UM10489

2-Tone Test BGU7004 and BGU7008 GPS LNA

Rev. 1.0 — 9 June 2011 **User manual**

Document information

Info	Content
Keywords	LNA, GPS, BGU7004, BGU7008 Linearity Measurements
Abstract	This document describes 2-Tone Linearity Measurements with the BGU7004 and BGU7008 AEC-Q100 qualified GPS low noise amplifier evaluation board.

Revision history

Rev	Date	Description
1.0	20110609	First Release.

Contact information

For additional information, please visit: http://www.nxp.com

For sales office addresses, please send an email to: salesaddresses@nxp.com

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1. Introduction

NXP Semiconductors BGU7004 and BGU7008 are AEC-Q100 qualified low-noise amplifiers for GPS receiver applications in a plastic, leadless 6 pin, extremely thin small outline SOT886 package. The typical gain is 16.5 dB for the BGU7004 and 18.5 dB for the BGU7008. Both types have a noise figure of 0.9 dB (incl. board losses) or 0.85 dB (board losses subtracted). They have a superior linearity performance to suppress interference and noise from co-habitation cellular transmitters, while retaining sensitivity.
The GPS LNA evaluation boards (EVB's) are designed to evaluate the performance of the BGU7004 and BGU7008 applied as a GPS LNA (Figure 1).
The application diagram, board layout, bill of materials, and typical results of the EVB's are given in separate application notes about the BGU7004 and BGU7008.
This document shows examples of the linearity performance to suppress interference from co-habitation (cellular) transmitters with a 2-Tone test.

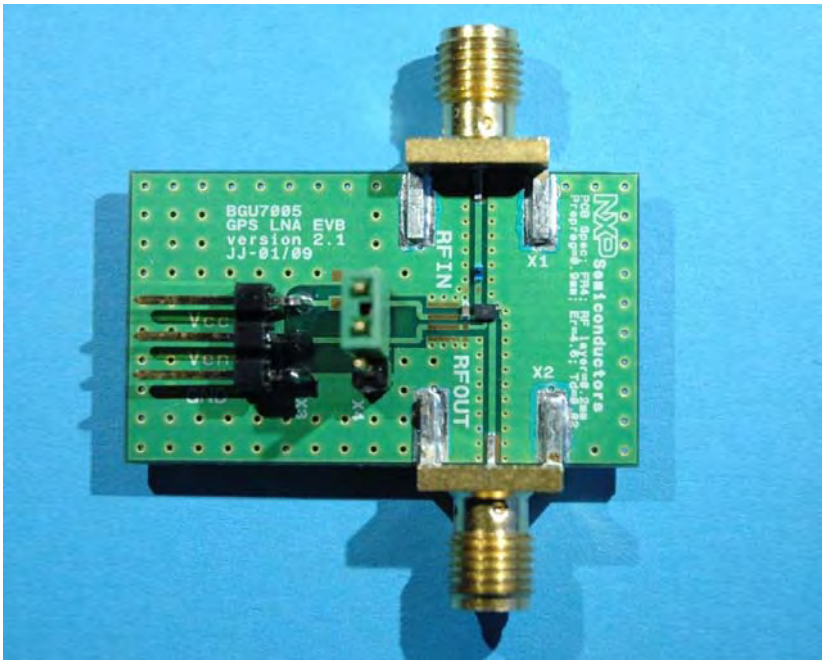

Fig 1. BGU7008 GPS LNA evaluation board (Same board is used for the BGU7008).

Note 1: Including PCB losses.

The BGU7004 and BGU7008 GPS LNA evaluation boards simplify the evaluation of the BGU7004 and BGU7008 GPS LNA's for the GPS applications. The evaluation boards enable testing of the device performance and require no additional support circuitry. The boards are fully assembled with the BGU7004 or BGU7008, including the input series inductor as well as a decoupling capacitor to optimize the performance. The boards are supplied with two SMA connectors for input and output connection to RF test equipment. The BGU7004 and BGU7008 can operate from a 1.5 V to 2.85 V single supply and consumes about 5 mA.

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Application Circuit

The circuit diagram and EVB-layout of the evaluation board are shown below. With jumper JU1 the enable pin can be controlled to either to V_{cc} or GND.

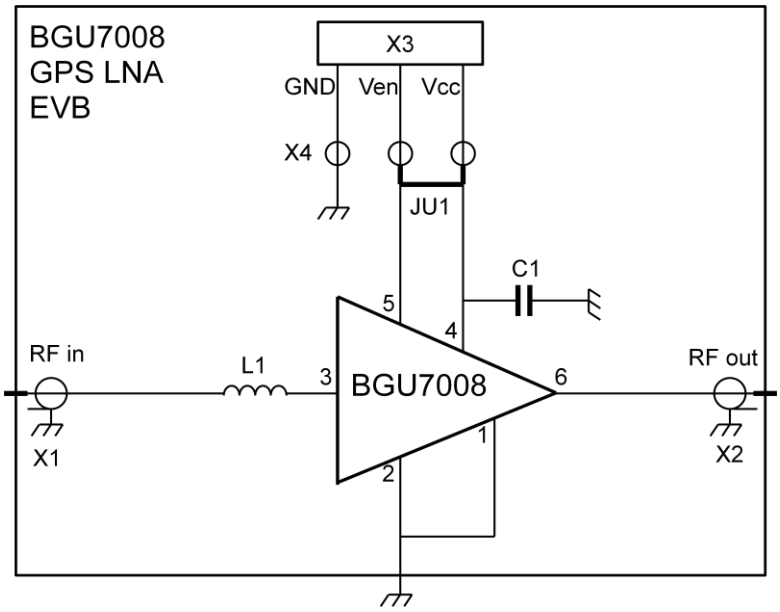

Fig 2. Circuit diagram of the BGU7008 evaluation board

Board Layout

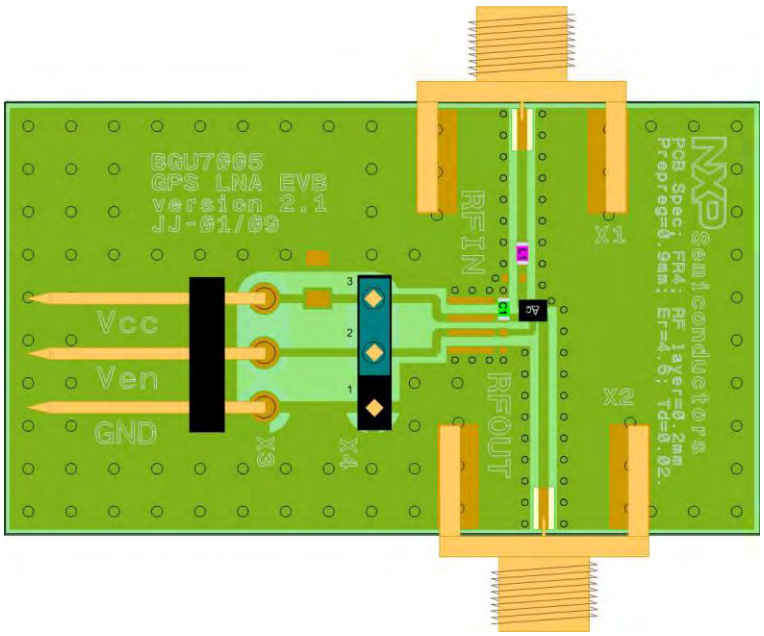

Fig 3. Printed circuit board lay-out of the BGU7008 GPS LNA evaluation board

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2. Out-of-Band Second- and Third-Order Intercept Points

At the average power levels of –130 dBm that have to be received by a GPS receiver, the system will not have in-band intermodulation problems caused by the GPS-signal itself. Strong out-of-band cell phone TX jammers however can cause linearity problems, and result in third-order intermodulation products in the GPS frequency band.

