

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14

### About this document

#### Scope and purpose

This application note describes Infineon's SP4T Diversity Antenna Switch with GPIO Interface: BGS14GA14 as switch for Mobile phones in different RF FE applications such as diversity or band selection switch.

1. This application note documents the behavior of BGS14GA14 for different LTE bands (Band 1, 2, 5, 7 and Band 13).
2. The BGS14GA14 is used in this document.
3. General purpose wideband RF switch for diversity application and as band selection switch.
4. Key Parameters:
  - 4 high-linearity TRx paths with power handling capability of up to 30 dBm
  - Low insertion loss
  - Low harmonic generation
  - High port-to-port-isolation
  - Suitable for Edge / CDMA2000 / LTE / WCDMA applications

BGS14GA14 is part of the family BGS1xGA14:

- BGS13GA14: Single Pole Three Throw
- BGS14GA14: Single Pole Four Throw
- BGS15GA14: Single Pole Five Throw
- BGS16GA14: Single Pole Six Throw
- BGS17GA14: Single Pole Seven Throw
- BGS18GA14: Single Pole Eight Throw

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

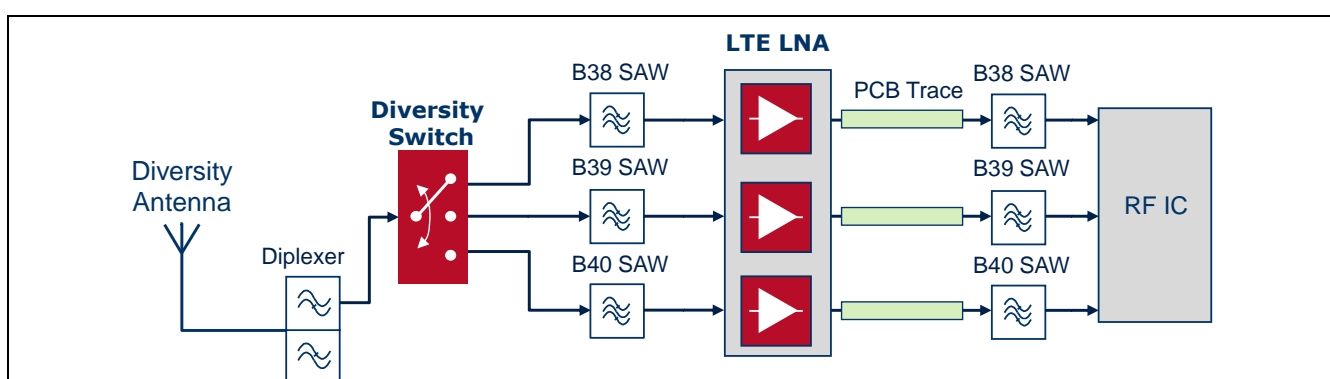
## 1 Introduction

Infineon's RF CMOS switches are the first on the market to be based purely on standard industrial CMOS processes that offer low insertion loss, high isolation and low harmonics generation for high-volume production. They are widely used for band selection/switching or diversity switching at the antenna or different RF paths within the RF Front-End (FE).

The BGS14GA14 RF MOS switch is specifically designed for cell phone and mobile applications. Any of the 4 ports can be used as termination of the diversity antenna handling up to 30 dBm.

This SP4T offers low insertion loss and high robustness against interferer signals at the antenna port and low harmonic generation in termination mode. The on-chip controller integrates CMOS logic and level shifters, driven by control inputs from 1.35 V to VDD. The BGS14GA14 RF Switch is manufactured in Infineon's patented MOS technology, offering the performance of GaAs with the economy and integration of conventional CMOS including the inherent higher ESD robustness. The device has a very small size of only 2x2 mm<sup>2</sup> and a maximum height of 0.6 mm.

The recent trend of smartphone and tablet users to download more and more data anytime and anywhere increases the demand for more bandwidth and for an additional receiver channel called the diversity path. To select the right receive band, a diversity switch with low insertion loss and excellent RF performance is one method of choice. Nowadays, diversity switches covering up to 7 or more different UMTS/LTE bands are becoming more and more popular in smartphones and tablets (Overview LTE Bands).



**Figure 1** Example of TD-LTE band for diversity path

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Introduction

**Table 1 Overview LTE Bands**

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	
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	Mid-Band	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	
15		reserved	reserved	FDD	
16		reserved	Reserved	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	Mid-Band	1447.9-1462.9 MHz	1495.9-1510.9 MHz	FDD	
22	High-Band	3410-3500 MHz	3510-3600 MHz	FDD	
23	Mid-Band	2000-2020 MHz	2180-2200 MHz	FDD	
24	Mid-Band	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	
30	High-Band	2305-2315 MHz	2350-2360 MHz	FDD	
31	Low-Band	452.5-457.5 MHz	462.5-467.5MHz	FDD	
32	Mid-Band	N/A	1452-1496 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	

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Introduction

**Table 1**      **Overview LTE Bands**

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	High-Band	3400-3600 MHz	TDD	
43	High-Band	3600-3800 MHz	TDD	
44	Low-Band	703-803 MHz	TDD	
46	High-Band	5150-5925 MHz	TDD	

*Note: FDD: Frequency Division Duplexing; TDD: Time Division Duplexing*

## 2 BGS14GA14 Features

### 2.1 Main Features

- 4 high-linearity, interchangeable RX ports
- Low insertion loss
- Low harmonic generation
- High port-to-port-isolation
- Suitable for Edge / C2K / LTE / WCDMA Applications
- 0.1 to 6 GHz coverage
- No decoupling capacitors required if no DC applied on RF lines
- On chip control logic including ESD protection
- General Purpose Input-Output (GPIO) Interface
- Small form factor 2.0mm x 2.0mm
- No power supply blocking required
- High EMI robustness
- RoHS and WEEE compliant package

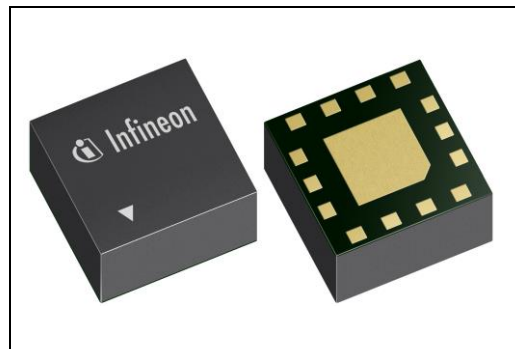


Figure 2 BGS14GA14

### 2.2 Functional Diagram

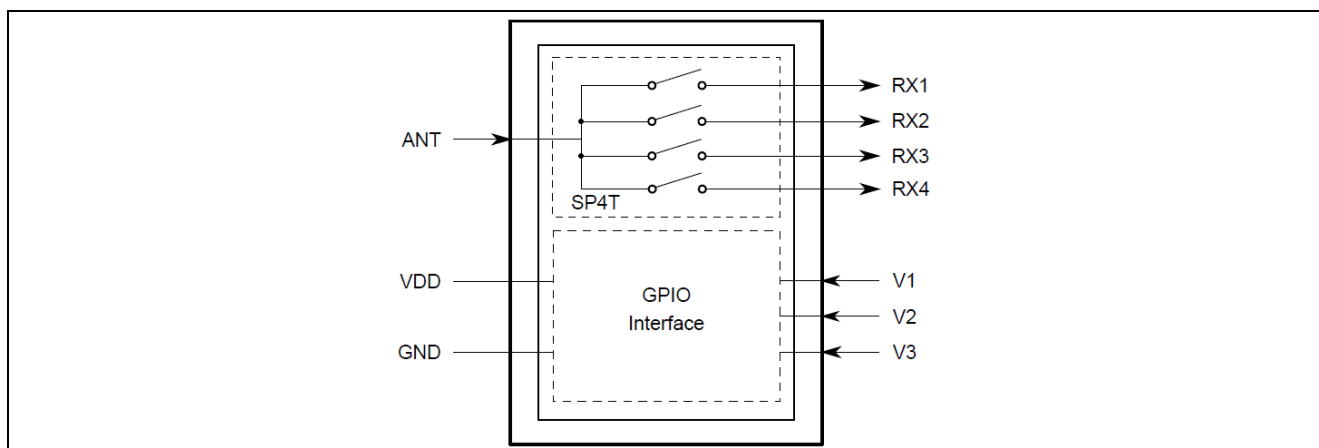


Figure 3 Equivalent Circuit Block diagram of BGS14GA14



# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### BGS14GA14 Features

## 2.3 Signal Description

**Table 2 Pin Configuration of BGS14GA14**

Pin No.	Name	Pin Type	Function
0	GND	GND	RF Ground; die pad
1	NC		Not connected
2	RX3	I/O	RX port 3
3	RX1	I/O	RX port 1
4	VDD	PWR	V <sub>DD</sub> supply
5	V3	I	GPIO control pin
6	V2	I	GPIO control pin
7	V1	I	GPIO control pin
8	NC		Not connected
9	RX2	I/O	RX port 2
10	RX2	I/O	RX port 4
11	NC		Not connected
12	NC		Not connected
13	ANT	I/O	Antenna Port
14	NC		Not connected

