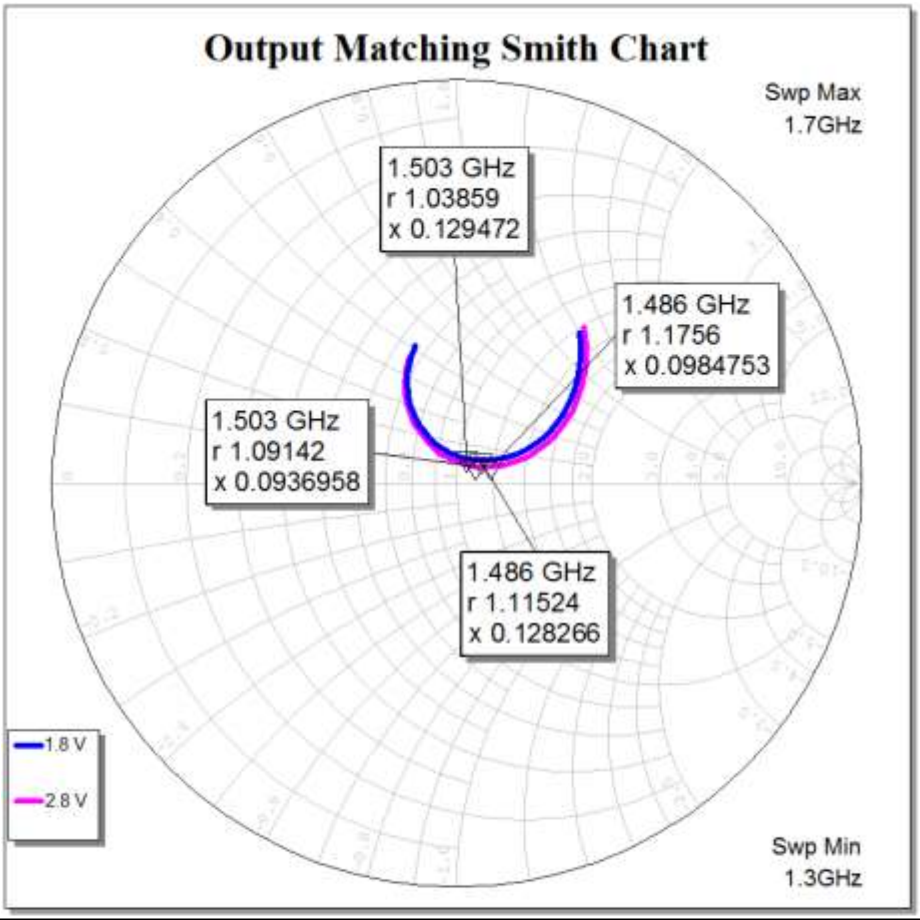

Figure 11 Input Matching (Smith Cahrt) of the BGA824N6 for LTE band-11 and band-21