The Out-of-Band Second- and Third-Order Intercept Points (IIP2 and IIP3) are measured by a two-tone measurement where the carriers have been chosen is such a way that one of the following conditions is met:

1. Second-Order distortion: $f_{spur} = f_1 + f_2 \sim 1575$ MHz
2. Third Order Distortion: $f_{spur} = 2f_1 - f_2 \sim 1575$ MHz

With f_{spur} is around the center of the GPS band (~1575 MHz).

Figure 4 gives an overview of the frequency-spectrum caused by second- and third order intermodulation in a 2-Tone test.

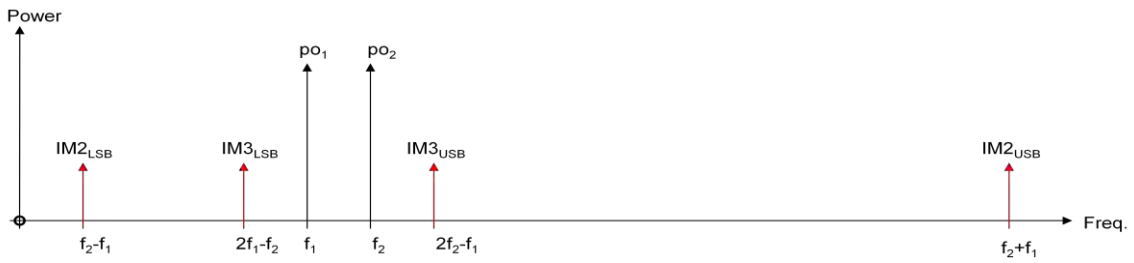

Fig 4. O-IIP3 at V_{cc} = 1.5 V, 1.8V and 2.85 V

Several cases can be found for which one of the above conditions is valid. In this document 4 test- cases will be discussed in more detail. Table 1 gives the four cases. The f_{spur}-component which falls inside the GPS-band is high-lighted.

Table 1 Test cases Out-of-Band Input Second- and Third-Order Intercept Point

Test Case	Signal Type f_1	Signal Type f_2	$IM2_{LSB}$-Comp.	$IM3_{LSB}$-Comp.	**Input Tone-1**	**Input Tone-2**	$IM3_{USB}$-Comp.	$IM2_{USB}$-Comp.
			f_2-f_1	$2f_1-f_2$	**f_1**	**f_2**	$2f_2-f_1$	f_2+f_1
			[MHz]	[MHz]	**[MHz]**	**[MHz]**	[MHz]	[MHz]
1	UMTS FDD	GSM1800	138	1575.42	**1713.42**	**1851.42**	1989.42	3564.84
2	LTE	LTE	0.6	786.8	**787.4**	**788**	788.6	1575.4
3	GSM900	BT/WLAN	1575.4	-750.8	**824.6**	**2400**	3975.4	3224.6
4	GSM1800	WLAN	3425	|-1575 |	**1850**	**5275**	8700	7125
5	GPS	GPS	1	1574	**1575**	**1576**	1577	3151

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The two carriers in the Table 1 (f_1 and f_2) can be seen as two TX jammers (for example in UMTS FDD and GSM1800 cell phone systems). One of the third-order products ($2f_1$-f_2) generated in the LNA due to amplifier third order non-linearity's can fall at the desired 1575.42 MHz frequency as follows:

$2f_1$-f_2=2(1713.42 MHz)-1851.42 MHz=1575.42 MHz (test-case 1).

This third-order product can influence the sensitivity of the GPS receiver drastically. So this third-order intermodulation product needs to be as low as possible, meaning the out-of-band intercept point must be as high as possible.

As an example Figure 5 shows the In- and Output-IP3 of the BGU7008 at different supply voltages (typical values). The results of all test-cases will be discussed later.

In Figure 5 the Pin-Pout-curve and third-order spur ($IM3_{LSB}$) and their trend lines are given. The point where both dashed trend lines meet gives the in- and output IP3.