**Table 3 Modes of Operation: Truth Table of BGS14GA14**

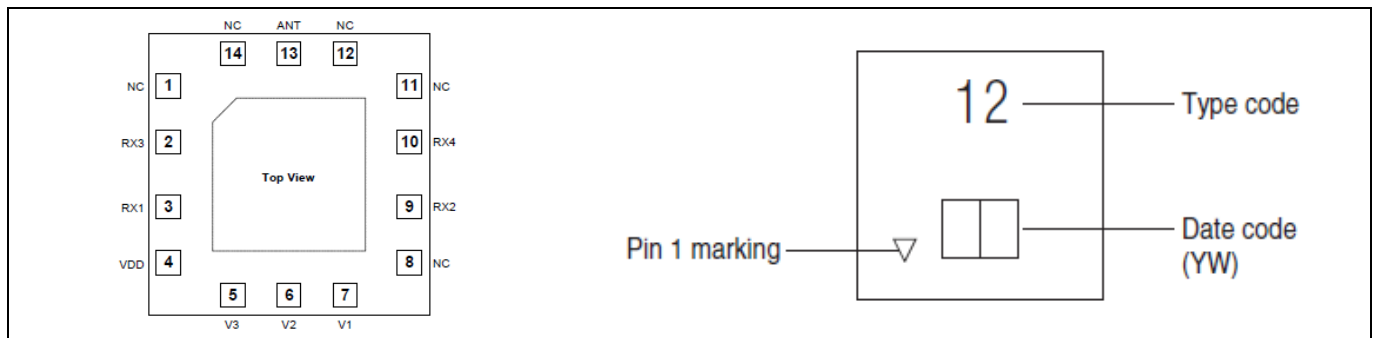
		Control Inputs		
State	Mode	V1	V2	V3
1	RX1-ANT	0	0	0
2	RX2-ANT	0	0	1
3	RX3-ANT	0	1	0
4	RX4-ANT	0	1	1
5	Isolation	1	0	0
6	50Ω	1	0	1
7	Shutdown	1	1	1
1	RX1-ANT	0	0	0

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### BGS14GA14 Features



**Figure 4** Package and pin connections (top view) of BGS14GA14

## 3 Application Circuit and Performance Overview

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

<b>Device:</b>	<b>BGS14GA14</b>
<b>Application:</b>	<b>SP4T Diversity Antenna Switch with GPIO Interface</b>
<b>PCB Marking:</b>	<b>BGS1xGA14</b>

### 3.1 Summary of Measurement Results

All measurement results of this application note are measured with a typical device of the BGS14GA14 on an application board. The measurement procedure is shown in chapters Intermodulation, Harmonic Generation and Evaluation Board and Layout Information including the needed de-embedding for s-Parameter measurements.

The small signal characteristics are measured at 25 °C, -5 dBm  $P_{in}$ , 2.8V  $V_{dd}$ , 1.8V  $V_{crlt}$  up to 4GHz with a Network Analyzer connected to an automatic multiport switch box in single ended mode.

In the following tables and graphs the most important RF parameter of the BGS14GA14 are shown. The markers are set to the most important frequencies of the WCDMA and LTE systems.

## 3.2 Insertion Loss

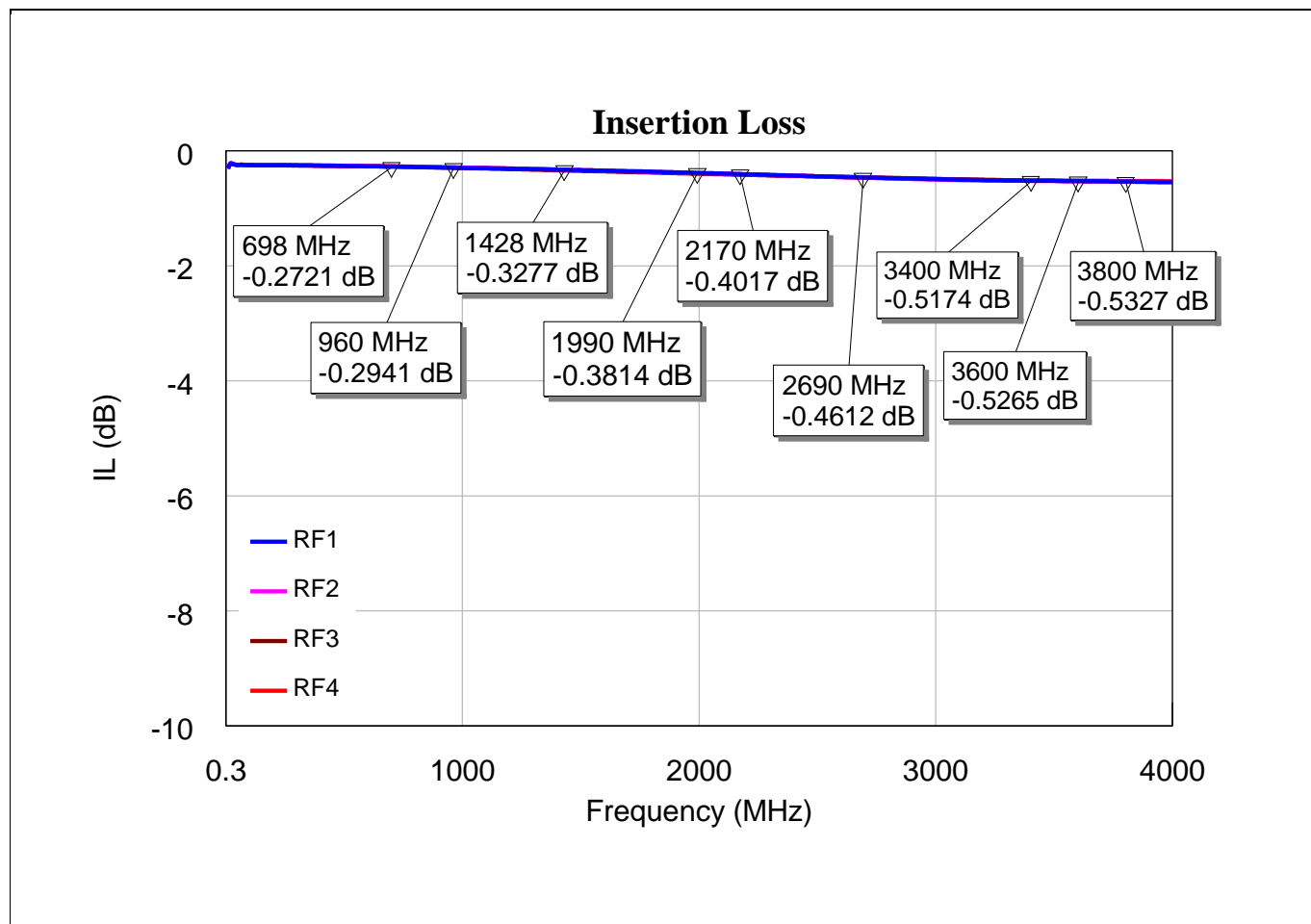


Figure 5 Insertion Loss in dB up to 3GHz

Table 4 Forward Transmission in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF1	0.27	0.29	0.33	0.38	0.40	0.46	0.52	0.52	0.53
RF2	0.27	0.29	0.33	0.39	0.41	0.47	0.52	0.53	0.53
RF3	0.27	0.29	0.34	0.40	0.41	0.46	0.52	0.52	0.53
RF4	0.27	0.29	0.33	0.39	0.41	0.46	0.51	0.52	0.52

