AN11390

BGU7224 Low Noise Amplifier (256 QAM) 2.4 GHz WiFi LNA MMIC with Bypass

Rev. 2 — 16 March 2016 Application note

Document information

Info	Content
Keywords	BGU7224, 2.4 GHz LNA, 2.4-2.5 GHz ISM, WiFi (WLAN)
Abstract	This document provides circuit schematic, layout, BOM and typical evaluation board performance for a 2.4 GHz WiFi (WLAN) LNA

Revision history

Rev	Date	Description
2	20160316	Chapter 5 “Thermal info” added
1	20141003	First publication

Contact information

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1. Introduction

The BGU7224 is a fully integrated MMIC Low Noise Amplifier (LNA) for wireless receiver applications in the 2.4 GHz to 2.5 GHz ISM band. Manufactured using NXP's high performance SiGe:C technology, the BGU7224 couples best-in-class gain, noise figure, linearity and efficiency with the process stability and ruggedness that are the hallmarks of SiGe technology. The BGU7224 features a robust temperature-compensated internal bias network and an integrated bypass / shutdown feature that stabilizes the DC operating point over temperature and enables operation in the presence of high input signals, while minimizing current consumption in bypass (standby) mode. The 1.6 mm x 1.6 mm footprint, with only two external components (a decoupling capacitor at the Vcc pin, and an optional shunt inductor for impedance matching at RF input pin), makes the BGU7224 the smallest 256 QAM WLAN LNA with bypass solution on the market, ideal for space sensitive applications.

Key Benefits:

- Fully integrated, high performance LNA with built-in bypass
- Exceptional 1.0 dB noise figure with 13 mA current consumption
- Extremely low bypass current (<2 µA)
- Single supply 3.0 V to 3.6 V operation
- Integrated, temperature stabilized bias network
- High IIP3 and low EVM
- High ESD protection of 2 kV (HBM) on all pins
- Ultra small, 0.5 mm pitch, 1.6 x 1.6 x 0.5 mm QFN-style package, MSL 1 at 260ºC
- Compliant to Directive 2002/95/EC, regarding Restriction of Hazardous Substances (RoHS) following NXP's RHF-2006 indicator D (dark green)

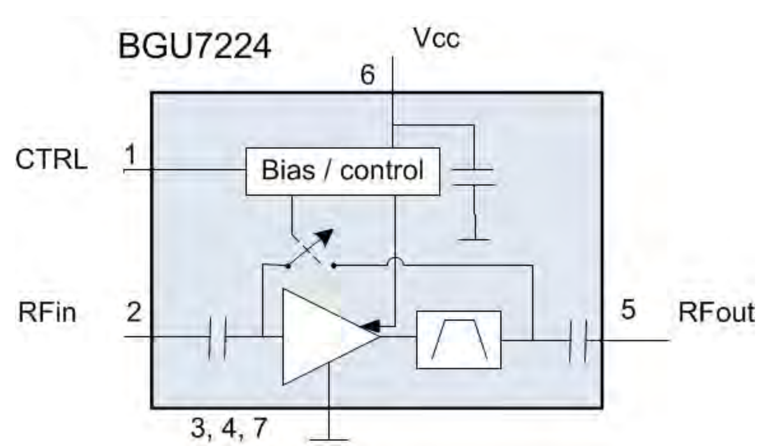


Fig 1. BGU7224 Block Diagram

2. Design and Application

The overall intent of this application note is to demonstrate the performance of the BGU7224 in a 2.4 GHz LNA application e.g. 802.11 b/g/n “MIMO” WiFi (WLAN) applications up to 256 QAM. Key requirements for this type of WLAN application are gain, noise figure, linearity, input and output return loss, and turn on/off time.

The BGU7224 itself is a fully integrated MMIC consisting of an internal temperature compensated bias network, an RF Gain block, bypass mode functionality, ESD protection, internal RF matching, and internal DC blocking. Only two external components, a 4.7 nF DC-decoupling capacitor and an optional 8.2 nH shunt inductor for matching at RF input is necessary.

The BGU7224 can be also used without the matching inductor at the RF_IN, but then the input return loss will be degraded by ~2 dB at 2.4 GHz !

The 2.4 GHz WiFi LNA evaluation board simplifies the evaluation of the BGU7224 application. The evaluation board enables testing of the device performance and requires no additional support circuitry. The board is fully assembled with the BGU7224 MMIC, and includes the 4.7 nF DC-decoupling capacitor and the 8.2 nH input matching inductor. The board is also supplied with two SMA connectors for input and output connection to RF test equipment.

A 50 ohm “through line” is provided at the top of the evaluation board in case the user wishes to verify RF connector and grounded coplanar wave guide losses for de-embedding purposes.

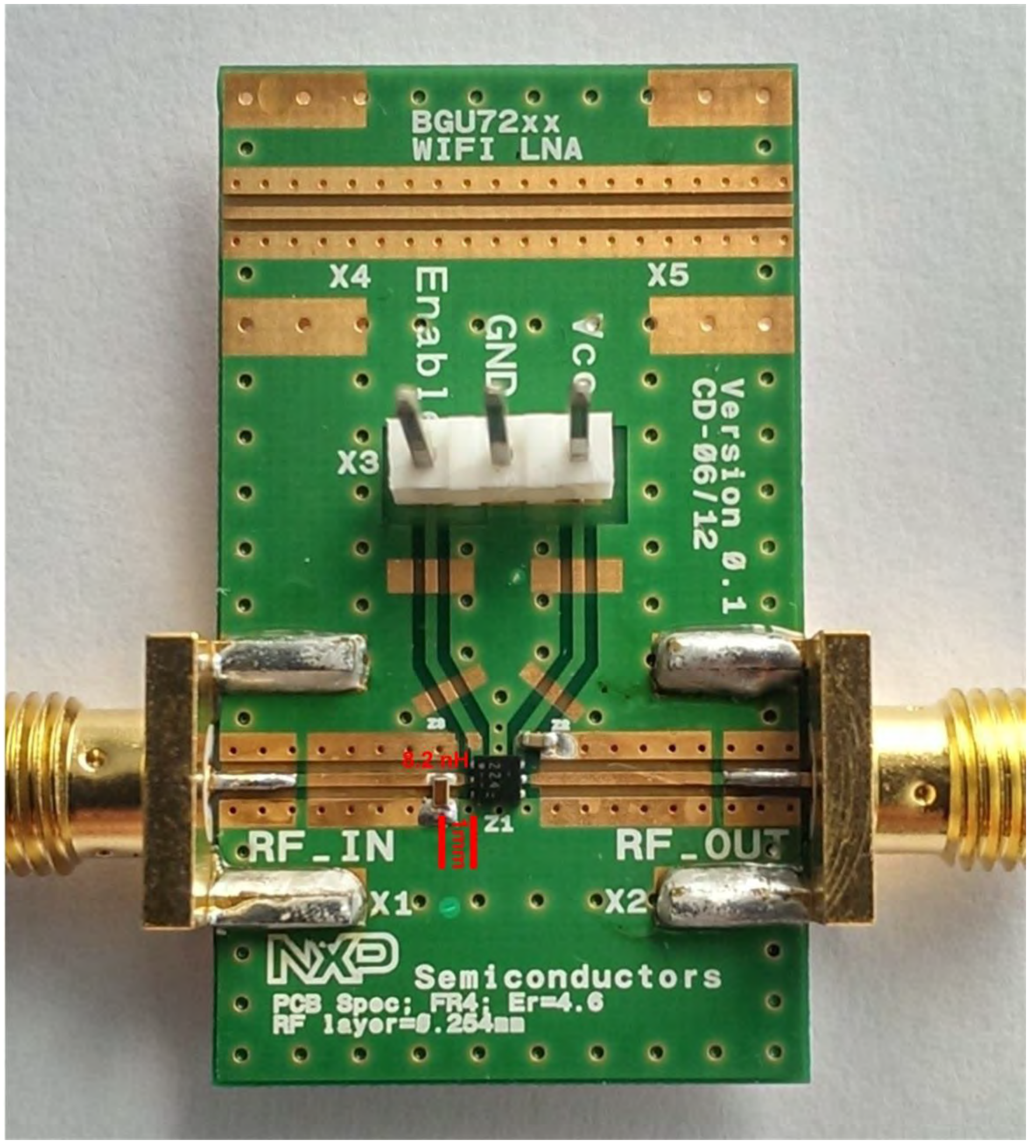


Fig 2. BGU7224 Evaluation Board 2.4 GHz WiFi LNA EVB

2.1 Application Circuit Schematic

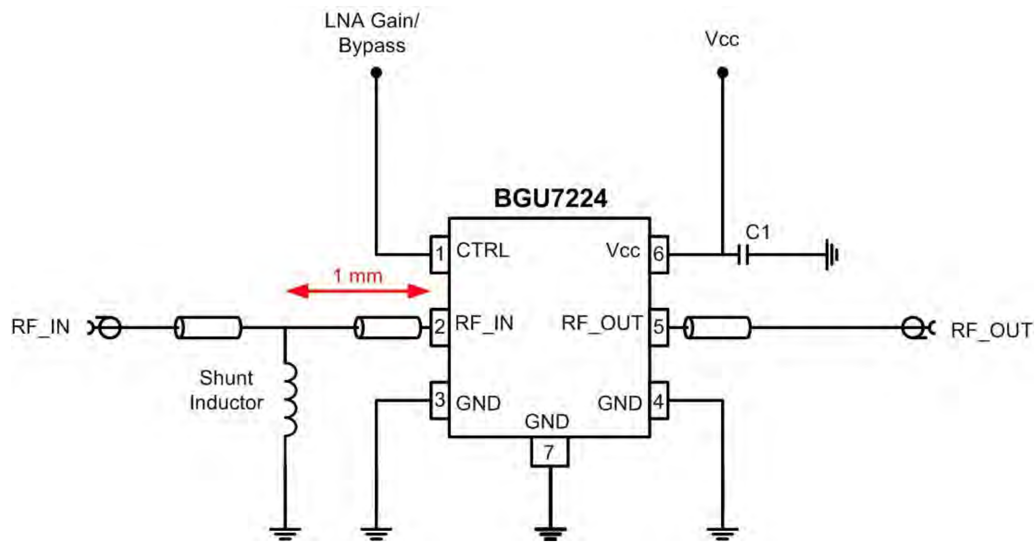


Fig 3. BGU7224 Evaluation Board: Schematic

Note: Figure 3 is the schematic for BGU7224 evaluation board, only two external components (matching shunt inductor on RF_IN and DC-decoupling capacitor, placed near the V_{CC} pin).