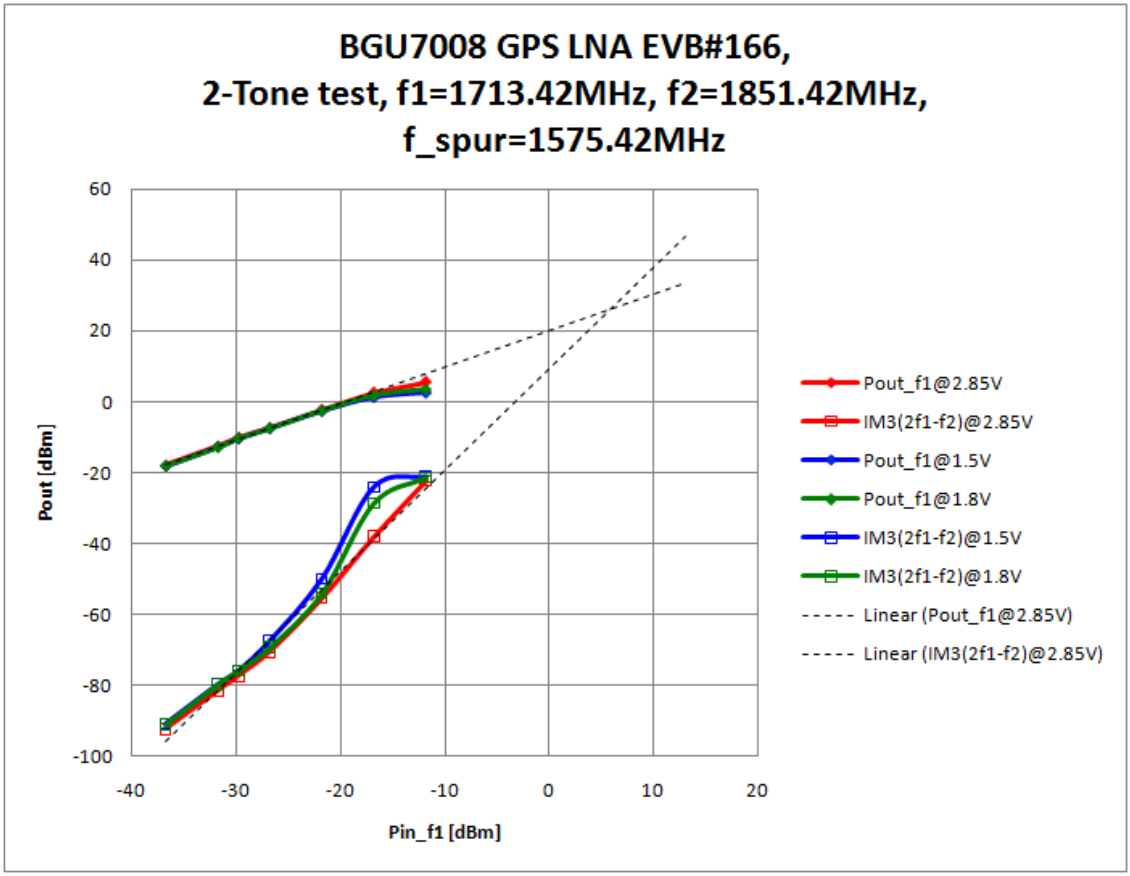

Fig 5. O-IIP3 at V_{cc} = 1.5 V, 1.8 V and 2.85 V

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The formula's to calculate the IP2 and IP3 are taken from literature and given below:

Formula's IP2:

f_1:	$OIP2_{LSB} = po_1 + po_2 - IM2_{LSB}$	[dBm]	(1)
f_2:	$OIP2_{USB} = po_2 + po_1 - IM2_{USB}$	[dBm]	(2)
	$IIP_2 = OIP2_{LSB} - Gp_1$	[dBm]	(3)
	$IIP_2 = OIP2_{USB} - Gp_2$	[dBm]	(4)
With	Gp_1 = power gain = $po_1 - pi_1$	[dB]	(5)
	Gp_2 = power gain = $po_2 - pi_2$	[dB]	(6)

Formula's IP3:

f_1:	$OIP3_{LSB} = po_1 + (po_2 - IM3_{LSB})/2$	[dBm]	(7)
f_2:	$OIP3_{USB} = po_2 + (po_1 - IM3_{USB})/2$	[dBm]	(8)
	$IIP3_{LSB} = OIP3_{USB} - Gp_1$	[dBm]	(9)
	$IIP3_{USB} = OIP3_{LSB} - Gp_2$	[dBm]	(10)

Note: The in- and output powers in the formula's are for in- and output-levels of the DUT. Therefore the cable losses and RF-Combiner losses have to be measured. These losses can be used to correct the measured power levels.

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3. Required Equipment

In order to measure the evaluation board the following is necessary:

- ✓ DC Power Supply up to 30 mA at 1.5 V to 2.85 V;
- ✓ Two RF signal generators capable of generating an RF signal at the jammer frequencies f_1 and f_2 listed in Table 1;
- ✓ An RF spectrum analyzer that covers at least the operating frequency of 1575 MHz as well as a few of the harmonics, so up to 6 GHz should be sufficient;
- ✓ Amp meter to measure the supply current (optional);
- ✓ RF-Combiner;
- ✓ Proper RF cables.

The table below gives an overview of the equipment used for the 2 Tone test. It can be used as an example which equipment to use.

Table 2 Equipment used for 2-Tone test

Equipment	Type	Settings
RF-Generator f_1	R&S SMA 100A (9 kHz…6 GHz)	
RF-Generator f_2	R&S SMR20 (10 MHz…20 GHz)	
Power Splitter/Combiner	Agilent 11667B (DC-26.5 GHz)	
Spectrum Analyzer	HP8595E	Res. BW: 10 kHz Video BW: 10 kHz (AUTO) Video AVG: ON (100x) Pref: -20 dBm Att.: 10 dB Fcenter Fmeas Fspan: 100 kHz Tweep: Auto

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4. Connections and setup

The BGU7004 and BGU7008 GPS LNA evaluation boards are fully assembled and tested. Figure 6 gives an overview of the 2-Tone test setup. Please follow the steps below for a step-by-step guide to operate the evaluation board and testing the device functions.

1. Measure the cable- and RF-Combiner losses at the frequencies which are used during the evaluation to (see Table 1). These losses are used to correct the measured power levels.
2. Connect the DC power supply to the Vcc, and GND terminals. Set the power supply to the desired supply voltage, between 1.5 V and 2.85 V, but never exceed 3.1 V as it might damage the BGU7008.
3. Jumper JU1 is connected between the Vcc terminal of the evaluation board and the Ven pin of the BGU7004 or BGU7008.