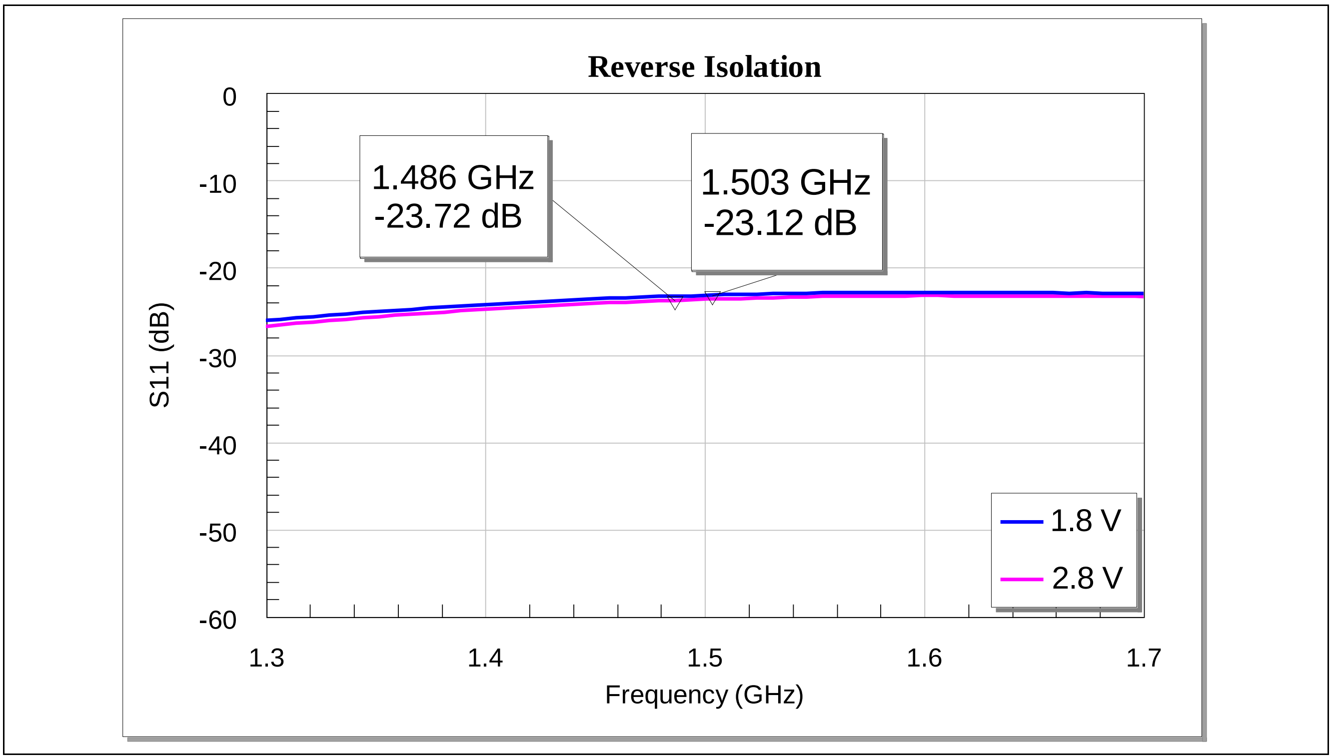

Figure 12 Reverse Isolation of the BGA824N6 for LTE band-11 and band-21

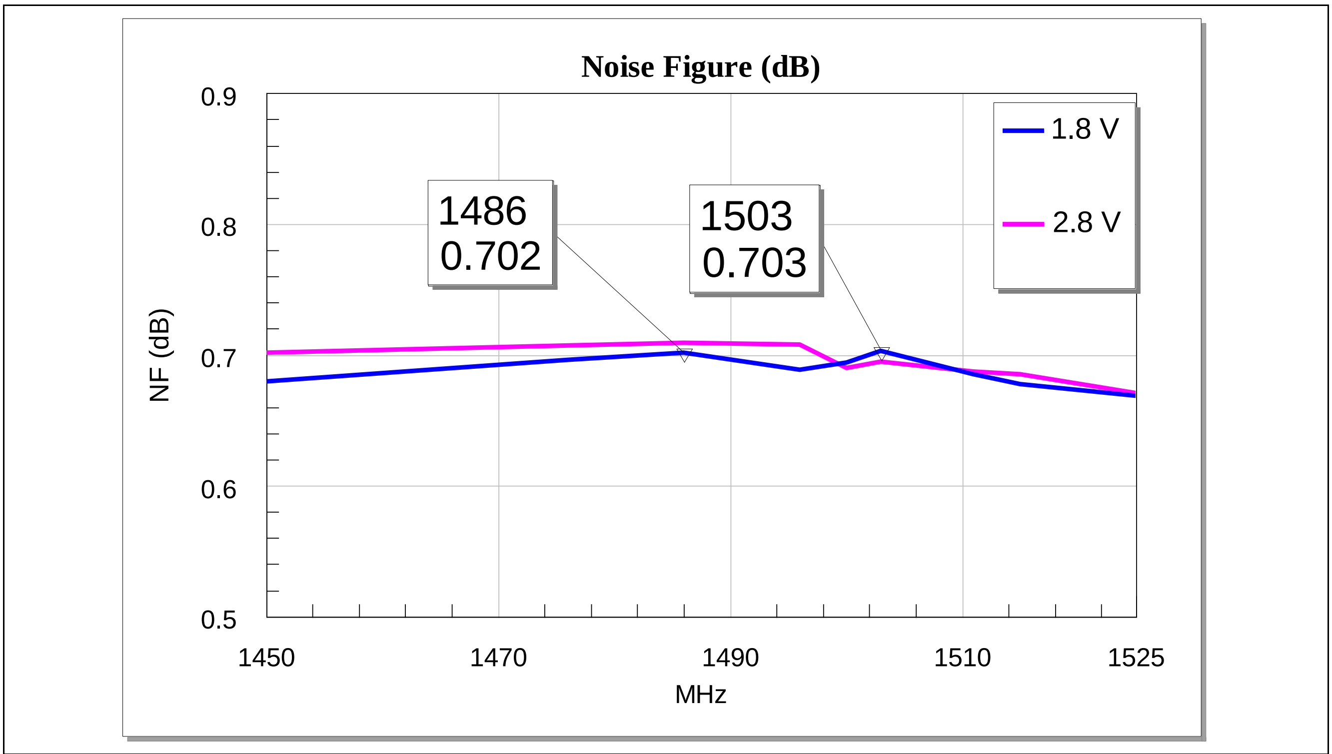