The BGU7224 can be also used without the matching inductor at the RF_IN, but then the input return loss will be degraded by ~2 dB at 2.4 GHz!

2.2 PCB Layout

- Use controlled impedance lines (50 Ω) for RF_in & RF_out
- Place the decoupling capacitor as close as possible to the device pin 6 (Vcc)
- Proper grounding of the RF GND especially pin 7 (ground pad) is essential for good RF-performance. Connect the GND pins direct to ground plane and use through vias on ground pad (size and amount depends on the technology used)

2.3 Board Layout

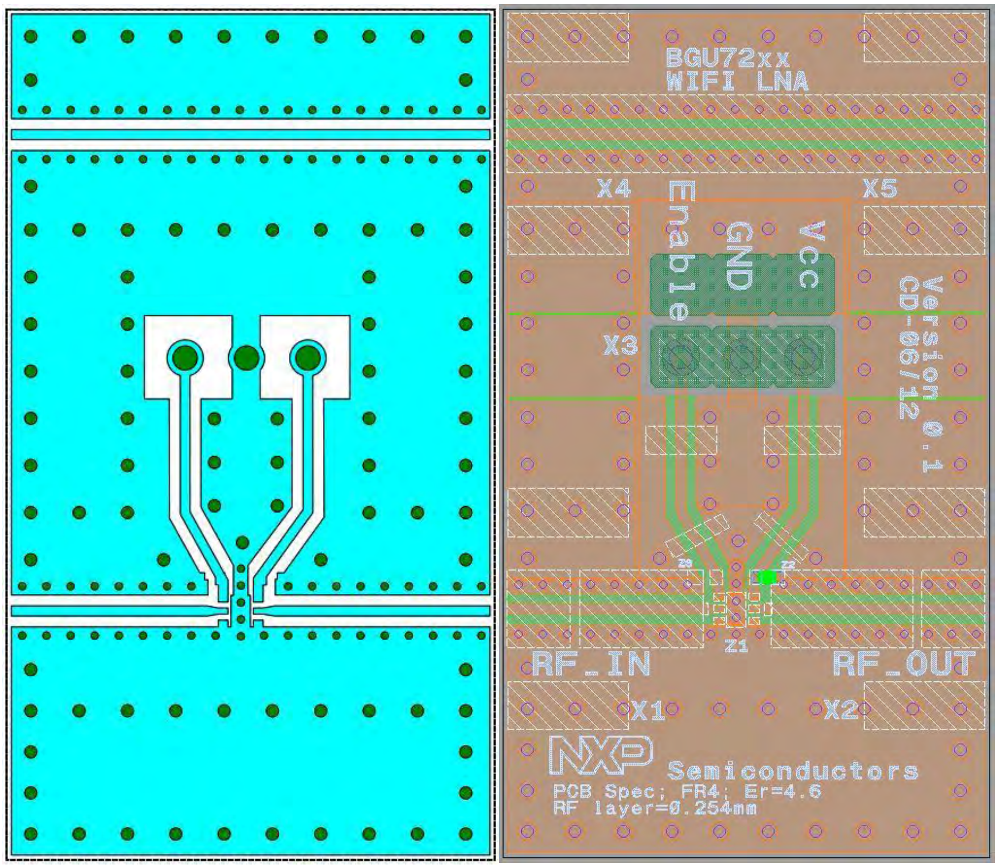


Fig 4. BGU7224 Evaluation Board

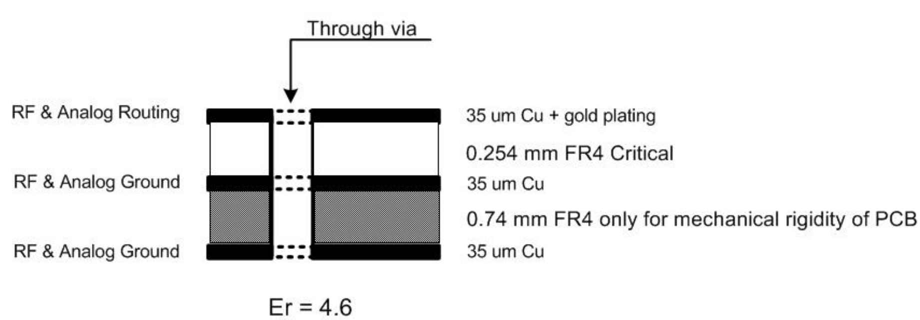


Fig 5. BGU7224 Stack of the PCB material

2.4 Application Board Bill-Of-Material

Table 1. BGU7224 2.4 GHz WiFi LNA Part List

Customer can choose their preferred vendor but should be aware that the performance could be affected. “0402” case size passives are used on NXP’s evaluation board.

Item	Position on Layout	Reference (Fig 2)	Type	Vendor	Value
1	Z1	BGU7224	BGU7224	NXP SEMICONDUCTORS	BGU7224
2	Z2	C1	GRM155	Murata	4.7nF
3	RF_IN	Shunt Inductor	LQP15	Murata	8.2nH
3	X1, X2	RF_IN, RF_OUT		Emerson Network Power	CON-SMA-1
4	X3	Vcc/LNA gain/bypass		Molex	CON-3PIN

3. Typical Application Board Test Result

This section presents the results of a typical BGU7224 as used in NXP’s Application Circuit. Unless otherwise noted, all measurement references are at the SMA connectors on the evaluation board.

3.1.1 S-Parameters

Figures 6 and 7 below show the broadband (10 MHz – 10 GHz) and narrowband s-parameters for the BGU7224 respectively. Figure 8 shows the measured stability factor from 1 GHz – 20 GHz.