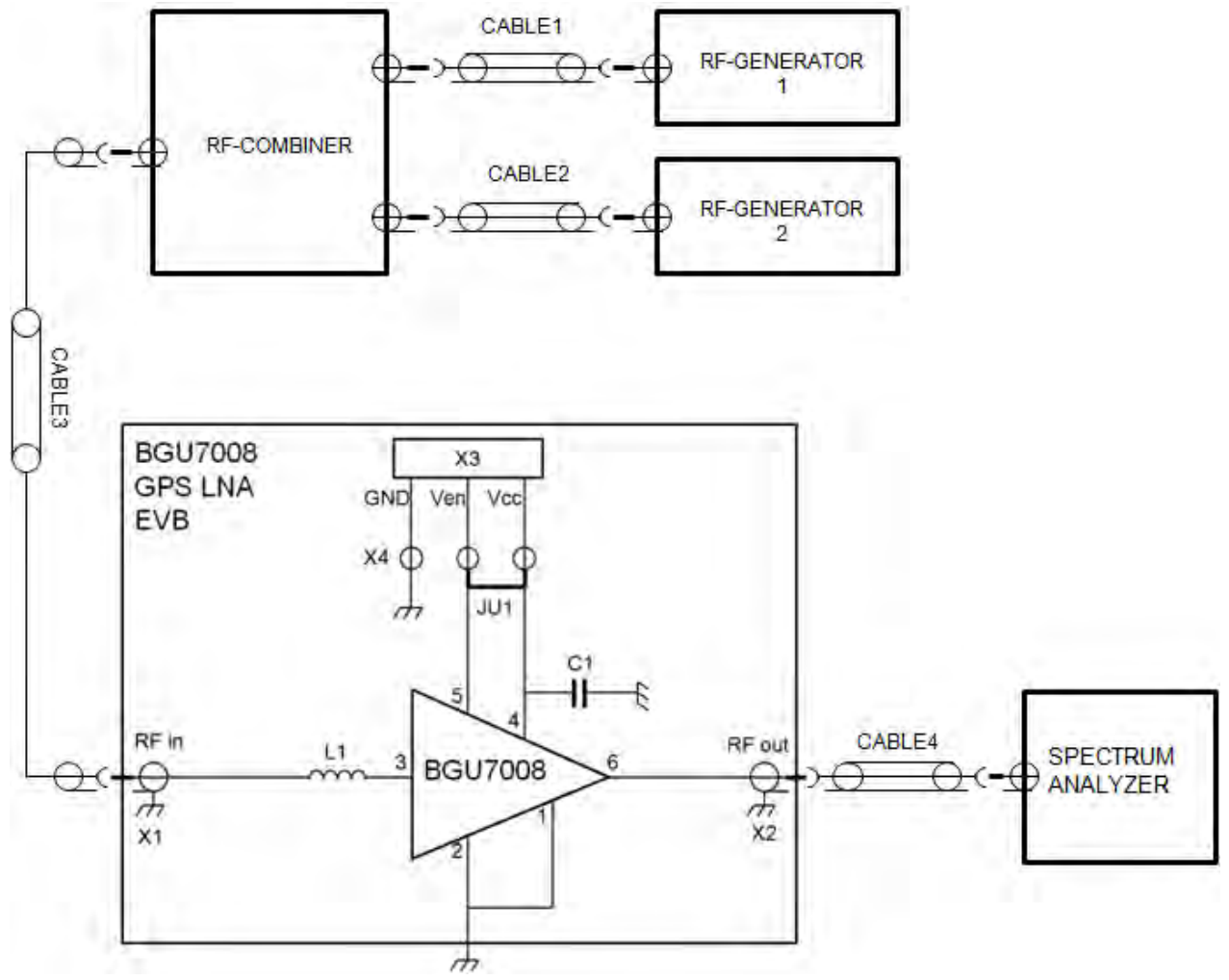

Fig 6. 2-Tone Test Setup.

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4. Connect the RF signal generators via the RF-combiner to the RF input and the spectrum analyzer to the RF output of the evaluation board (See Figure 6). Do not turn on the RF output of the Signal generators yet, set it to -30 dBm output power at f_1 and f_2 (see Table 1), set the spectrum analyzer at f_{spur} (~1575 MHz, see Table 1) center frequency and a reference level of -20 dBm.
5. Turn on the DC power supply and it should read approximately 5 mA.
6. Enable the RF output of the generators; the spectrum analyzer displays a tone of around –95 dBm at f_{spur} (~1575 MHz, see Table 1).
7. Increase the RF output-level of the Signal generators of f_1 and f_2 from -30 dBm to approx. -5 dBm and check the spectrum analyzer level at f_{spur} (~1575 MHz, see Table 1).

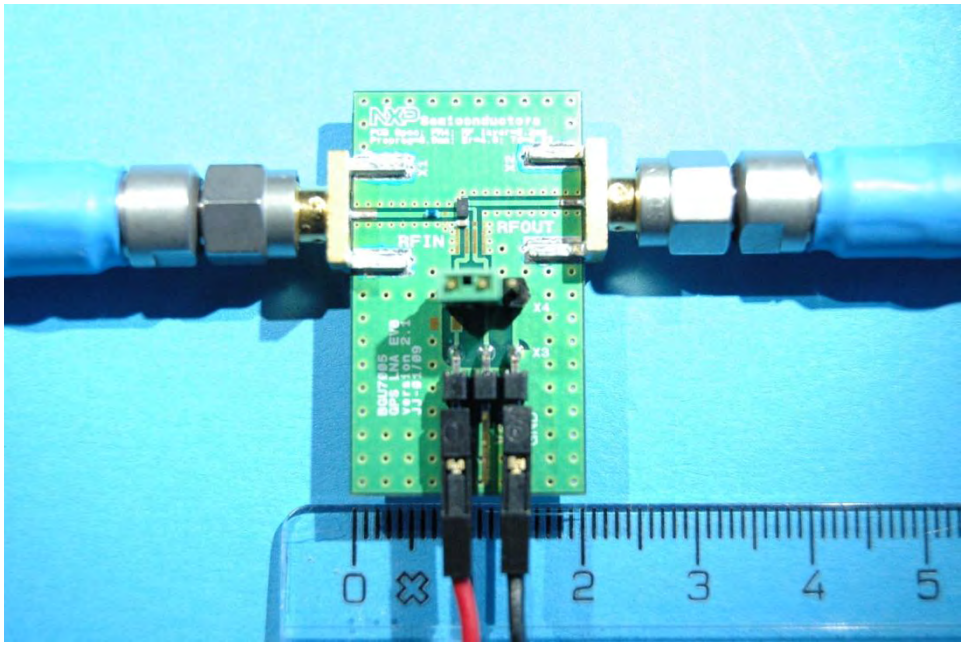

Fig 7. BGU7008 evaluation board including its connections

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5. Typical Evaluation Board results

5.1 Test-Case 1

Generators: f_1 = 1713.42 MHz, f_2 = 1851.42 MHz

Spectrum Analyzer: Third Order Product f_{spur} = 1575.42 MHz

Figure 8 gives measured results of 2-Tone test for BGU7008 and BGU7004 EVB's:

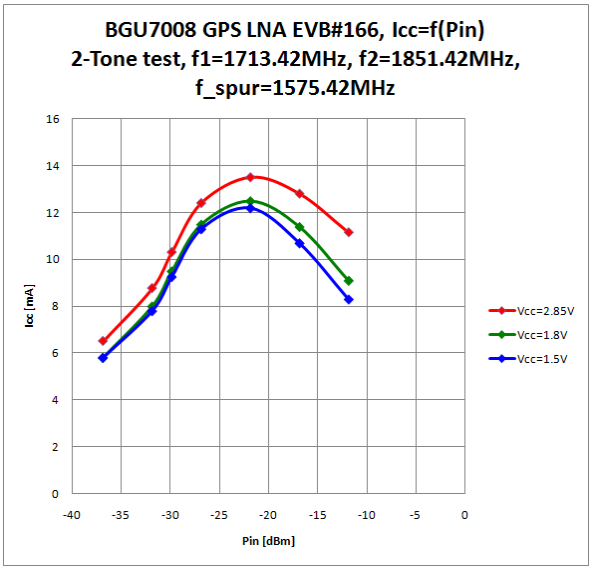

Fig 8. Tone Test Results Test-Case 1, BGU7008.