Figure 13 Noise Figure of the BGA824N6 for band-11 and band-21

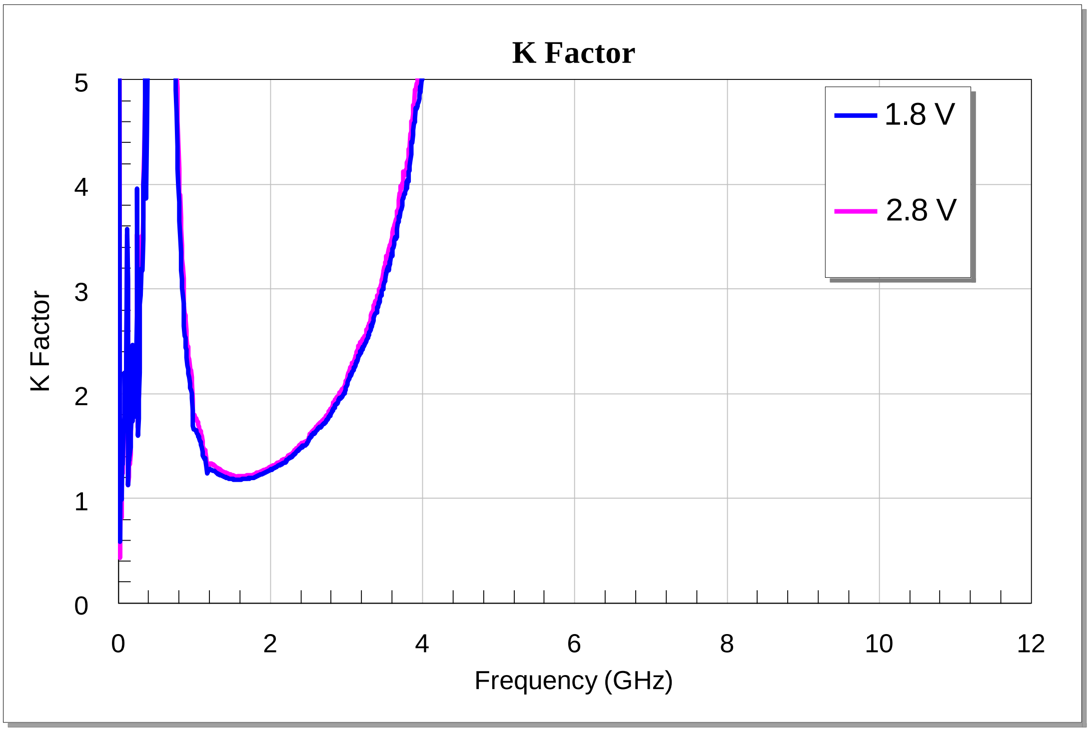

Figure 14 Stability K Factor and Delta Factor of the BGA824N6 for LTE band-11 and band-21