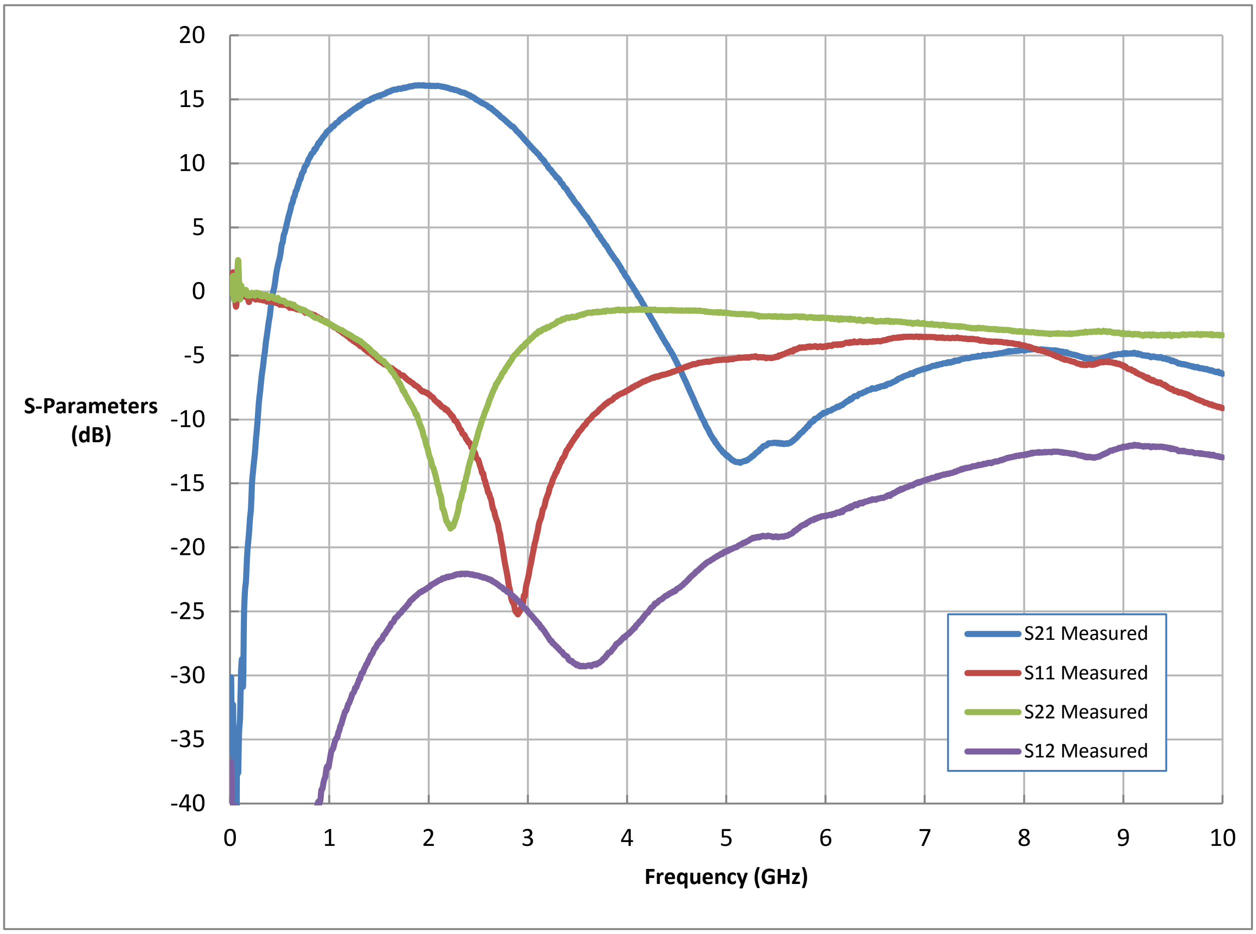


Fig 6. BGU7224 Broadband S-Parameters V_{CC} = 3.3V 25°C ambient

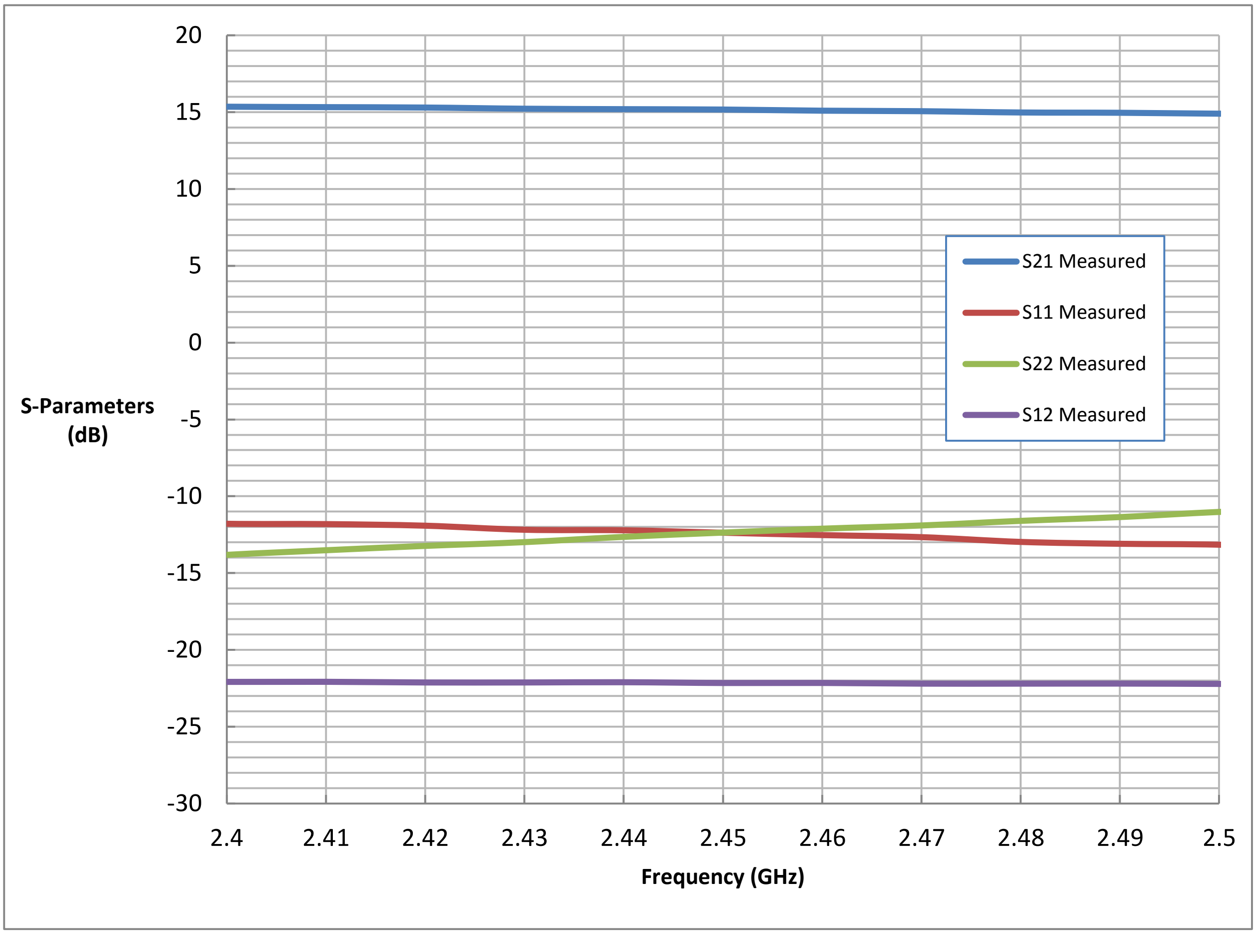


Fig 7. BGU7224 Narrowband S-Parameters V_{CC} = 3.3V 25°C ambient

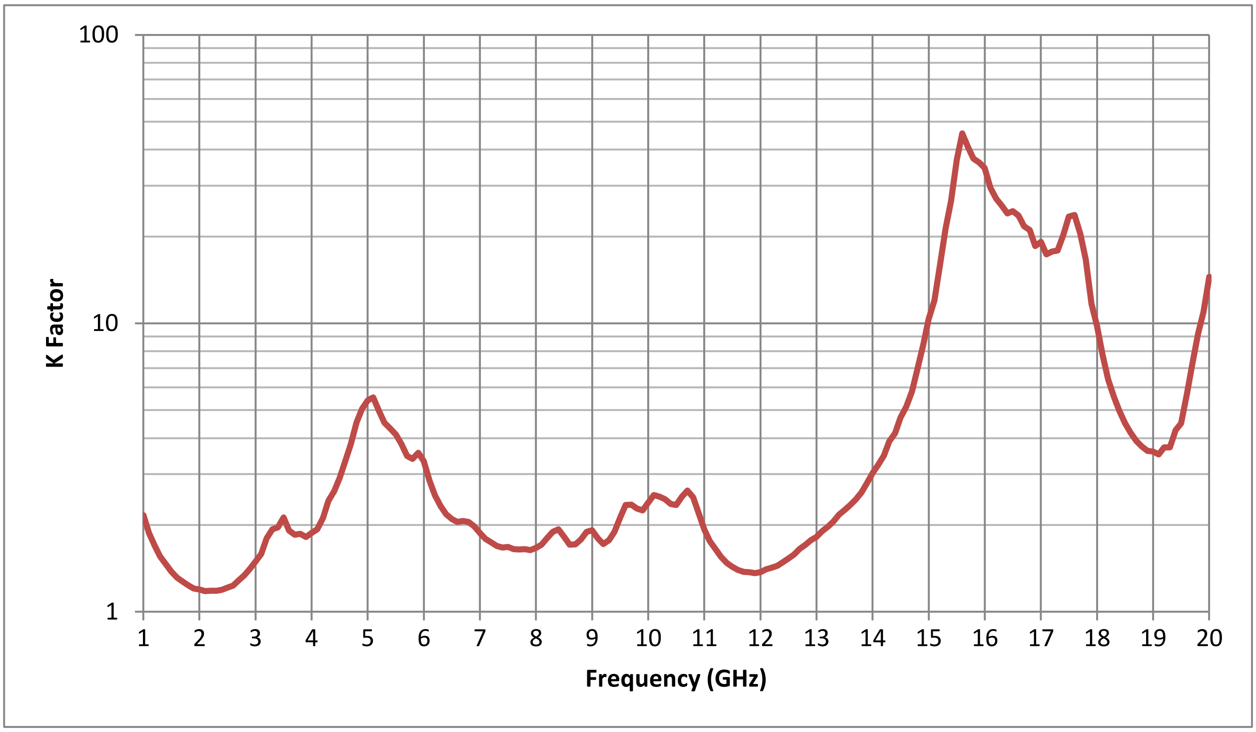


Fig 8. BGU7224 Broadband K Factor (Rollett Stability Factor) V_{CC} = 3.3V 25°C ambient

3.1.2 S-Parameters in Bypass Mode

Figure 9 and 10 below shows the gain, input return loss, and output return loss of the BGU7224 in bypass mode.