## 3.3 Antenna Return Loss

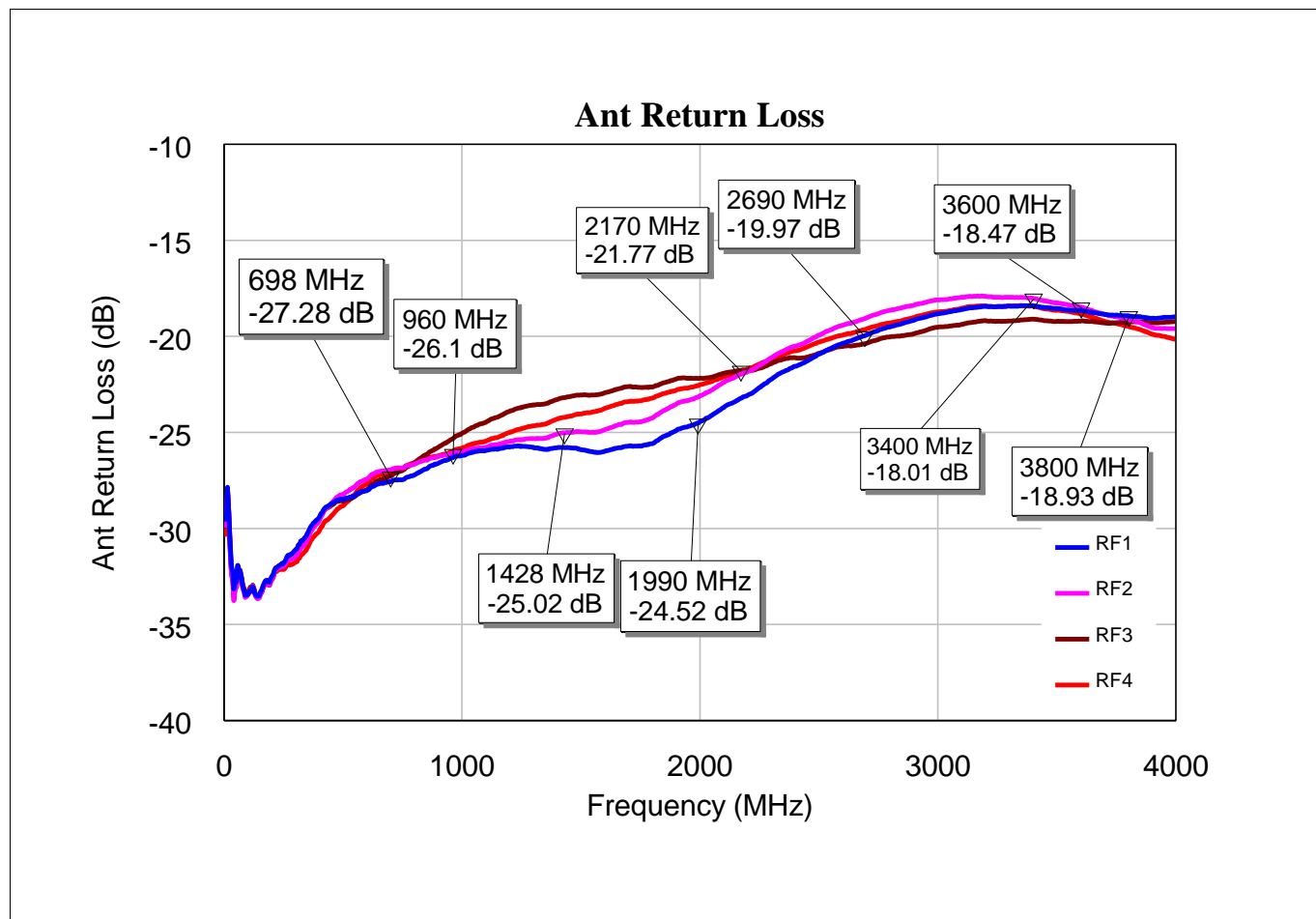


Figure 6 RF matching @ Ant Port in dB

Table 5 Insertion Loss in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF1	27.56	26.33	25.78	24.52	23.23	19.97	18.40	18.66	18.93
RF2	26.96	26.10	25.02	23.17	21.98	19.08	18.01	18.47	19.11
RF3	27.28	25.34	23.19	22.19	21.77	20.39	19.10	19.20	19.25
RF4	27.10	26.00	24.22	22.57	21.81	19.65	18.43	18.83	19.48