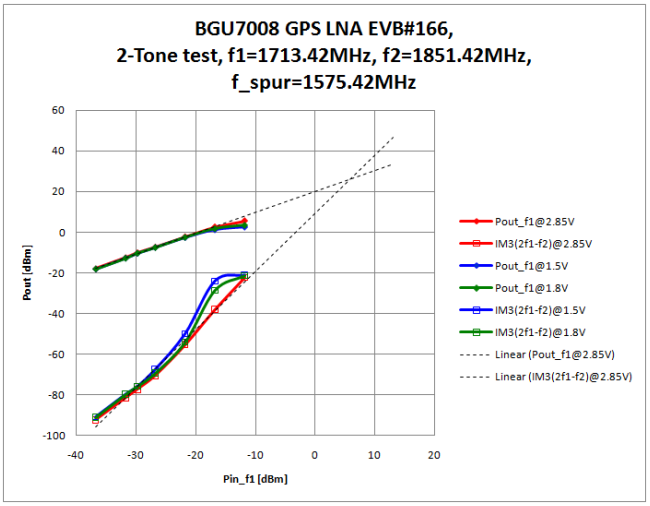

Fig 9. 2-Tone Test Results Test-Case 1, BGU7008

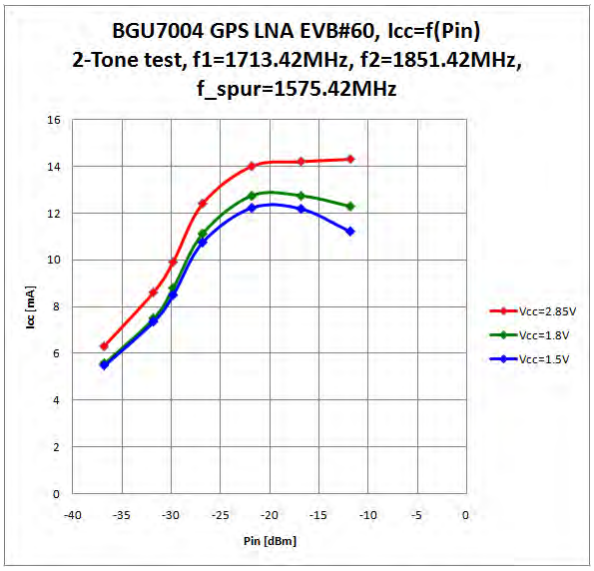

Fig 10. Tone Test Results Test-Case 1, BGU7004

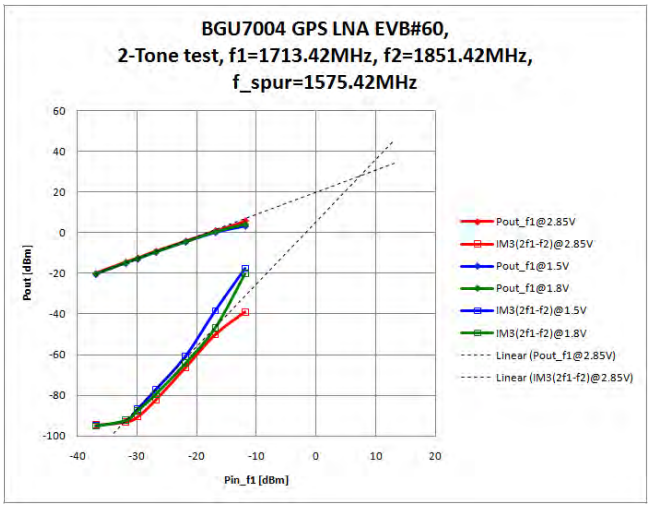

Fig 11. 2-Tone Test Results Test-Case 1, BGU7004

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Table 3 Results Test case 1: Third-Order Intercept Points, Temp = 25 °C.

				DUT	DUT	DUT	DUT	DUT	DUT
		Vsup	Isup	Pin_f_1	Pout_f_1	Gp_DUT_f_1	IM3_$(2f_1-f_2)$	OIP3_$(2f_1-f_2)$	IIP3_$(2f_1-f_2)$
Type	EVB#	[V]	[mA]	[dBm]	[dBm]	[dB]	[dBm]	[dBm]	[dBm]
BGU7008	166	1.5	9.26	-29.84	-10.41	19.43	-75.90	21.59	2.16
BGU7008	166	1.8	9.5	-29.84	-10.30	19.54	-75.80	21.70	2.16
BGU7008	166	2.85	10.3	-29.84	-10.10	19.74	-77.30	22.75	3.01
BGU7004	60	1.5	8.5	-29.84	-12.90	16.94	-86.70	23.30	6.36
BGU7004	60	1.8	8.8	-29.84	-12.70	17.14	-87.60	24.00	6.86
BGU7004	60	2.85	9.9	-29.84	-12.40	17.44	-90.50	25.95	8.51

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5.2 Test-Case 2

Generators: f_1 = 787.4 MHz, f_2 = 788 MHz

Spectrum Analyzer: Second Order Product f_{spur} = 1575.4 MHz

The figures below give the measured results of the 2-Tone test for BGU7008 and BGU7004 EVB's:

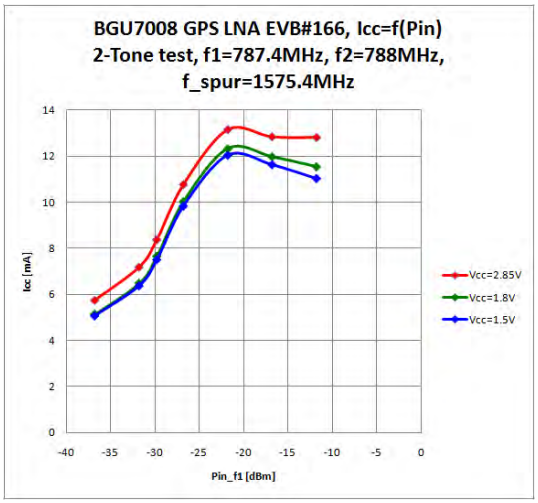

Fig 12. Tone Test Results Test-Case 2, BGU7008.