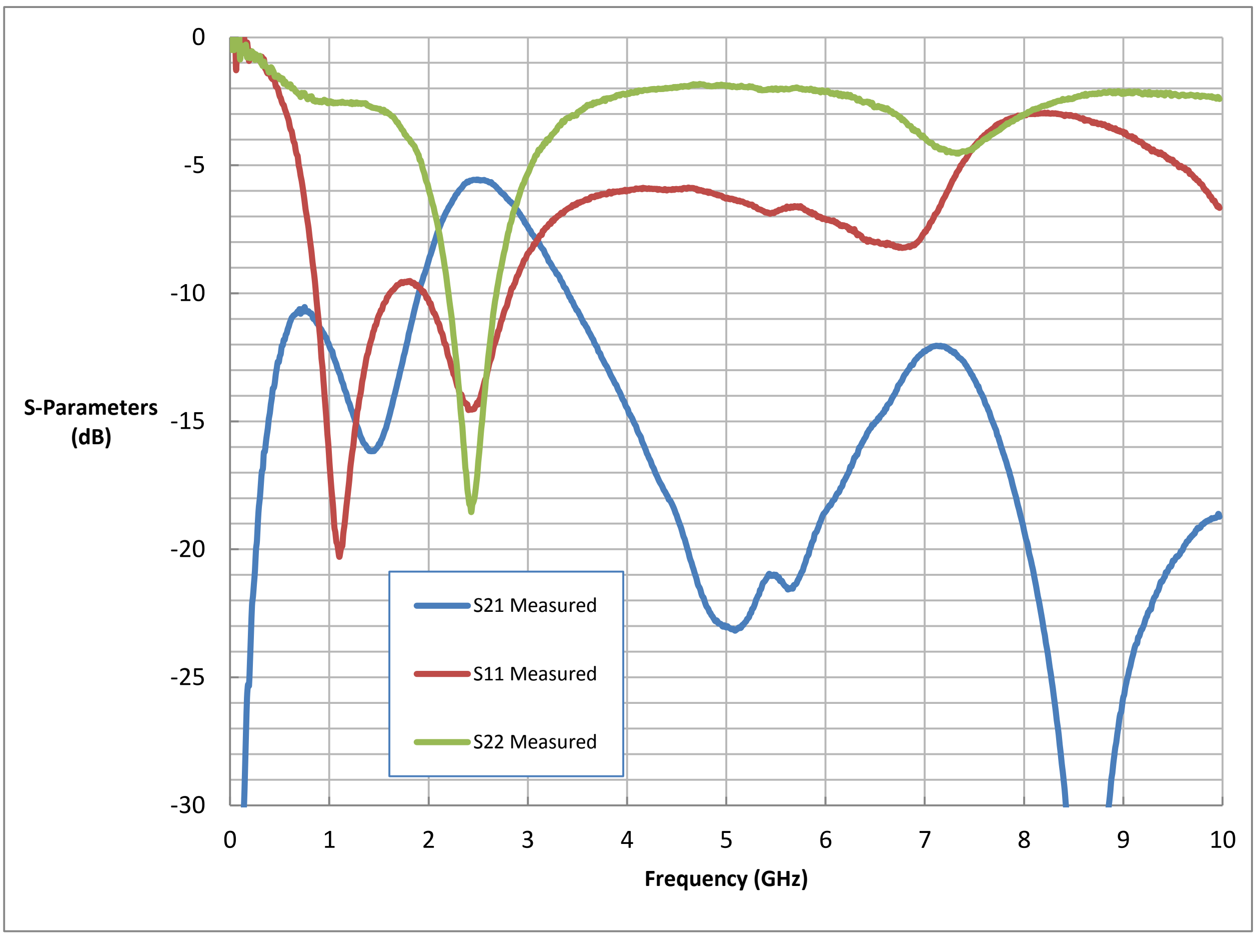


Fig 9. BGU7224 Broadband S-Parameters Bypass Mode Vcc = 3.3V 25°C ambient

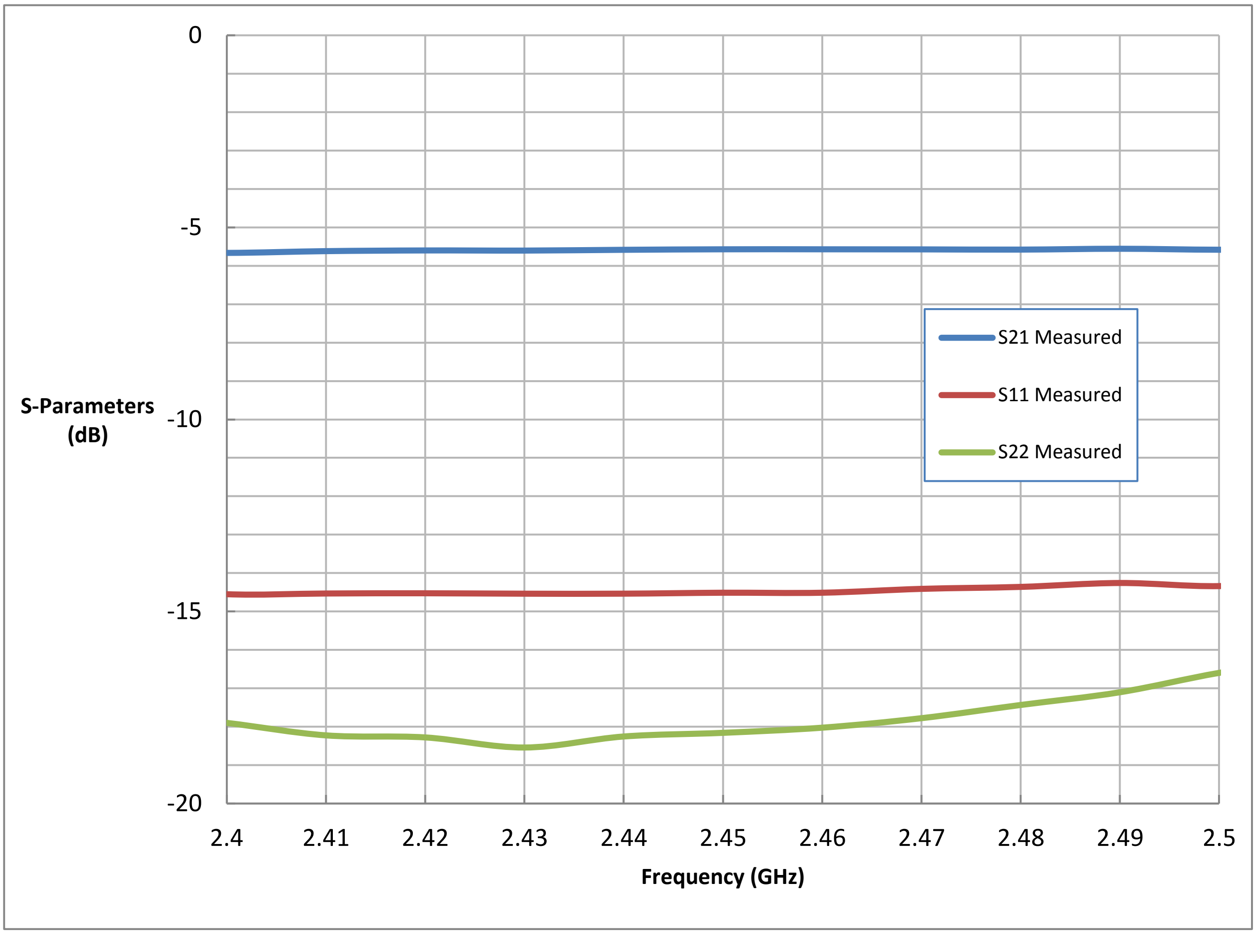


Fig 10. BGU7224 Narrowband S-Parameters Bypass Mode Vcc = 3.3V 25°C ambient

3.1.3 Noise Figure

The noise figure is physically measured at the SMA connectors of the evaluation board. The total loss of the connectors and the printed circuit board are 0.3dB at 2.4 GHz (RF_IN to RF_OUT). After de-embedding the connector and PCB losses (0.15dB at 2.4 GHz) to the device pins, the noise figure is less than 0.8 dB at 2.4 GHz. Figure 11 below shows both the noise figure at the EVB level and the de-embedded noise figure.