## 3.4 Port Return Loss

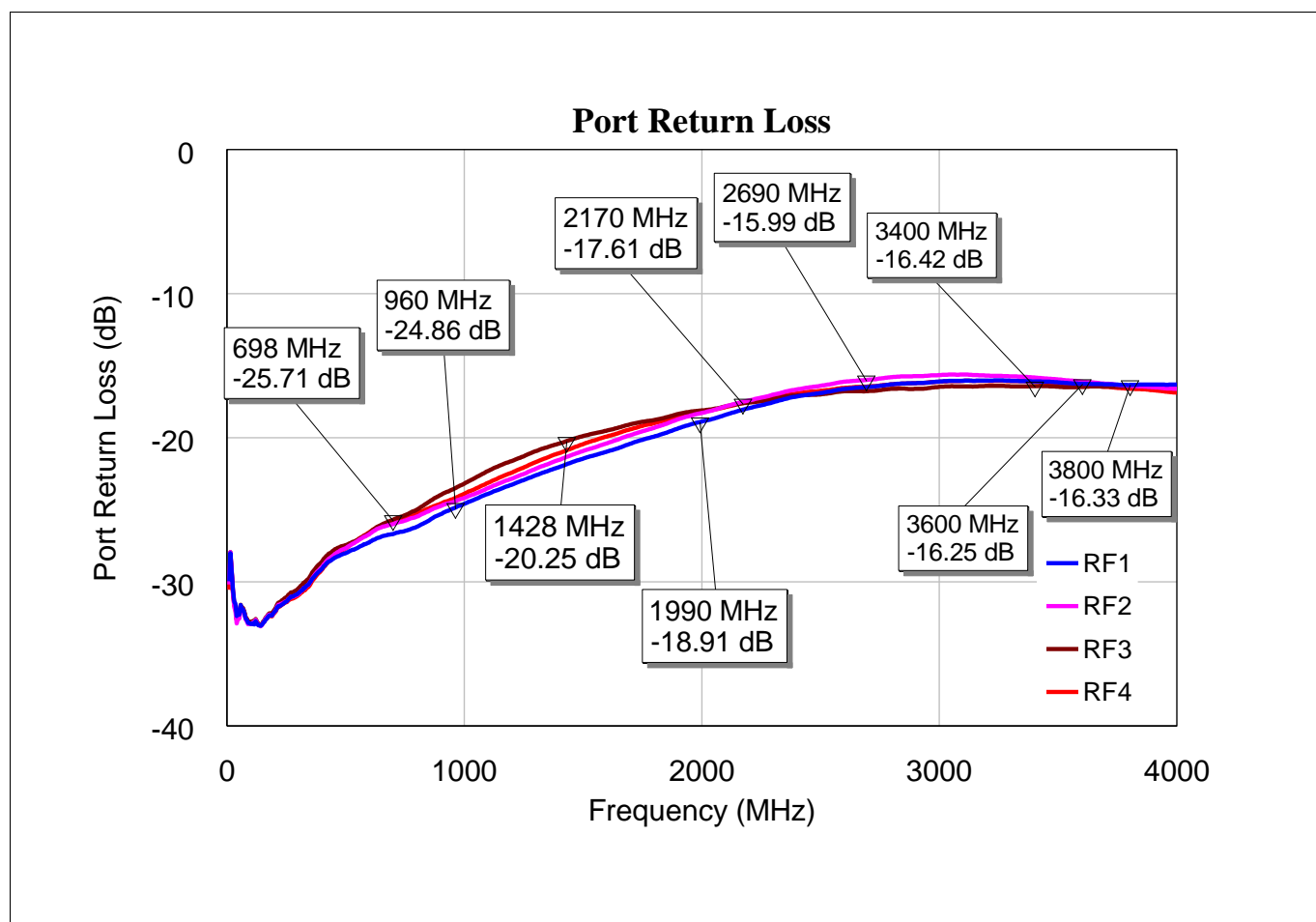
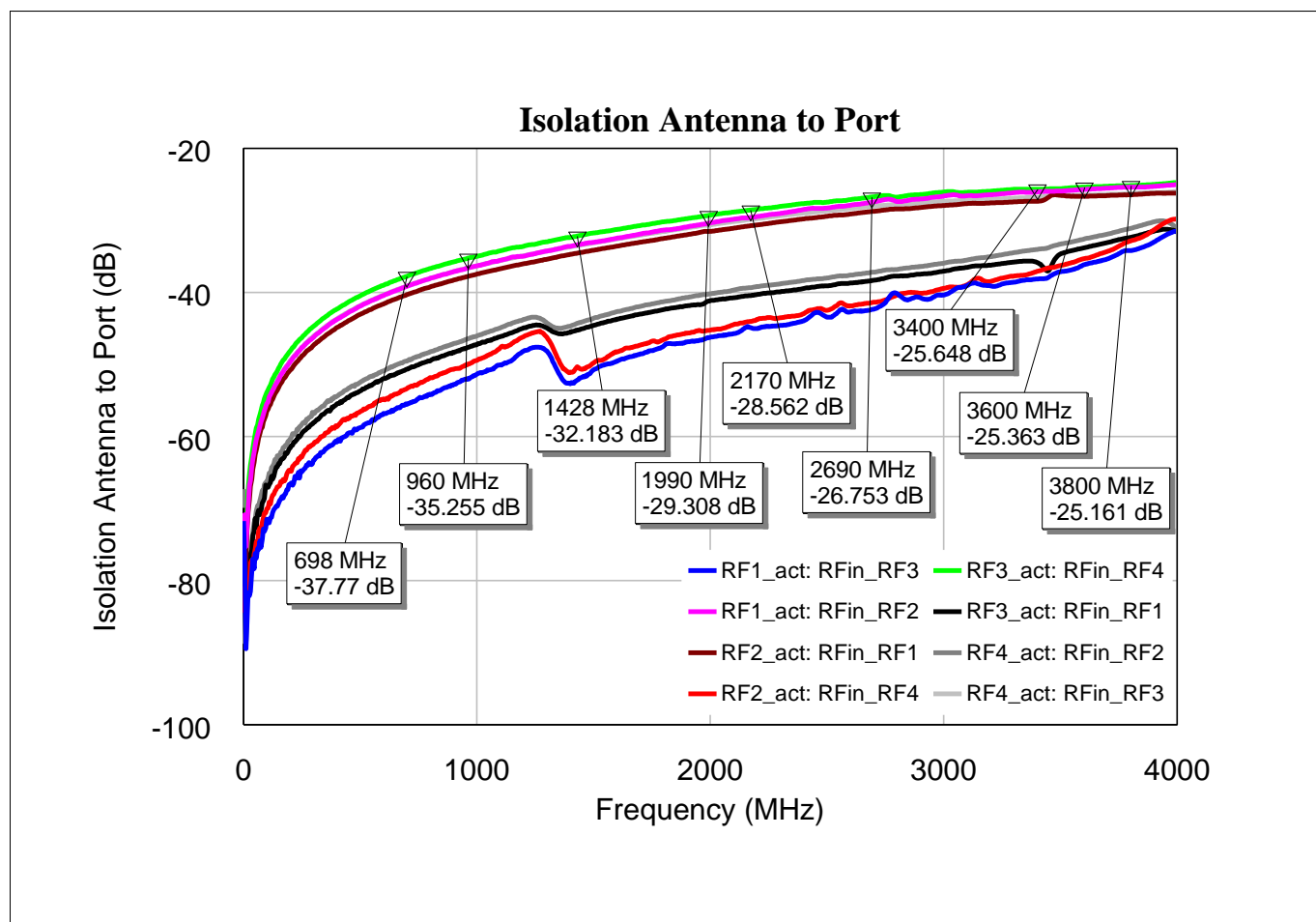


Figure 7 RF matching @ RFx Ports in dB

Table 6 Port Return Loss in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF1	26.69	24.86	21.86	18.91	18.06	16.49	16.09	16.25	16.33
RF2	26.00	24.41	21.35	18.31	17.51	16.00	15.82	16.10	16.39
RF3	25.71	23.51	20.25	18.12	17.61	16.77	16.42	16.47	16.41
RF4	25.83	24.19	20.90	18.23	17.60	16.45	16.11	16.33	16.59