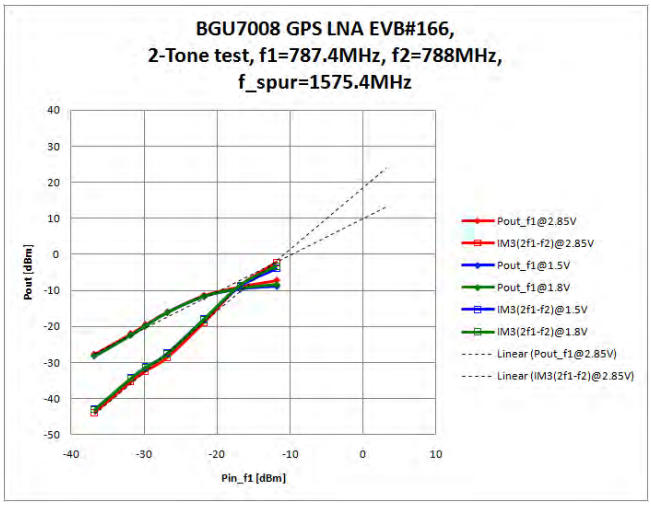

Fig 13. 2-Tone Test Results Test-Case 2, BGU7008

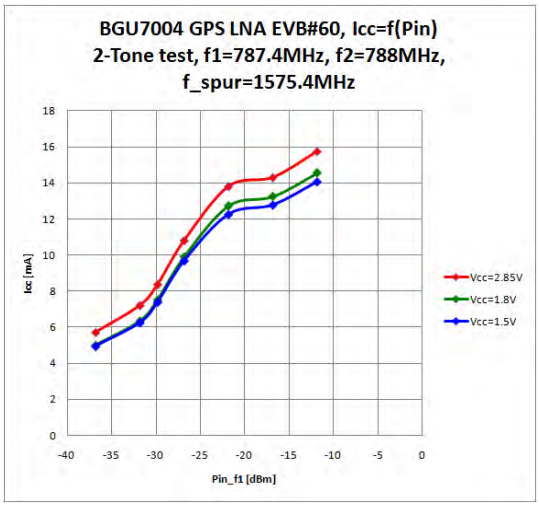

Fig 14. Tone Test Results Test-Case 2, BGU7004

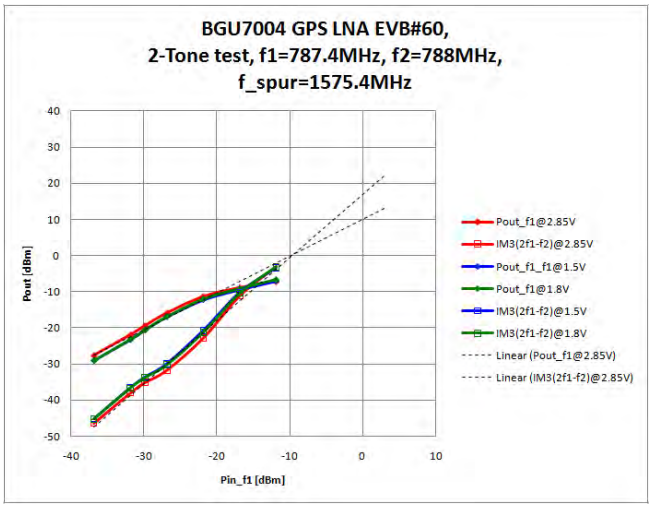

Fig 15. 2-Tone Test Results Test-Case 2, BGU7004

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Table 4 Results Test case 2: Second Order Intercept Points, Temp = 25 °C.

				DUT	DUT	DUT	DUT	DUT	DUT
		Vsup	Isup	Pin_f_1	Pout_f_1	Gp_DUT_f_1	IM2_(f_2+f_1)	OIP2_(f_2+f_1)	IIP2_(f_2+f_1)
Type	EVB#	[V]	[mA]	[dBm]	[dBm]	[dB]	[dBm]	[dBm]	[dBm]
BGU7008	166	1.5	7.5	-29.84	-19.80	10.04	-31.25	-8.35	-18.39
BGU7008	166	1.8	7.65	-29.84	-19.80	10.04	-31.36	-8.24	-18.28
BGU7008	166	2.85	8.37	-29.84	-19.45	10.39	-32.45	-6.45	-16.84
BGU7004	60	1.5	7.39	-29.84	-20.65	9.19	-33.65	-7.65	-16.84
BGU7004	60	1.8	7.52	-29.84	-20.60	9.24	-33.84	-7.36	-16.60
BGU7004	60	2.85	8.36	-29.84	-20.30	9.54	-35.10	-5.50	-15.04

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5.3 Test-Case 3

Generators: f_1 = 824.6 MHz, f_2 = 2400 MHz

Spectrum Analyzer: Second Order Product f_{spur} = 1575.4 MHz

The figures below give the measured results of the 2-Tone test for BGU7008 and BGU7004 EVB's:

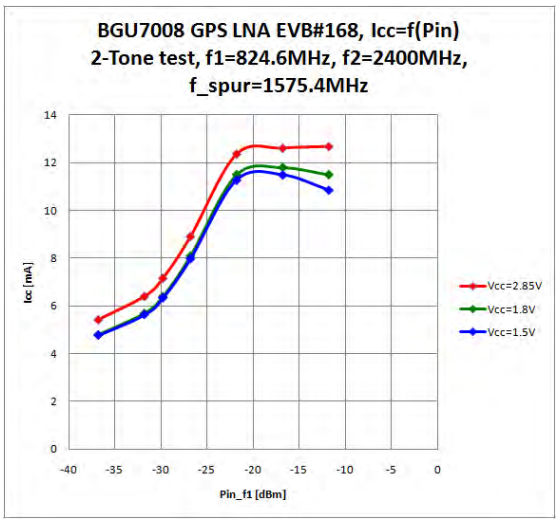

Fig 16. Tone Test Results Test-Case 3, BGU7008.

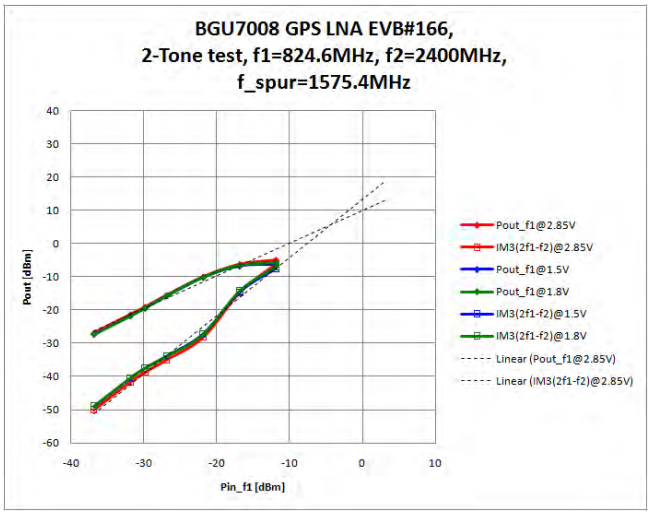

Fig 17. 2-Tone Test Results Test-Case 3, BGU7008

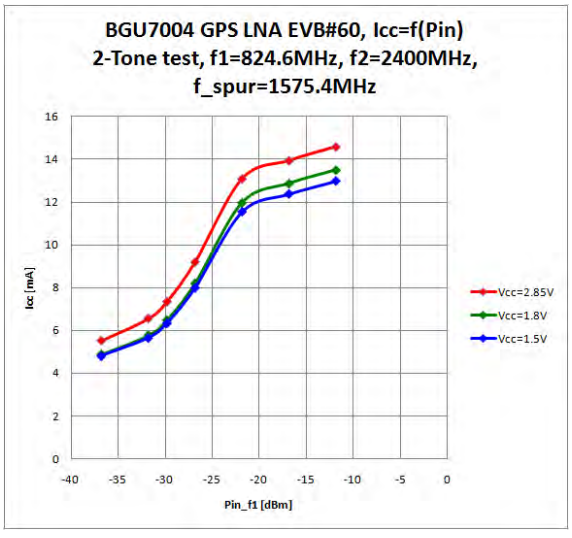

Fig 18. Tone Test Results Test-Case 3, BGU7004

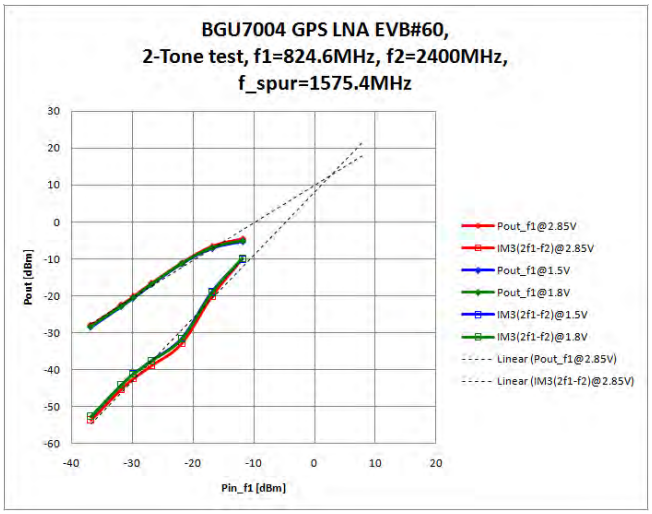

Fig 19. 2-Tone Test Results Test-Case 3, BGU7004

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Table 5 Results Test case 3: Second Order Intercept Points, Temp = 25 °C.