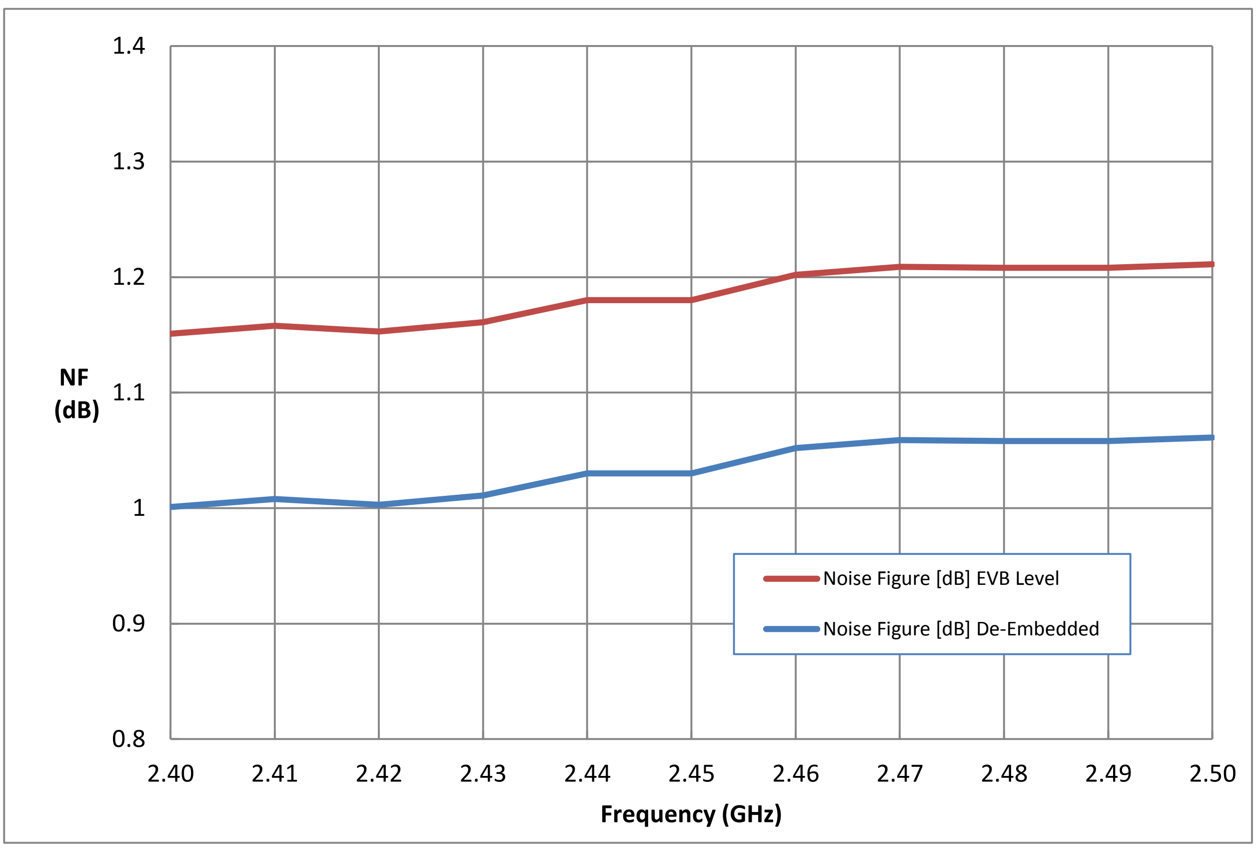


Fig 11. BGU7224 Noise Figure V_{CC} = 3.3V 25°C ambient

3.1.4 Small Signal Linearity in Gain mode

Figure 12 shows the input-referred IP3 level for the BGU7224, measured with 5 MHz tone spacing, -25 dBm input power per tone, and a swept center frequency from 2.4 GHz to 2.5 GHz.

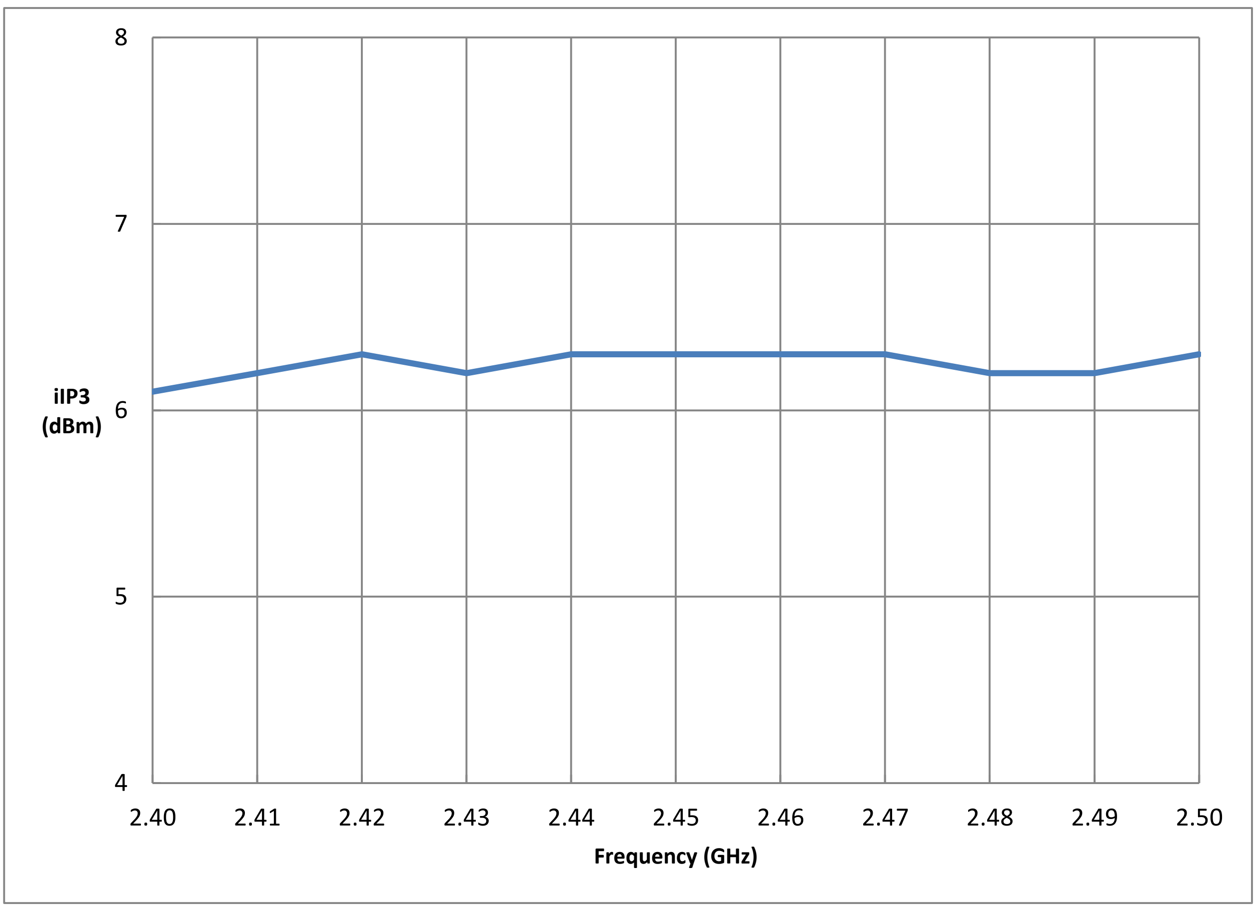


Fig 12. BGU7224 Swept input-IP3 5MHz Tone Spacing Pin=-25dBm/Tone V_{CC} = 3.3V 25°C ambient

3.1.5 Large Signal Linearity in Gain mode

Figure 13 shows the input referred P1dB level from 2.4 GHz to 2.5 GHz.

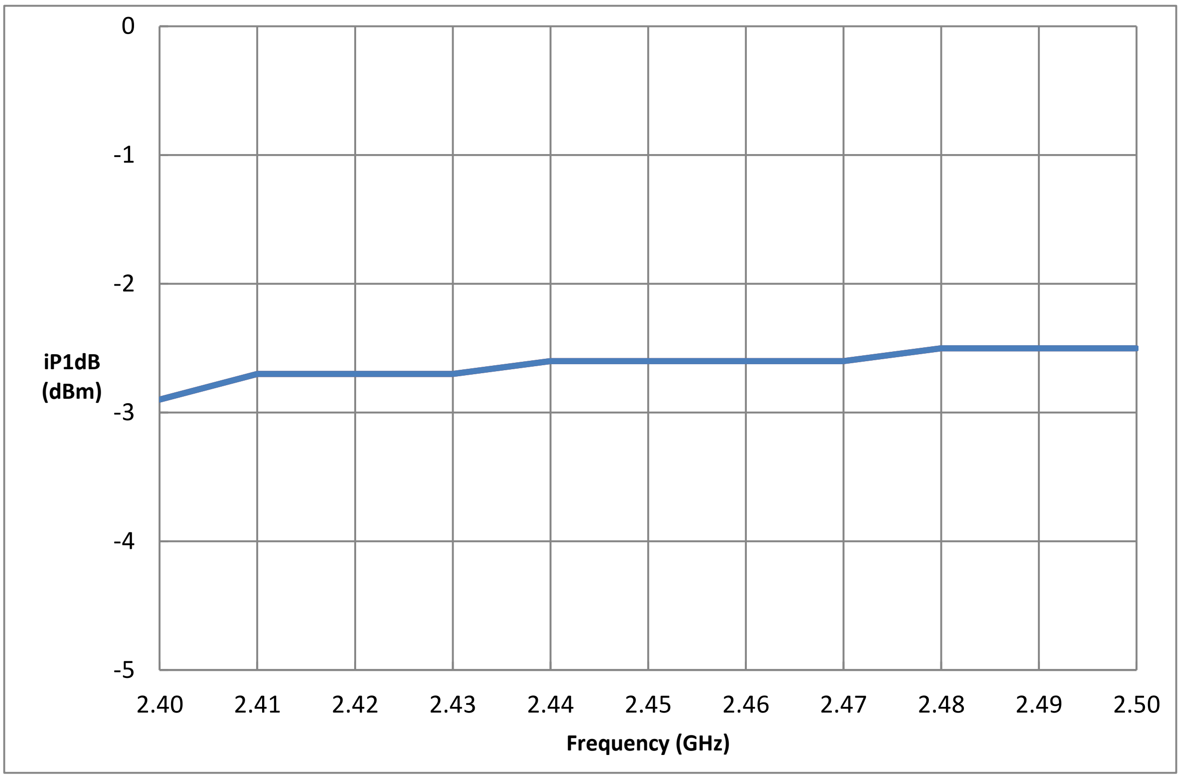


Fig 13. BGU7224 input-P1dB vs. frequency V_{CC} = 3.3V 25°C ambient

Figure 14 shows error vector magnitude (EVM) as a function of output power. Specifically, these data are captured using a 256 QAM OFDM waveform MSC9-VHT40. Note that the output power is the average power over the burst.