## 3.5 Isolation Antenna to Port

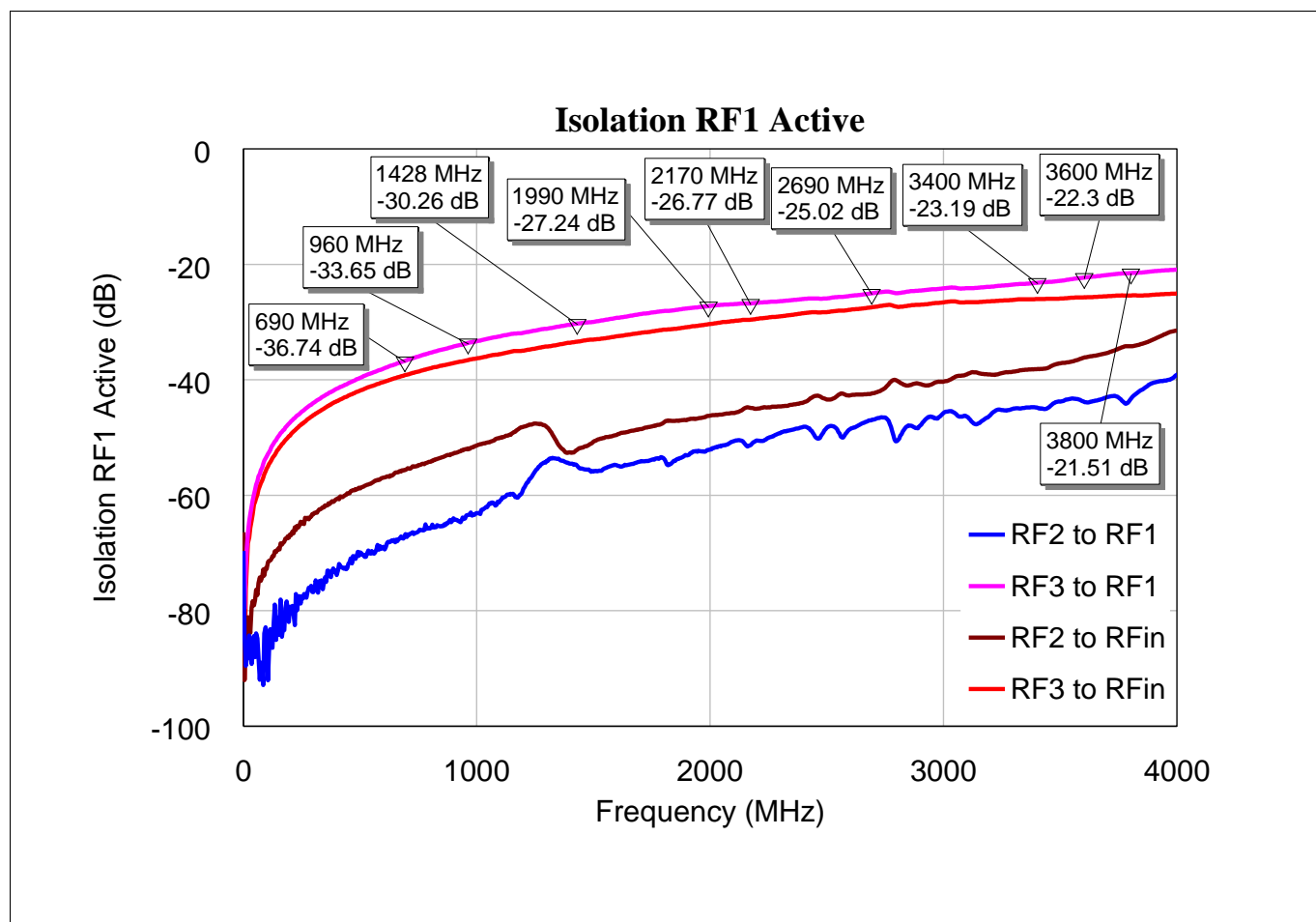


**Figure 8 Isolation Antenna to Port in dB**

**Table 7 Isolation Antenna to Port in dB**

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF1_act: RFin_RF3	55.51	51.97	52.21	46.25	44.86	42.39	38.13	36.16	34.19
RF1_act: RFin_RF2	39.17	36.60	33.41	30.39	29.61	27.48	26.03	25.70	25.37
RF2_act: RFin_RF1	40.33	37.80	34.55	31.54	30.74	28.76	27.32	26.65	26.44
RF2_act: RFin_RF4	53.38	49.96	50.39	45.25	44.02	41.40	37.07	35.29	32.86
RF3_act: RFin_RF4	37.77	35.26	32.18	29.31	28.56	26.75	25.65	25.36	25.16
RF3_act: RFin_RF1	50.66	47.66	45.24	41.21	40.42	38.38	35.81	33.81	32.36
RF4_act: RFin_RF2	49.53	46.44	44.32	40.23	39.33	37.21	34.02	32.59	31.10
RF4_act: RFin_RF3	39.13	36.61	33.49	30.63	29.85	28.04	26.79	26.48	26.26

## 3.6 Isolation Port to Port



**Figure 9 Isolation Port to Port with RF1 active in dB**

**Table 8 Isolation Port to Port with RF1 active in dB**

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF2 to RF1	67.33	62.66	55.07	52.11	51.56	46.78	44.98	43.35	42.89
RF3 to RF1	36.57	33.70	30.12	27.37	26.81	25.03	22.95	22.28	21.66
RF2 to RFin	55.51	51.97	52.21	46.25	44.86	42.39	38.13	36.16	34.19
RF3 to RFin	39.17	36.60	33.41	30.39	29.61	27.48	26.03	25.70	25.37



# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Application Circuit and Performance Overview

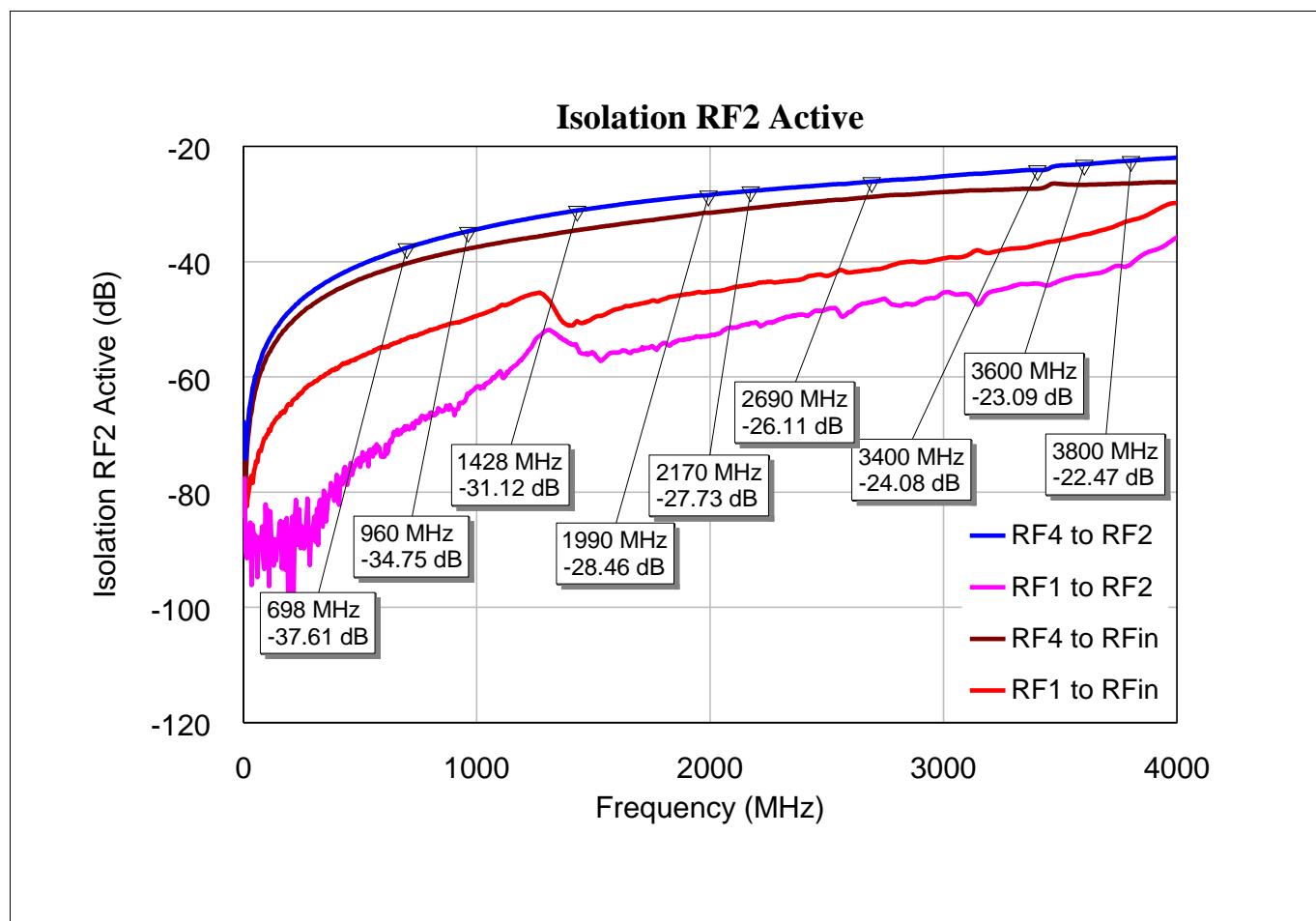


Figure 10 Isolation Port to Port with RF2 active in dB

Table 9 Isolation Port to Port with RF2 active in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF4 to RF2	37.61	34.75	31.12	28.46	27.73	26.11	24.08	23.09	22.47
RF1 to RF2	68.83	62.93	54.58	52.93	50.72	47.02	43.78	42.39	40.49
RF4 to RFin	40.33	37.80	34.55	31.54	30.74	28.76	27.32	26.65	26.44
RF1 to RFin	53.38	49.96	50.39	45.25	44.02	41.40	37.07	35.29	32.86

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Application Circuit and Performance Overview