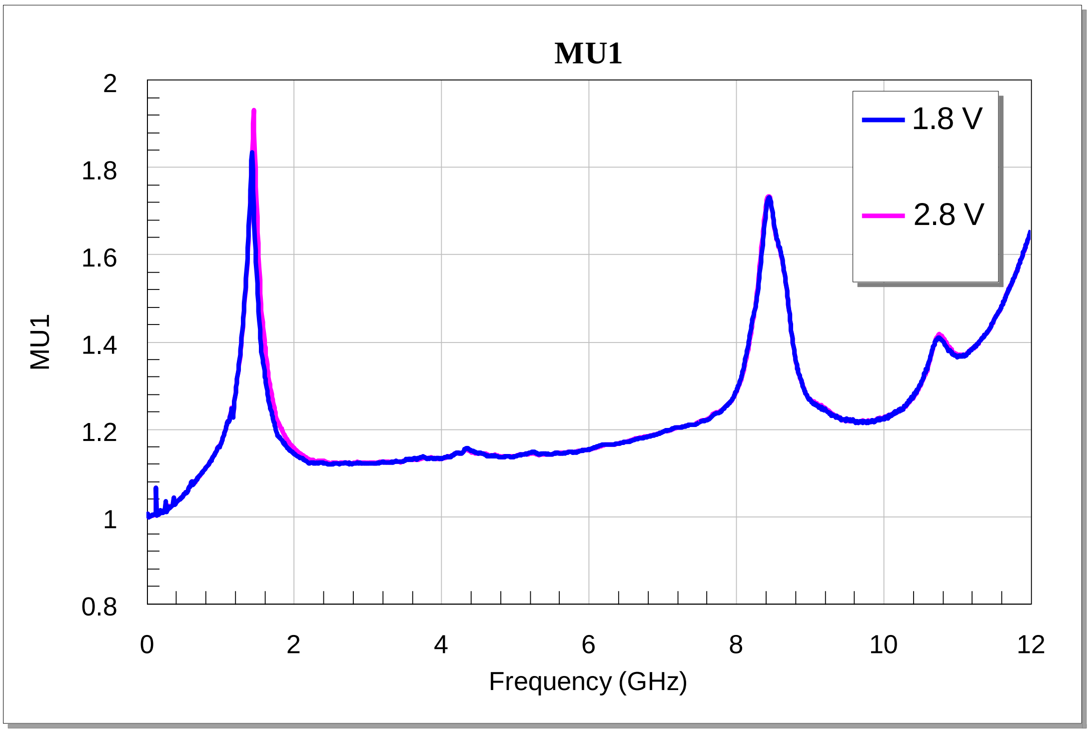

Figure 15 Stability µ1 Factor of the BGA824N6 for LTE band-11 and band-21

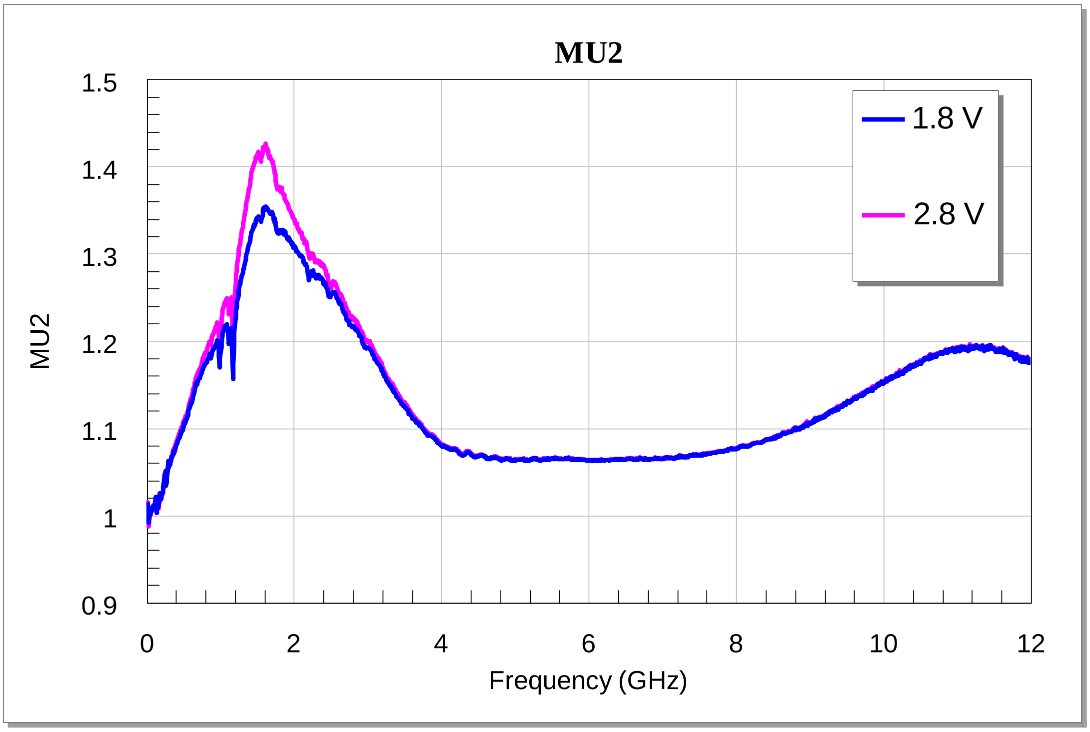

Figure 16 Stability µ2 Factor of the of the BGA824N6 for LTE band-11 and band-21