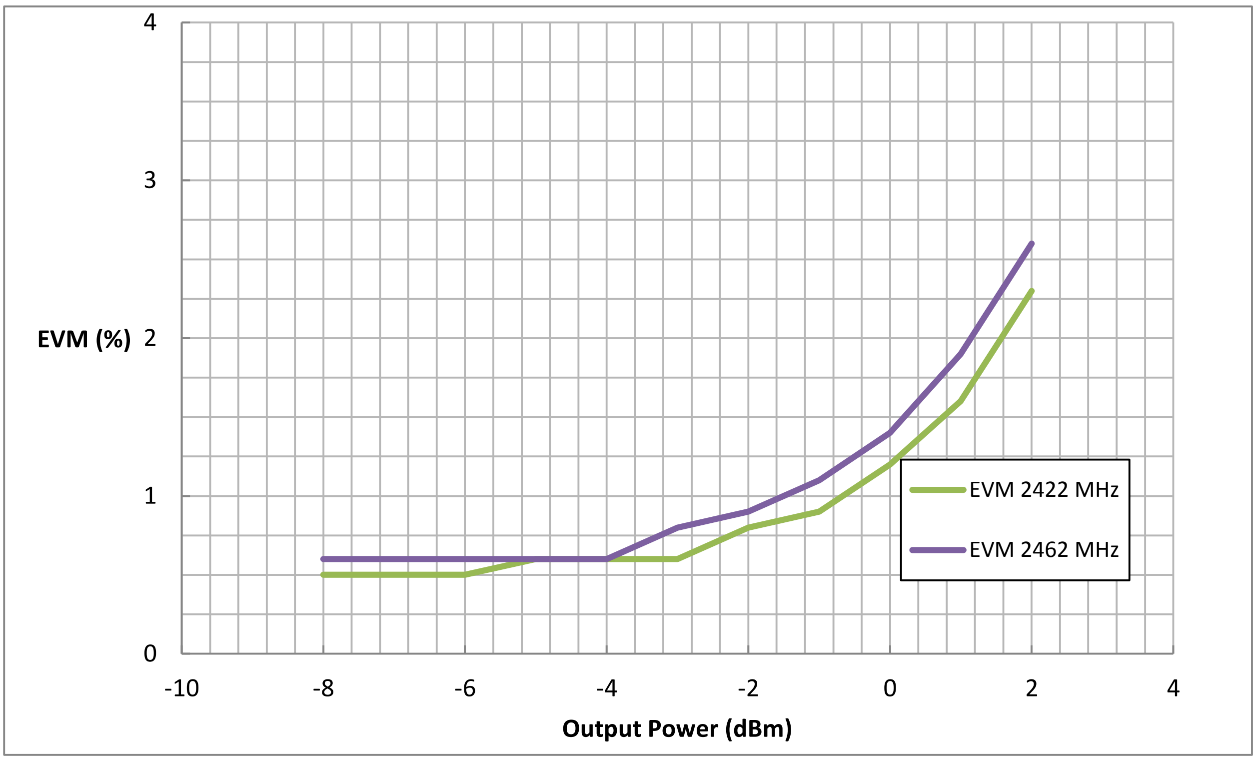


Fig 14. BGU7224 EVM vs. burst average output power MCS9-VHT40 V_{CC} = 3.3V 25°C ambient

3.1.6 Out-of-band spurious

In order to characterize the BGU7224 under potential jamming conditions, a 2.462 GHz signal is applied to the evaluation board at an RF input power level of -30 dBm. A second tone is applied at 5.180 GHz and swept over a range of input power levels. The 5.180 GHz “leakage” and the second order intermodulation product at 2.718 GHz are measured. The measurement set-up is shown in Figure 15. As a function of the 5.180 GHz jammer input level, Figure 16 reports the 5.180 GHz jammer output level, the 2.718 GHz IMD2 output level, and the 2.462 GHz Gain.

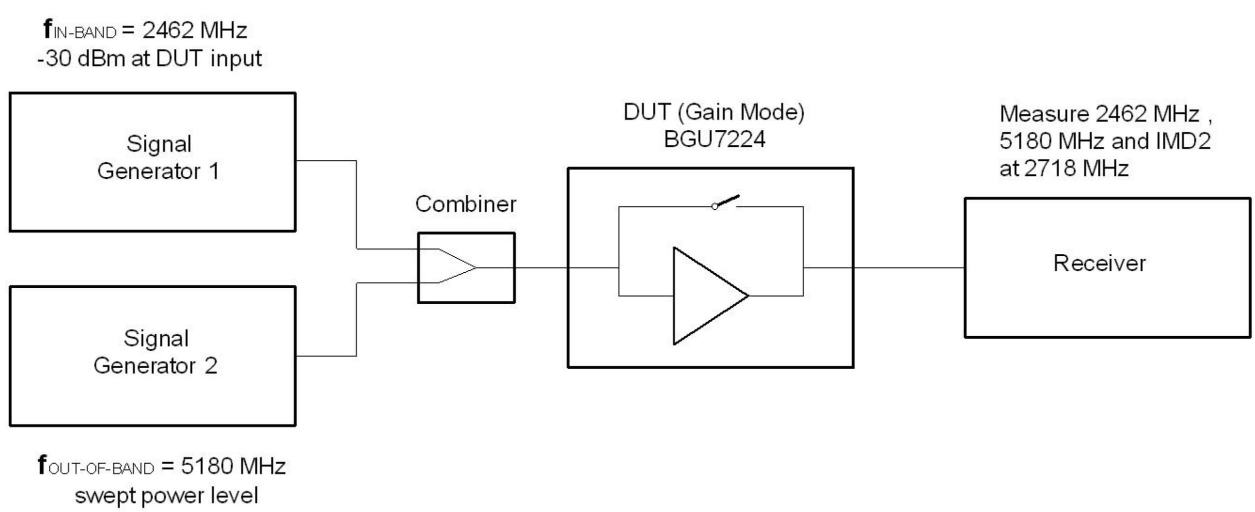


Fig 15. Out-of-band suppression test setup

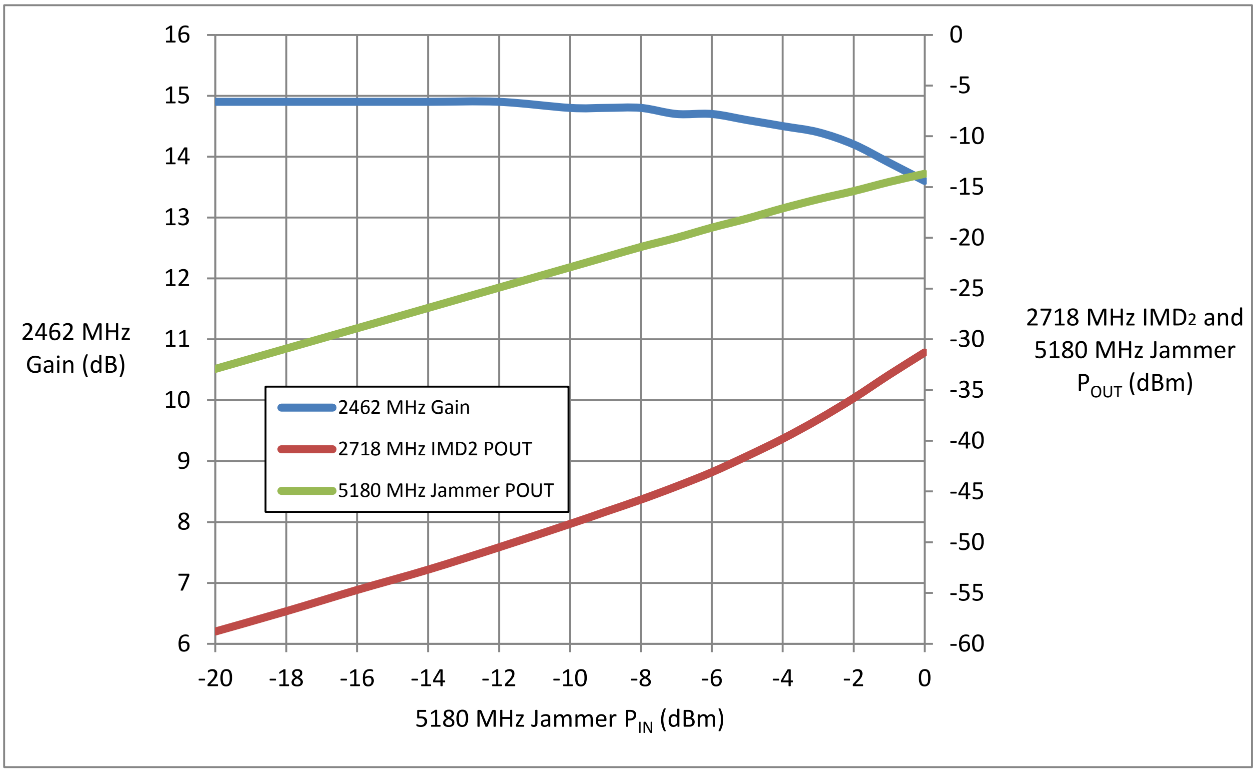


Fig 16. BGU7224 5180 MHz Jammer Level at Output, 2718 MHz IMD2 and 2462 MHz Gain vs. Jammer Input Power **V_{CC} = 3.3V 25°C ambient 2.462 GHz input at -30 dBm**

3.1.7 Harmonics

By applying large RF signals at the input during bypass mode (OFF mode) operation, harmonics can be created by the LNA and then emanate from its RF input. In a real operating environment, these harmonic signals can be re-emitted by the antenna. The measurement set up used for characterizing the harmonics generated by the BGU7224 in bypass mode is shown in Figure 17. A 2.447 GHz signal is used for the measurement results shown in Figure 18.