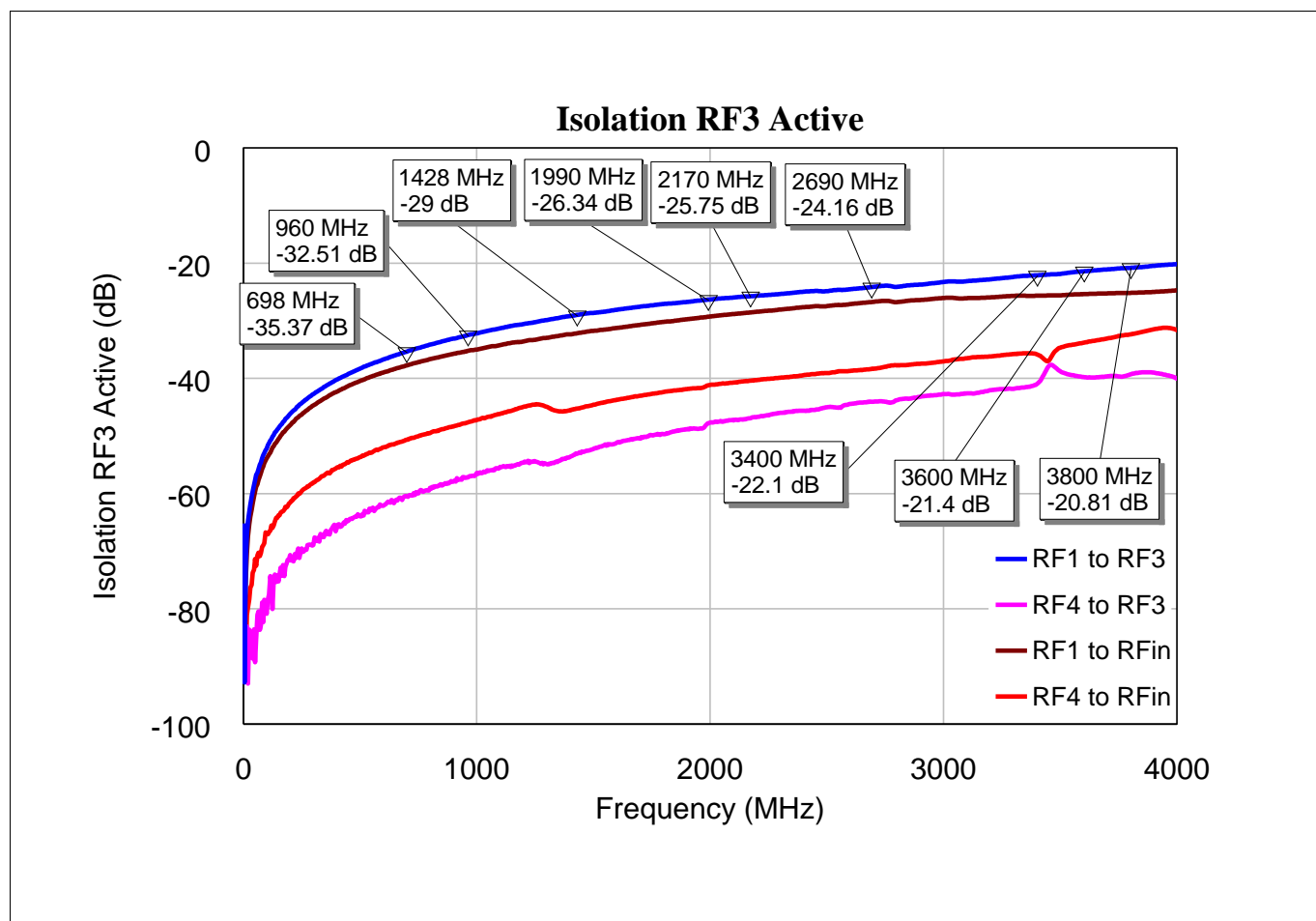


Figure 11 Isolation Port to Port with RF3 active in dB

Table 10 Isolation Port to Port with RF3 active in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF1 to RF3	35.37	32.51	29.00	26.34	25.75	24.16	22.10	21.40	20.81
RF4 to RF3	60.41	57.22	53.06	47.81	46.92	44.07	40.98	39.77	39.32
RF1 to RFin	37.77	35.26	32.18	29.31	28.56	26.75	25.65	25.36	25.16
RF4 to RFin	50.66	47.66	45.24	41.21	40.42	38.38	35.81	33.81	32.36

# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Application Circuit and Performance Overview

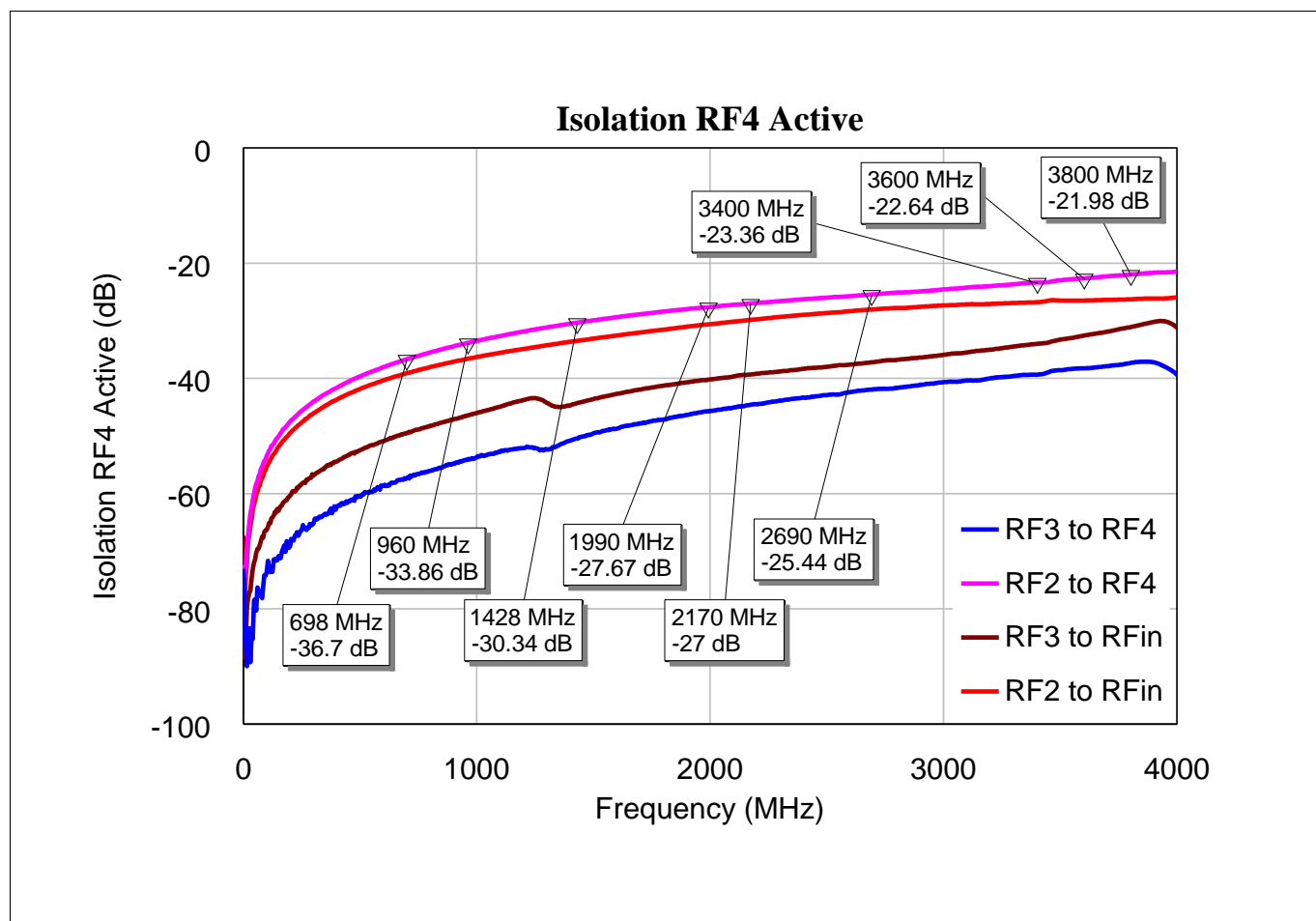


Figure 12 Isolation Port to Port with RF4 active in dB

Table 11 Isolation Port to Port with RF4 active in dB

Frequency (MHz)	698	960	1428	1990	2170	2690	3400	3600	3800
RF3 to RF4	57.39	54.17	50.46	45.73	44.62	41.97	39.34	38.25	37.32
RF2 to RF4	36.70	33.86	30.34	27.67	27.00	25.44	23.36	22.64	21.98
RF3 to RFin	49.53	46.44	44.32	40.23	39.33	37.21	34.02	32.59	31.10
RF2 to RFin	39.13	36.61	33.49	30.63	29.85	28.04	26.79	26.48	26.26