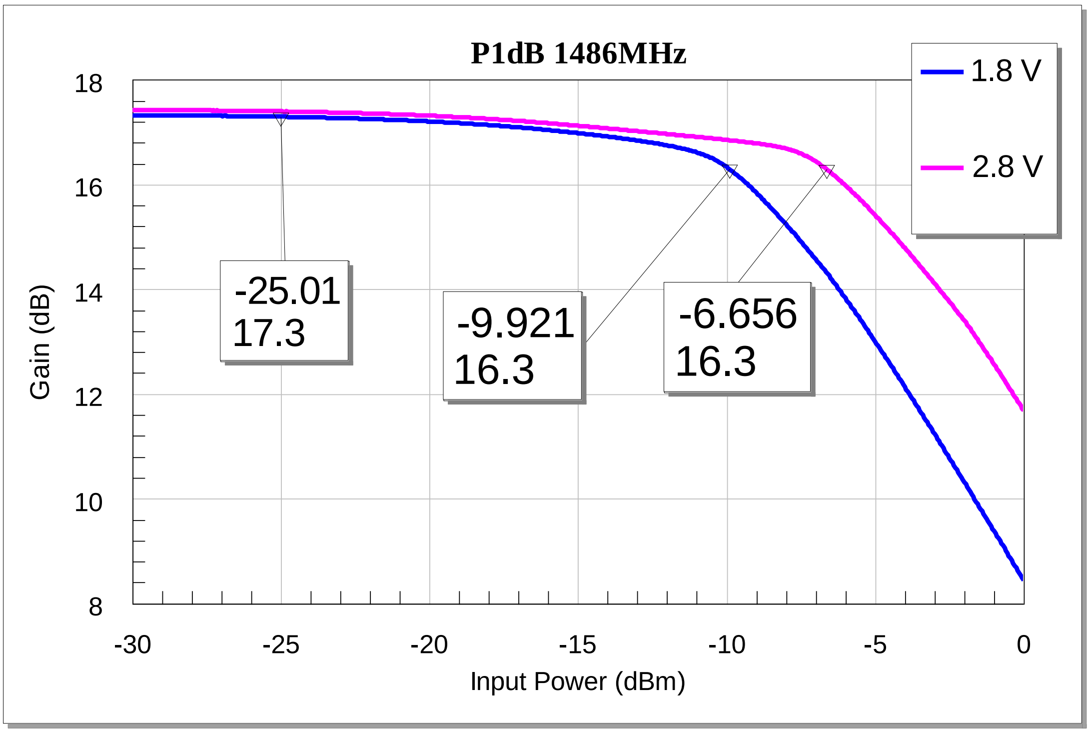

Figure 17 IP1dB of the BGA824N6 for LTE band-11

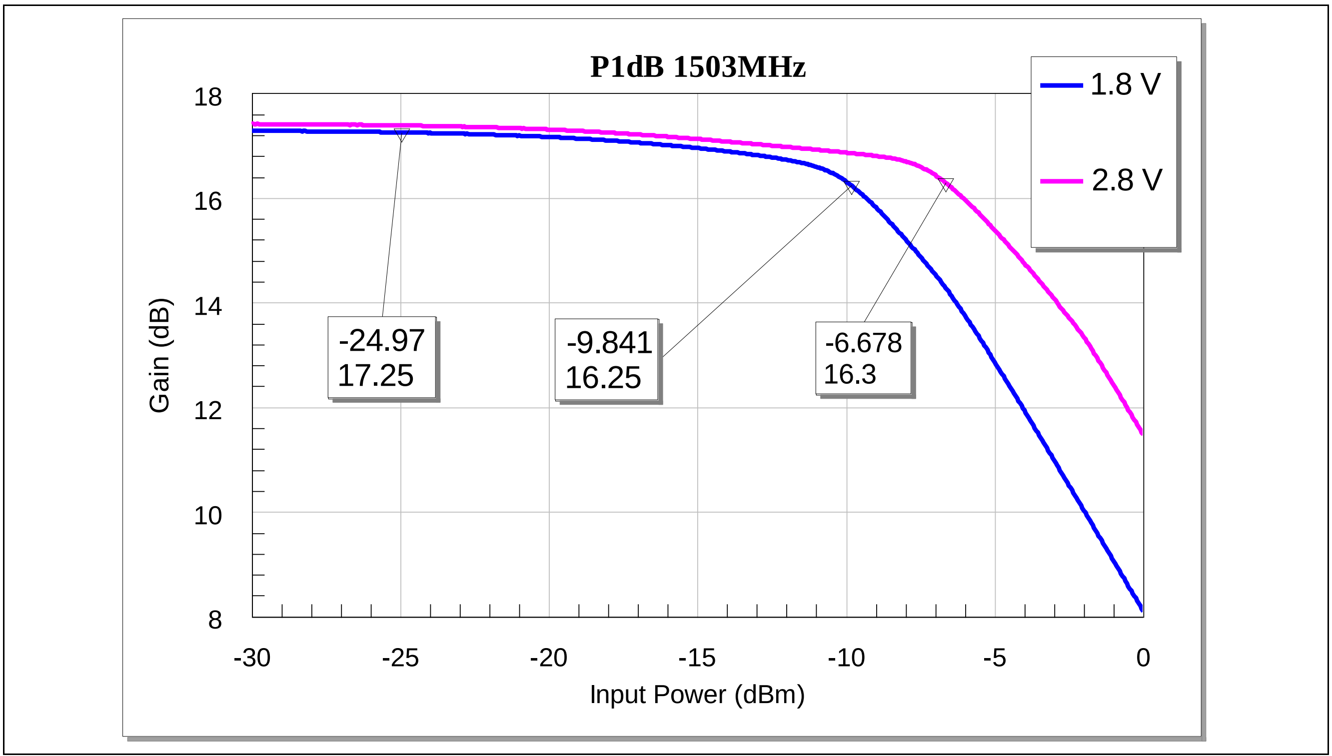

Figure 18 IP1dB of the BGA824N6 for LTE band-21

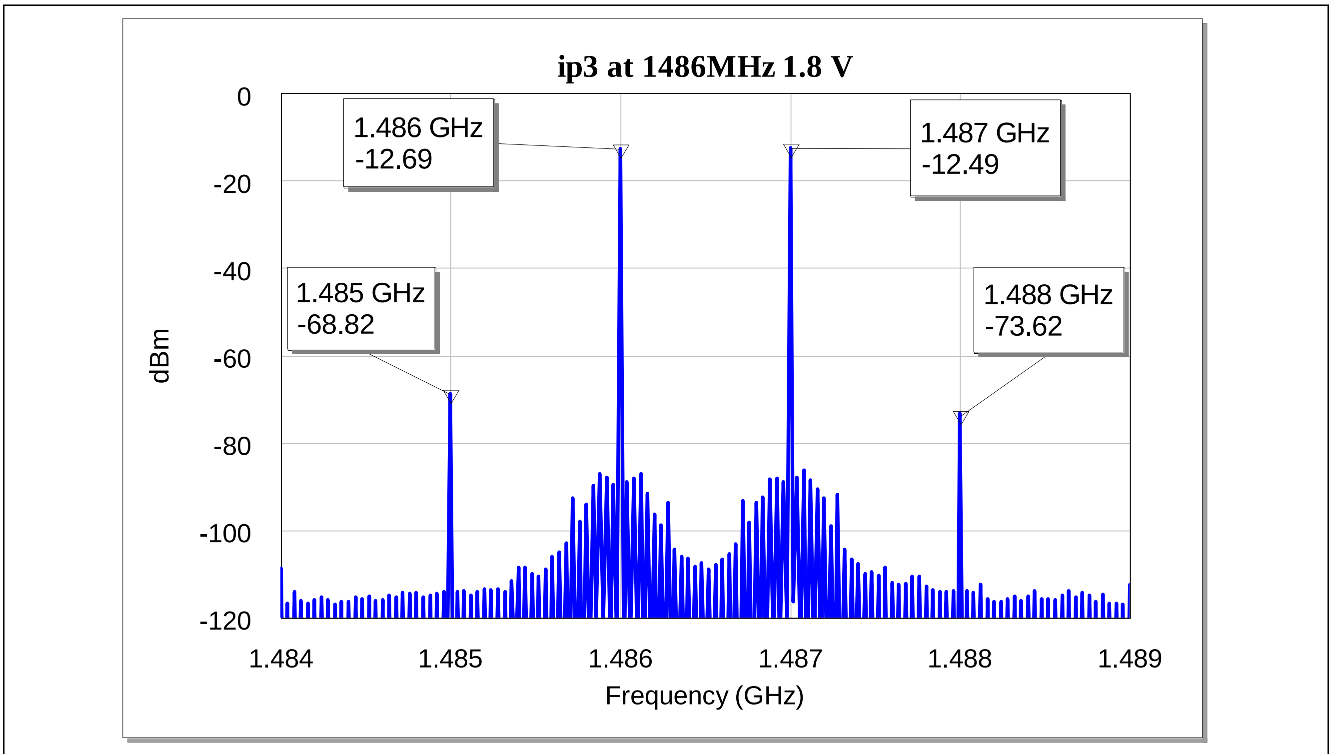