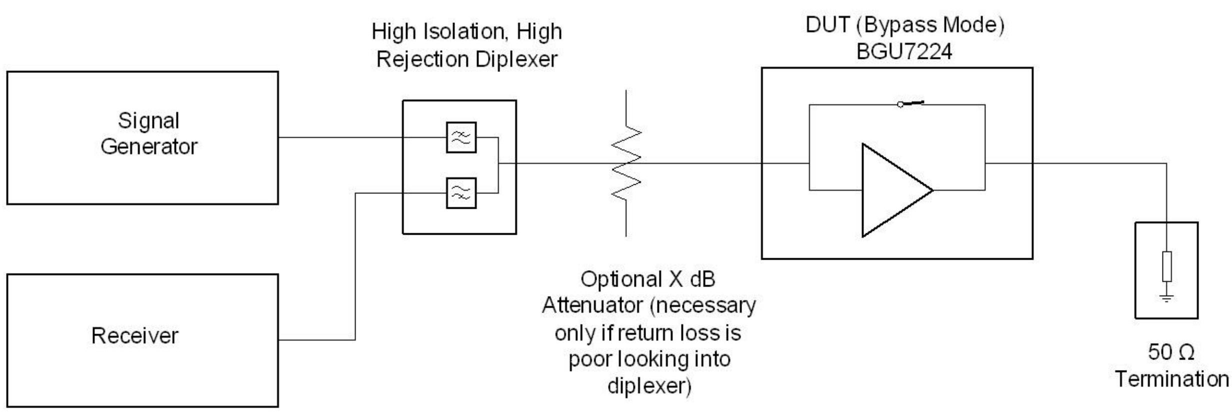
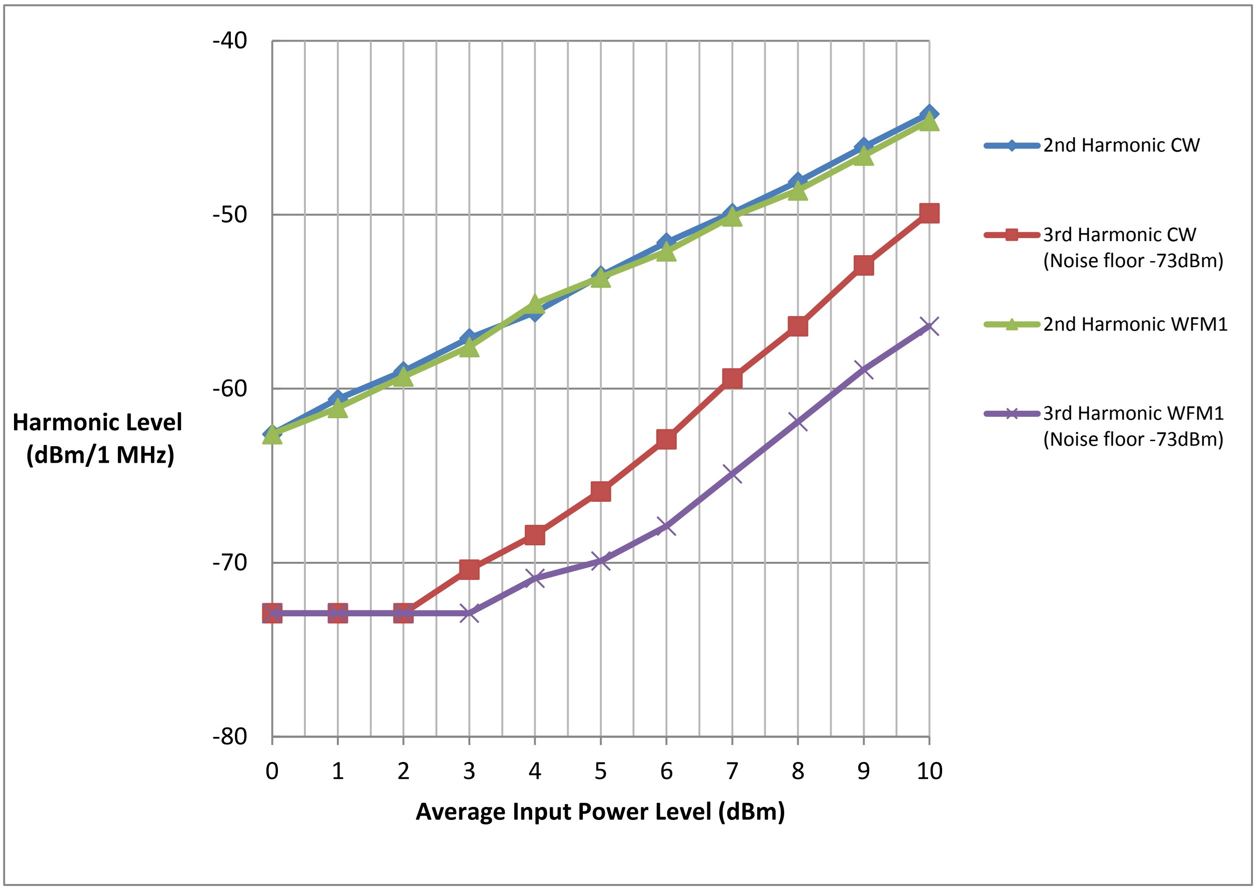


Fig 17. Harmonic test setup



(1) CW – Continuous Wave (only for test / comparison)

(2) WFM1 - 802.11b 1 Mbps (DBPSK) (worst case signal)

Fig 18. BGU7224 (Bypass Mode) 2nd and 3rd Reflected Harmonic Levels 2.447 GHz Fundamental

3.1.8 LNA Turn ON-OFF Time

The following diagram shows the setup to test LNA Turn ON and Turn OFF time.

The waveform generator is set to square wave mode and the output amplitude at 3.3V peak with 50Ω output impedance. The RF signal generator output level is -20dBm at 2.45 GHz. It is very important to minimize or compensate for the time delay skew between the trigger signal and the detector signal. Also note that the scope input impedances are set to 50Ω on both channels.

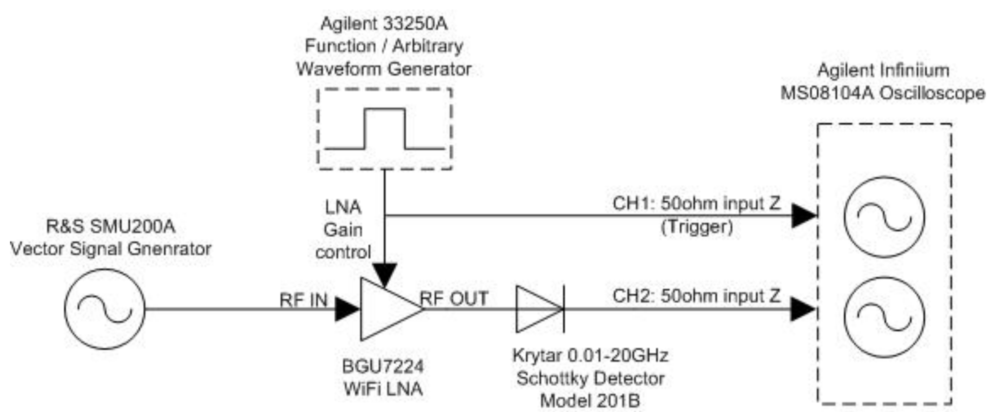
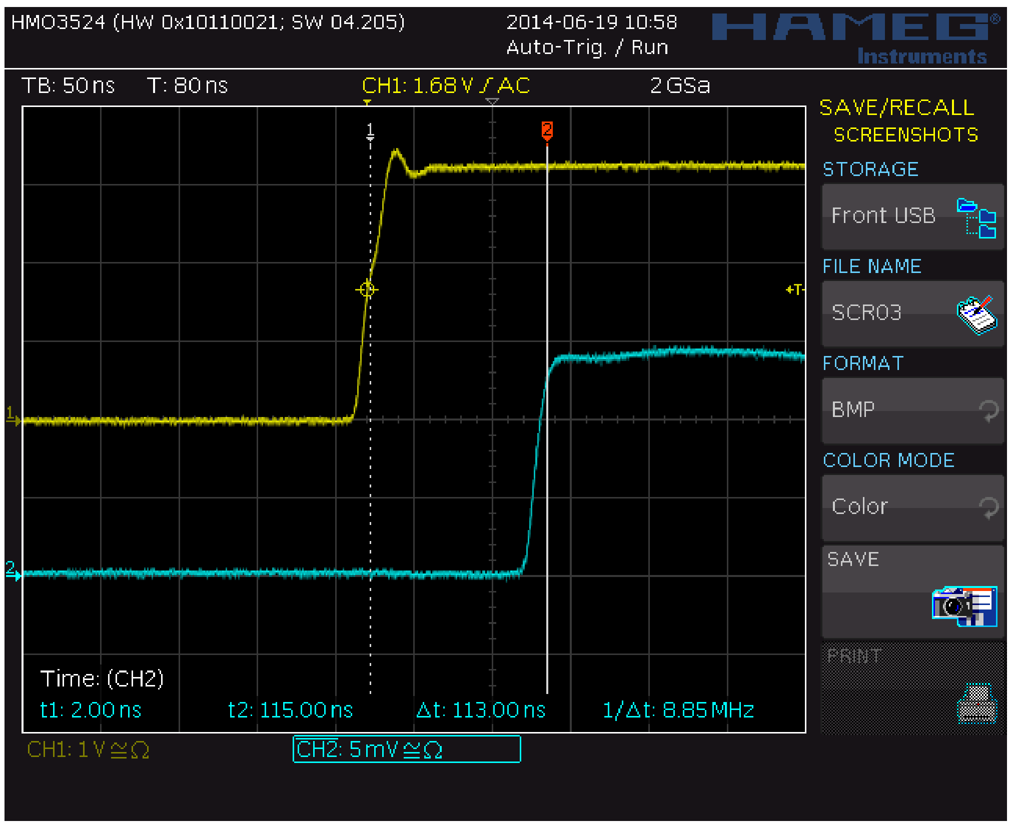


Fig 19. LNA Turn On and Turn Off time test setup

3.1.8.1 LNA Turn ON Time

Figure 20 below shows a screen capture from an oscilloscope used to record the turn on time of the BGU7224.