				DUT	DUT	DUT	DUT	DUT	DUT
		Vsup	Isup	Pin_f_1	Pout_f_1	Gp_DUT_f_1	IM2_(f_2-f_1)	OIP2_(f_2-f_1)	IIP2_(f_2-f_1)
Type	EVB#	[V]	[mA]	[dBm]	[dBm]	[dB]	[dBm]	[dBm]	[dBm]
BGU7008	166	1.5	6.64	-29.84	-19.50	10.34	-37.45	1.28	-9.06
BGU7008	166	1.8	6.75	-29.84	-19.45	10.39	-37.52	1.56	-8.83
BGU7008	166	2.85	7.48	-29.84	-19.11	10.73	-38.71	3.38	-7.35
BGU7004	60	1.5	6.33	-29.84	-20.60	9.24	-41.10	1.20	-8.04
BGU7004	60	1.8	6.48	-29.84	-20.50	9.34	-41.16	1.46	-7.88
BGU7004	60	2.85	7.34	-29.84	-20.10	9.74	-42.40	3.50	-6.24

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5.4 Test-Case 4

Generators: f_1 = 1850 MHz, f_2 = 5275 MHz

Spectrum Analyzer: Third Order Product f_{spur} = 1575 MHz

The figures below give the measured results of the 2-Tone test for BGU7008 and BGU7004 EVB's:

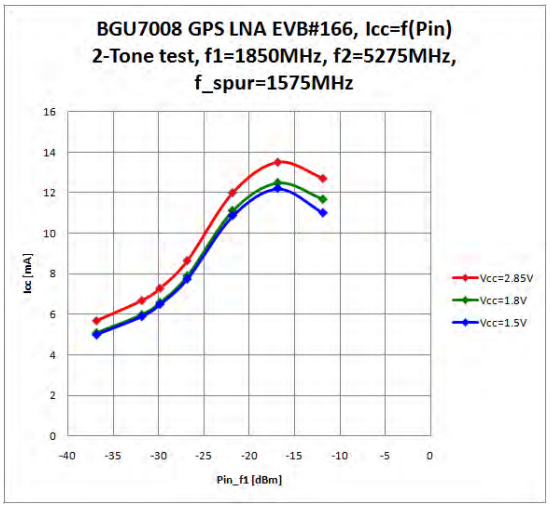

Fig 20. Tone Test Results Test-Case 4, BGU7008.

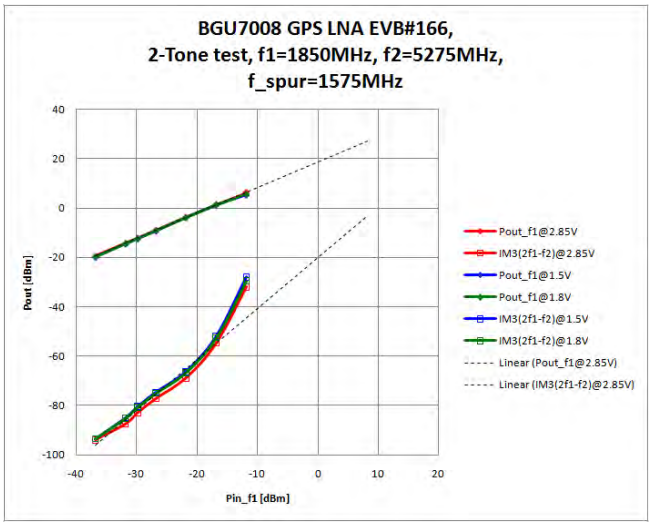

Fig 21. 2-Tone Test Results Test-Case 4, BGU7008

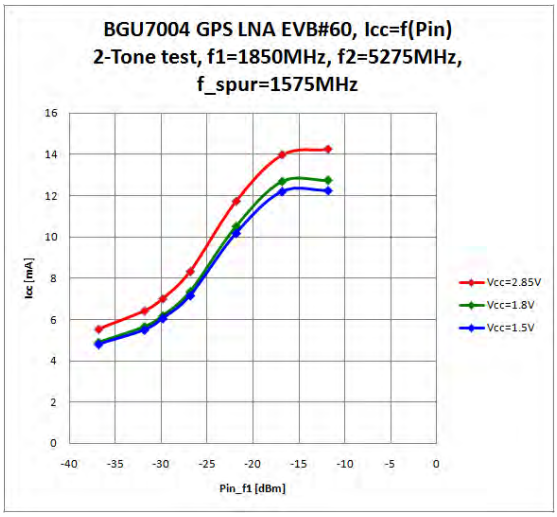

Fig 22. Tone Test Results Test-Case 4, BGU7004

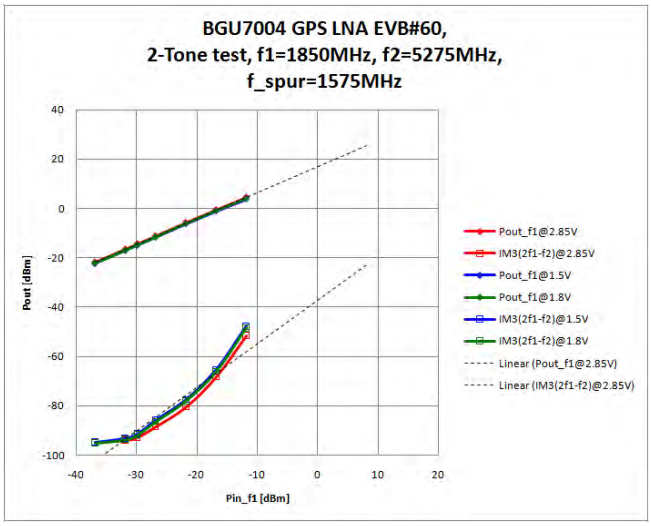

Fig 23. 2-Tone Test Results Test-Case 4, BGU7004

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Table 6 Results Test case 4: Third Order Intercept Points, Temp = 25 °C.