## Switching time

### 4 Switching time

#### 4.1 Measurement Specifications

Switching On Time: 50% Trigger signal to 90% RF Signal

Switching Off Time: 50% Trigger signal to 10% RF Signal

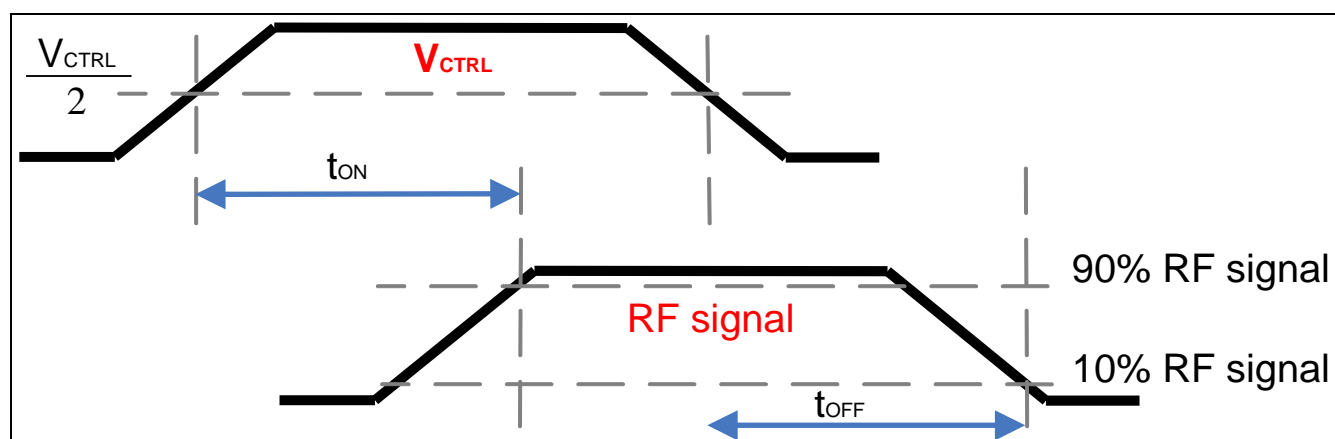


Figure 13 Switching Time

Rise time: 10% to 90% RF Signal

Fall time: 90% to 10% RF Signal

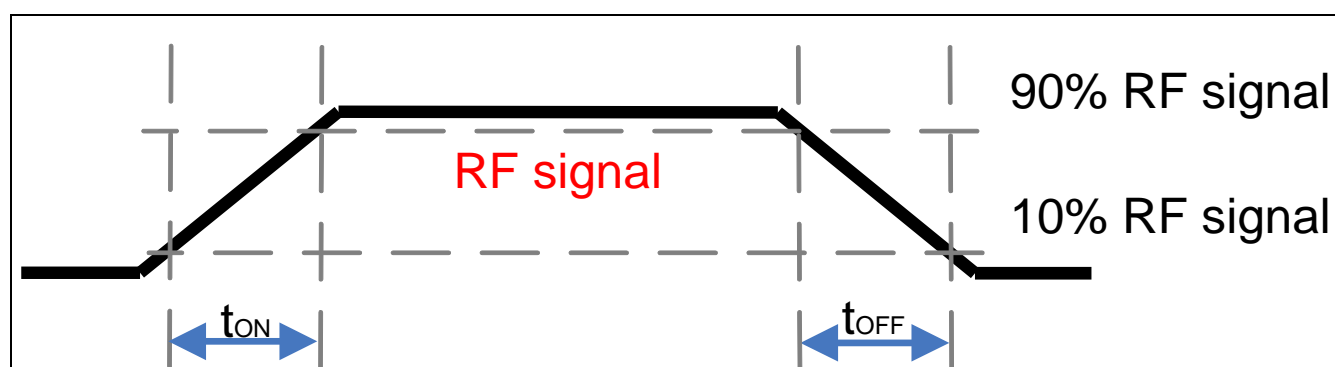
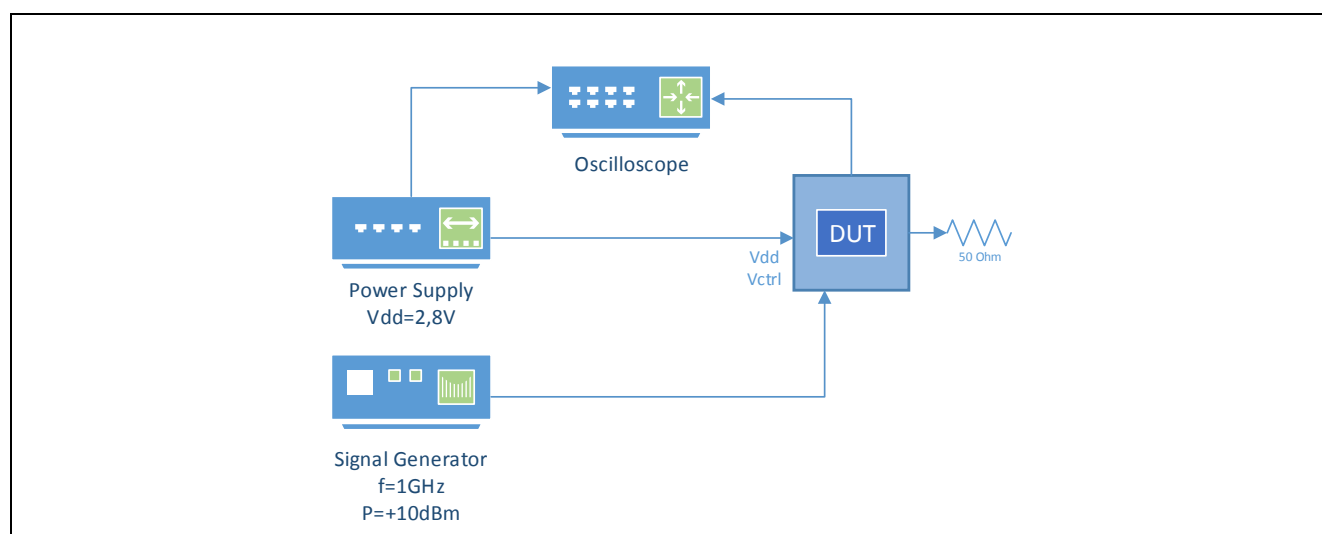


Figure 14 Rise/Fall Time

## 4.2 Measurement Setup

The setup on below is representing switching time measurement setup. In the Figure 15 the setup is configured for a SPDT switch, where the trigger signal is a one kHz signal with the amplitude of device-Vdd/Vctrl. The setup properties (RFin and trigger signal pulse) could be changed for measuring other devices like amplifier.



**Figure 15 Measurement setup**

## 4.3 Measurement results

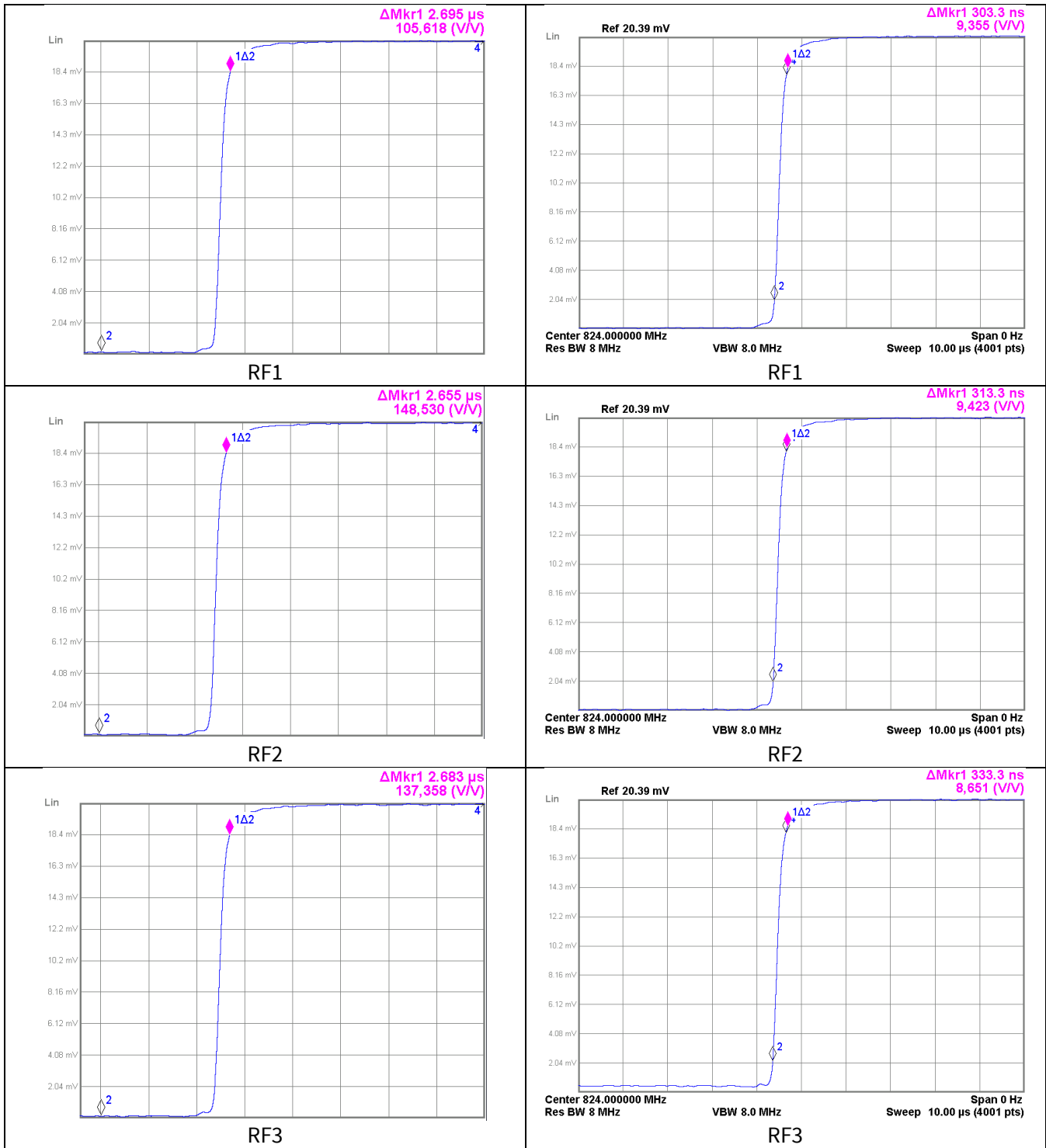
The switching Time measurement setup consist of one pulse generator which generates a square wave with 50% duty cycle and an amplitude of 1.8 Volts, an oscilloscope which can detect the 1 GHz signal and the 1 kHz signal and one Signal generator which is set to an output signal of 1GHz with a power level 10 dBm.