Figure 19 OIP3 Measurement of the BGA824N6 for LTE band-11 with 1.8 V power supply

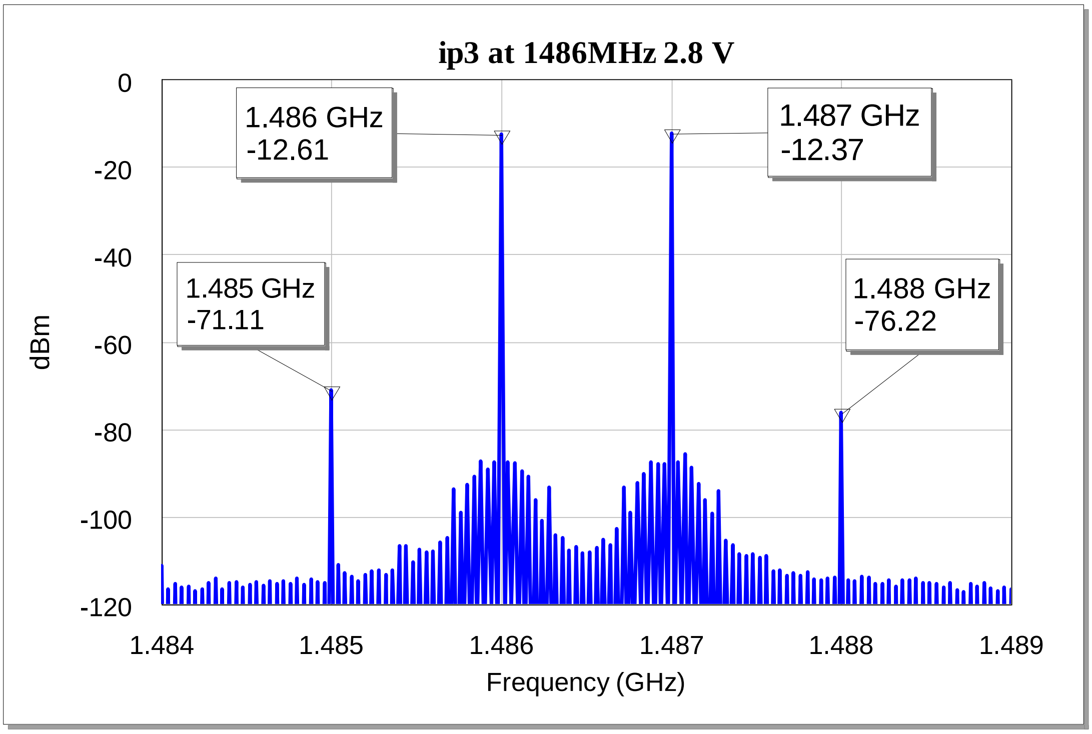

Figure 20 OIP3 Measurement of the BGA824N6 for LTE band-11 with 2.8 V power supply