				DUT	DUT	DUT	DUT	DUT	DUT
		Vsup	Isup	Pin_f_1	Pout_f_1	Gp_DUT_f_1	IM3_$(2f_1-f_2)$	OIP3_$(2f_1-f_2)$	IIP3_$(2f_1-f_2)$
Type	EVB#	[V]	[mA]	[dBm]	[dBm]	[dB]	[dBm]	[dBm]	[dBm]
BGU7008	166	1.5	6.5	-29.85	-12.40	17.45	-80.50	8.02	-9.44
BGU7008	166	1.8	6.6	-29.85	-12.30	17.55	-80.70	8.25	-9.30
BGU7008	166	2.85	7.3	-29.85	-12.10	17.75	-83.00	9.60	-8.15
BGU7004	60	1.5	6.05	-29.85	-14.84	15.01	-91.30	9.71	-5.30
BGU7004	60	1.8	6.18	-29.85	-14.68	15.17	-91.80	10.07	-5.10
BGU7004	60	2.85	7	-29.85	-14.29	15.56	-92.80	10.96	-4.60

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5.5 Test-Case 5

Generators: f_1 = 1575 MHz, f_2 = 1576 MHz

Spectrum Analyzer: Third Order Product f_{spur} = 1574 MHz

The figures below give the measured results of the 2-Tone test for BGU7008 and BGU7004 EVB's:

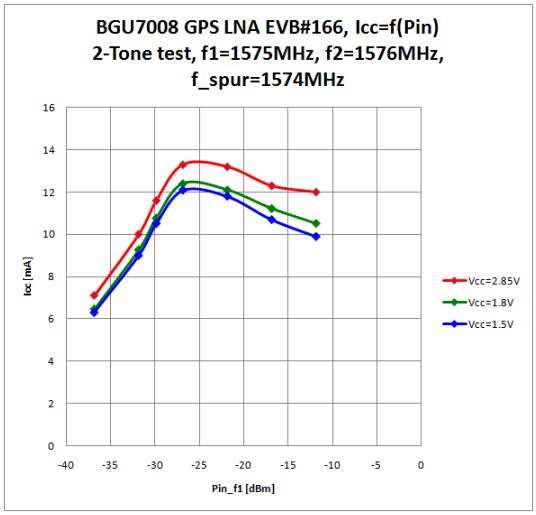

Fig 24. Tone Test Results Test-Case 5, BGU7008.

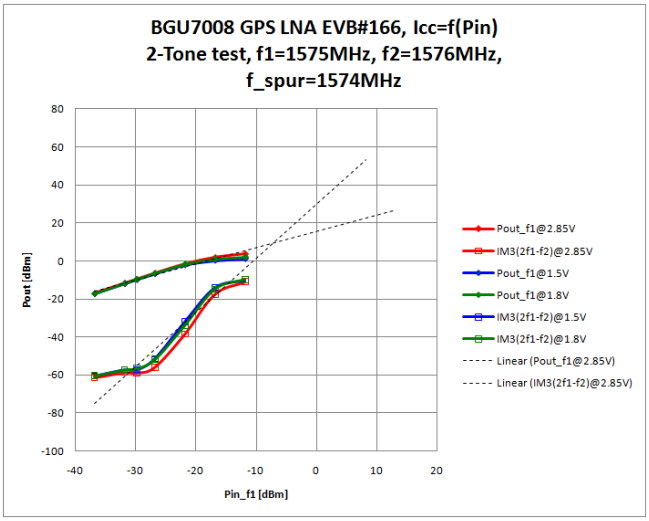

Fig 25. 2-Tone Test Results Test-Case 5, BGU7008

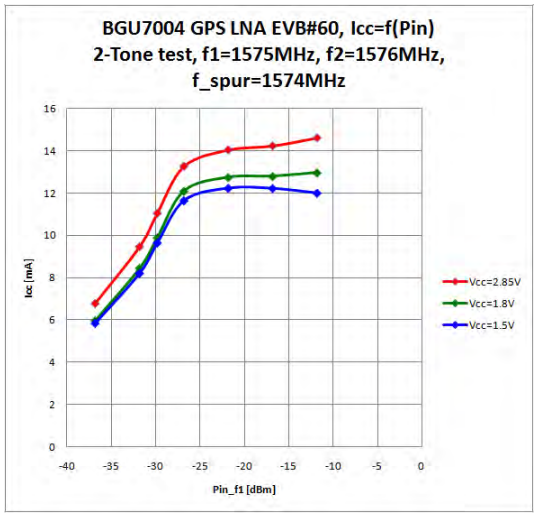

Fig 26. Tone Test Results Test-Case 5, BGU7004

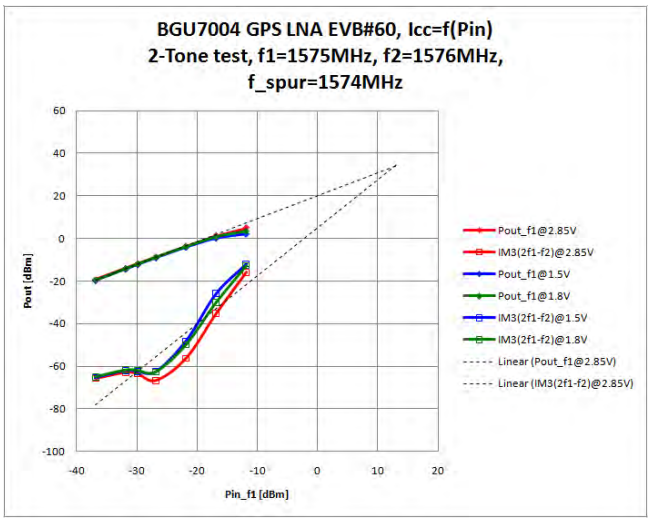

Fig 27. 2-Tone Test Results Test-Case 5, BGU7004

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Table 7 Results Test case 5: Third Order Intercept Points, Temp = 25 °C.

				DUT	DUT	DUT	DUT	DUT	DUT
		Vsup	Isup	Pin_f_1	Pout_f_1	Gp_DUT_f_1	IM3_$(2f_1-f_2)$	OIP3_$(2f_1-f_2)$	IIP3_$(2f_1-f_2)$
Type	EVB#	[V]	[mA]	[dBm]	[dBm]	[dB]	[dBm]	[dBm]	[dBm]
BGU7008	166	1.5	10.52	-29.84	-9.81	20.03	-57.24	13.80	-6.23
BGU7008	166	1.8	10.77	-29.84	-9.72	20.12	-56.60	13.61	-6.52
BGU7008	166	2.85	11.6	-29.84	-9.65	20.19	-58.90	14.85	-5.34
BGU7004	60	1.5	9.64	-29.84	-12.30	17.54	-62.50	12.70	-4.84
BGU7004	60	1.8	9.9	-29.84	-12.05	17.79	-62.00	12.80	-4.99
BGU7004	60	2.85	11.05	-29.84	-11.85	17.99	-63.50	13.85	-4.14

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