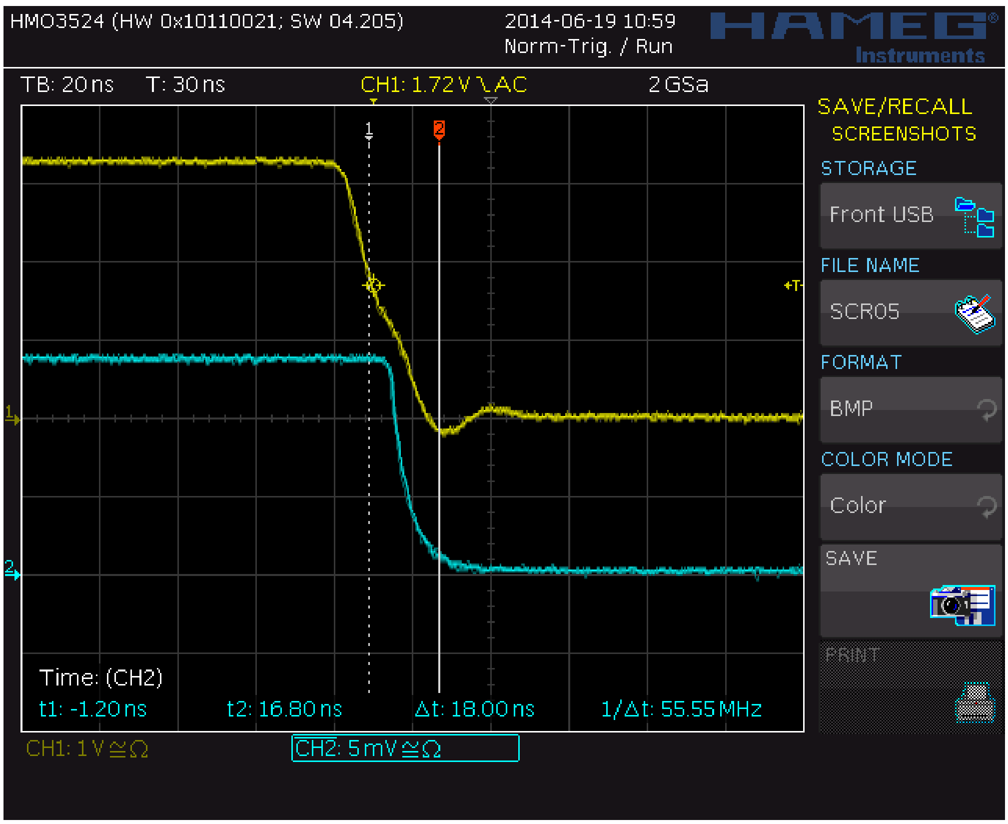


100Hz 0/3.3V Square Wave, applied on V_{enable} pin, measured from 50% of input pulse to 90% of maximum output power

Fig 20. BGU7224 Turn On Time

3.1.8.2 LNA Turn OFF Time

Figure 21 below shows an oscilloscope screen capture with the turn off time for the BGU7224.



100Hz 0/3.3V Square Wave, applied on V_{enable} pin, measured from 50% of input pulse to 10% of maximum output power

Fig 21. BGU7224 Turn Off Time

4. Summary of the Typical Evaluation Board Test Result

Table 2. Typical results measured on the BGU7224 2.4 GHz WiFi LNA Evaluation Board with 8.2 nH matching inductor at the RF_IN

Operating frequency 2.4-2.5 GHz, testing at 2.4 GHz and 2.5 GHz in Gain mode unless otherwise specified, Temp = 25°C. ***Unless noted, all measurements are done with SMA-connectors as reference plane.***

Parameter		Symbol	Value	Unit
Supply Voltage		V_{CC}	3.3	V
Supply Current		I_{CC}	12.5	mA
ByPass Current		I_{bypass}	1.2	µA
Noise Figure [1]	@ 2.4 GHz	NF	1.00	dB
	@ 2.5 GHz	NF	1.05	dB
Power Gain	@ 2.4 GHz	Gp	15.4	dB
	@ 2.5 GHz	Gp	14.9	dB
Input Return Loss	@ 2.4 GHz	IRL	11.5	dB
	@ 2.5 GHz	IRL	13.0	dB
Output Return Loss	@ 2.4 GHz	ORL	13.5	dB
	@ 2.5 GHz	ORL	11.0	dB
Reverse Isolation	@ 2.4 GHz	ISLrev	-22.1	dB
	@ 2.5 GHz	ISLrev	-22.2	dB
Power Gain (bypass mode)	@ 2.4 GHz	Gp	-5.6	dB
	@ 2.5 GHz	Gp	-5.6	dB
Input Return Loss (bypass mode)	@ 2.4 GHz	IRL	14.5	dB
	@ 2.5 GHz	IRL	14.3	dB
Output Return Loss (bypass mode)	@ 2.4 GHz	ORL	17.9	dB
	@ 2.5 GHz	ORL	16.5	dB
Input Third Order Intercept Point Two Tones: 5 MHz Tone Spacing Power: 0 dBm/tone (bypass mode)	@ 2.4 GHz	IIP3	34.8	dBm
	@ 2.5 GHz	IIP3	34.6	dBm
Output Third Order Intercept Point Two Tones: 5 MHz Tone Spacing Power: 0 dBm/tone (bypass mode)	@ 2.4 GHz	OIP3	29.2	dBm
	@ 2.5 GHz	OIP3	29.0	dBm
Input 1dB Gain Compression Point	@ 2.4 GHz	iP1dB	-2.9	dBm
	@ 2.5 GHz	iP1dB	-2.5	dBm
Output 1dB Gain Compression Point	@ 2.4 GHz	oP1dB	11.5	dBm
	@ 2.5 GHz	oP1dB	11.4	dBm
Error Vector Magnitude	@2.4 GHz	EVM	1.2	%

Parameter		Symbol	Value	Unit
Pout = 0dBm (256 QAM, MSC9-40)	@ 2.5 GHz	EVM	1.4	%
Input Third Order Intercept Point Two Tones: 5 MHz Tone Spacing power: -25 dBm/tone	@ 2.4 GHz	IIP3	6.1	dBm
	@ 2.5 GHz	IIP3	6.3	dBm
Output Third Order Intercept Point Two Tones: 5 MHz Tone Spacing power: -25 dBm/tone	@ 2.4 GHz	OIP3	21.5	dBm
	@ 2.5 GHz	OIP3	21.2	dBm
1dB input/output cross-compression with jammer	@2462 MHz with 5180 MHz Jammer		-1	dBm
Harmonics generated at RF input Pin = 7 dBm (2.447 GHz) CW signal input (bypass mode)	2.H. @ 4.894 GHz	H2	-50	dBm
	3.H. @ 7.341 GHz	H3	-59	dBm
Stability (1 - 20 GHz)		K	>1	
LNA Turn ON/OFF Time		Ton	120	nS
		Toff	20	nS

[1] PCB and connector losses excluded.

5. Thermal info

The following temperature simulations are done based on the BGU7224 soldered onto the NXP evaluation board (see Fig. 22) in still air and 85 °C ambient temperature.

Part number	θ_{JCbot} [1]	θ_{JB} [2]	Ψ_{JC} [3]	Maximum Junction Temperature	T_a
BGU7224	250 K/W	274 K/W	180 K/W	101 °C	85 °C

[1] Thermal resistance from junction to exposed diepad

[2] Thermal resistance from junction to board

[3] Thermal characterization parameter junction to package top

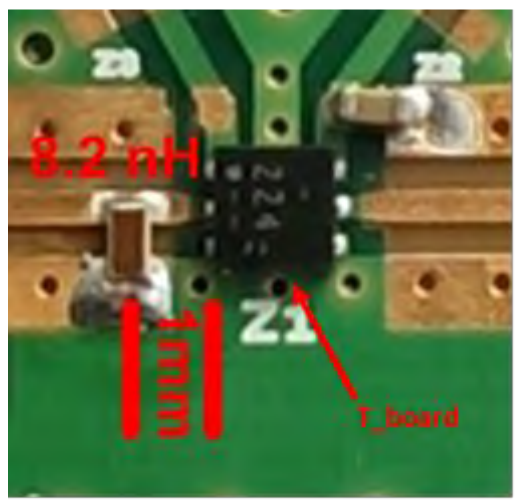


Fig 22. BGU7224 reference position board temperature

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