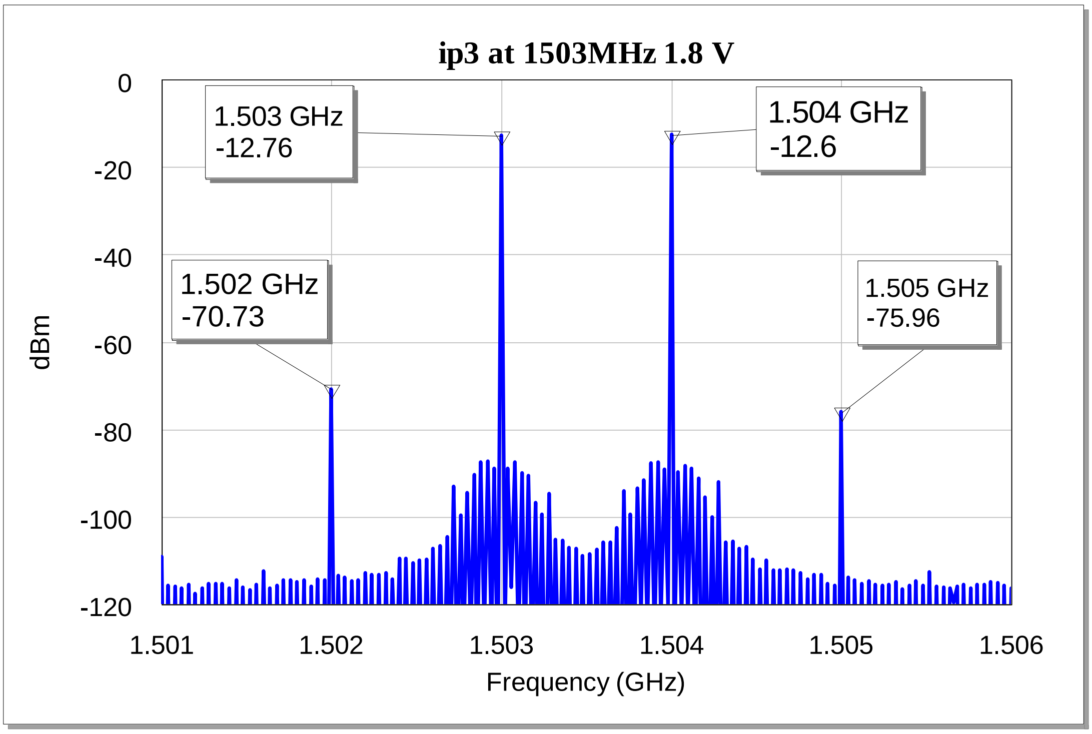

Figure 21 OIP3 Measurement of the BGA824N6 for LTE band-21 with 1.8 V power supply

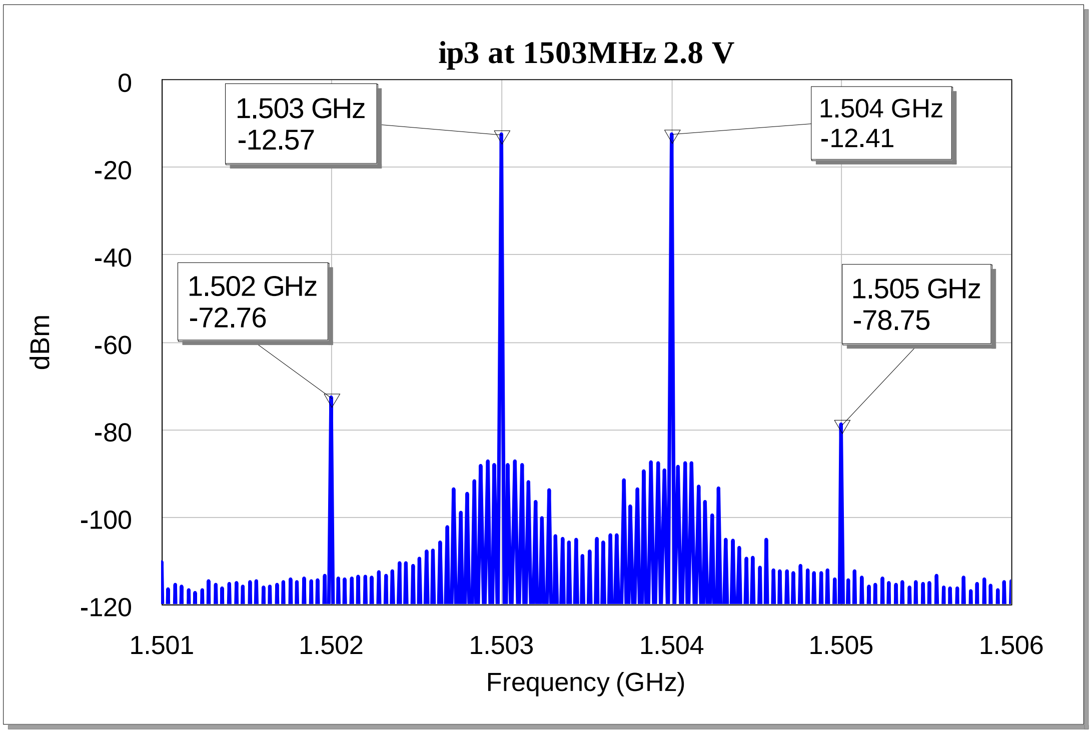

Figure 22 OIP3 Measurement of the BGA824N6 for LTE band-21 with 2.8 V power supply

5 Evaluation Board and Layout Information

In this application note, the following PCB is used:

PCB Marking: BGAx24N6 M260814

PCB material: **FR4**

ε_r of PCB material: **4.3 (FR4)**

Figure 23 Photo Picture of the Evaluation Board (overview) BGAx24N6 M260814 V3.1

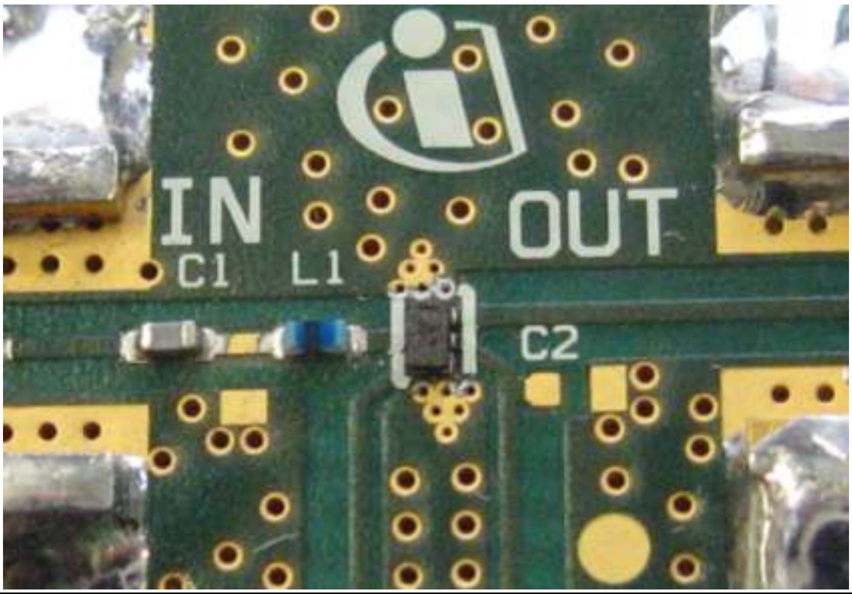

Figure 24 Photo Picture of the Evaluation Board (detailed view)

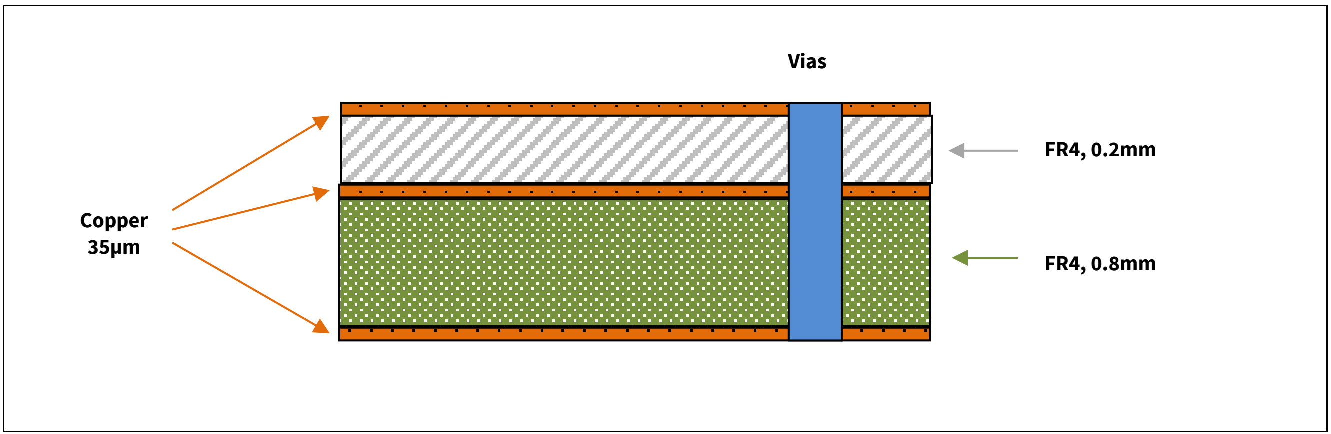

Figure 25 PCB Layer Information

6 Author

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