If the oscilloscope can not detect the 1 GHz signal of the RF path, due to small bandwidth, it is possible to use a crystal oscillator in front of the oscilloscope (such a device detects any RF signal present at input and commutate that one) that the RF signal can be detected

VDD= 2.7V  
Vctrl= 0/1.8V Pulsed with 600Hz 50% duty cycle  
RFin= 300MHz @ 0dBm

	Vctrl to RF	RF rise Time
Spec	2 - 4 $\mu$ s	2 $\mu$ s
RF1	2.695 $\mu$ s	303.3 ns
RF2	2.655 $\mu$ s	313.3 ns
RF3	2.683 $\mu$ s	333.3 ns
RF4	2.703 $\mu$ s	308.3 ns

### Switching time

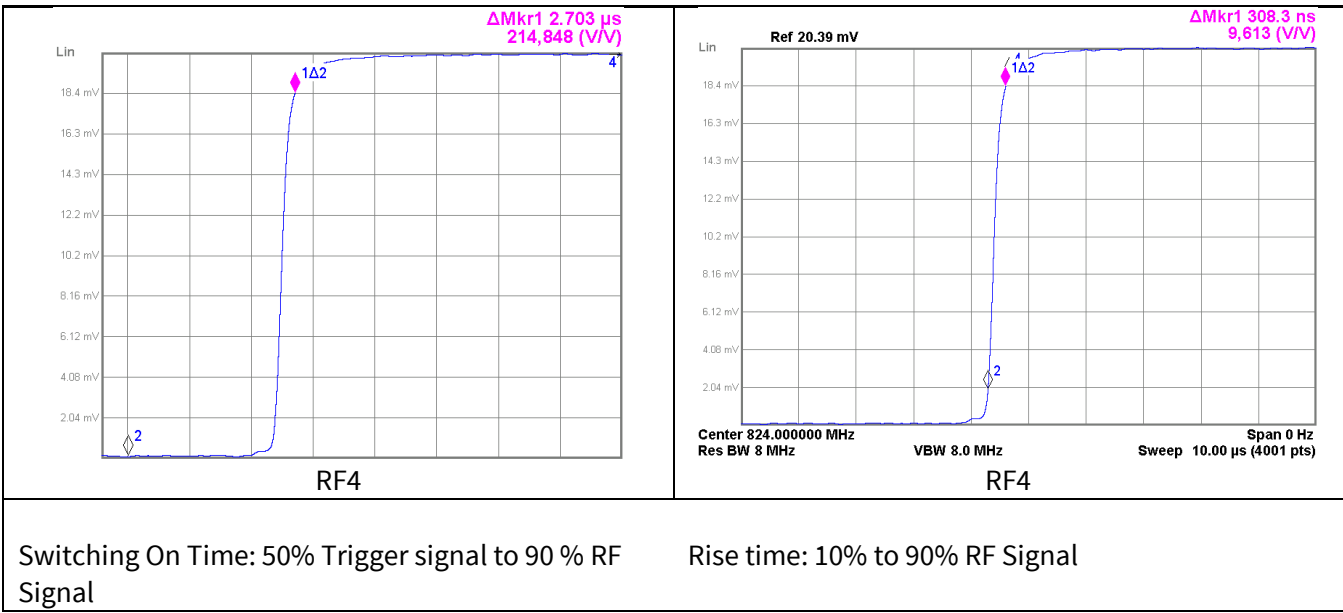


# SP4T Diversity Antenna Switch with GPIO Interface

## BGS14GA14



### Switching time



**Figure 16** Screenshots of switching times

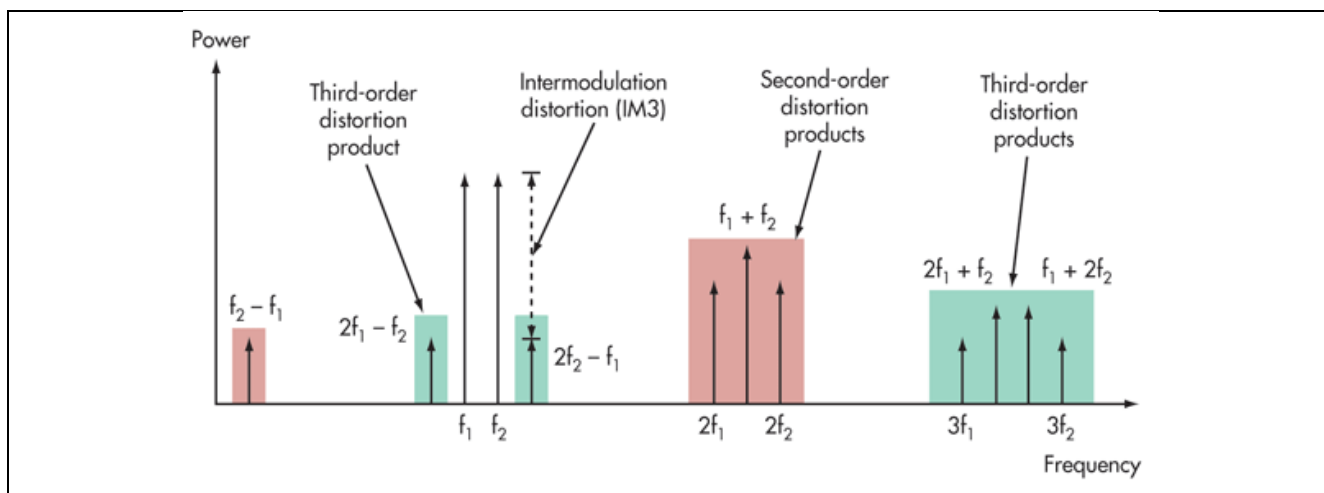
## 5 Intermodulation

Intermodulation distortion is characterized by the appearance in the output of frequencies equal to the sums and differences of integral multiples of the two or more component frequencies present in the input waveform.

Defined by the following expressions:

**Table 12 IMD Mathematical definitions**

<b>Second Order IMD</b>	$f_{IMD2low} = f_{Rx} - f_{Tx}$		$f_{IMD2high} = f_{Rx} + f_{Tx}$
<b>Third Order IMD</b>	$f_{IMD3l} = 2f_{Tx} - f_{Rx}$	$f_{IMD3m} = 2f_{Rx} + f_{Tx}$	$f_{IMD3h} = f_{Rx} + 2f_{Tx}$



**Figure 17 Representation of IMD products**



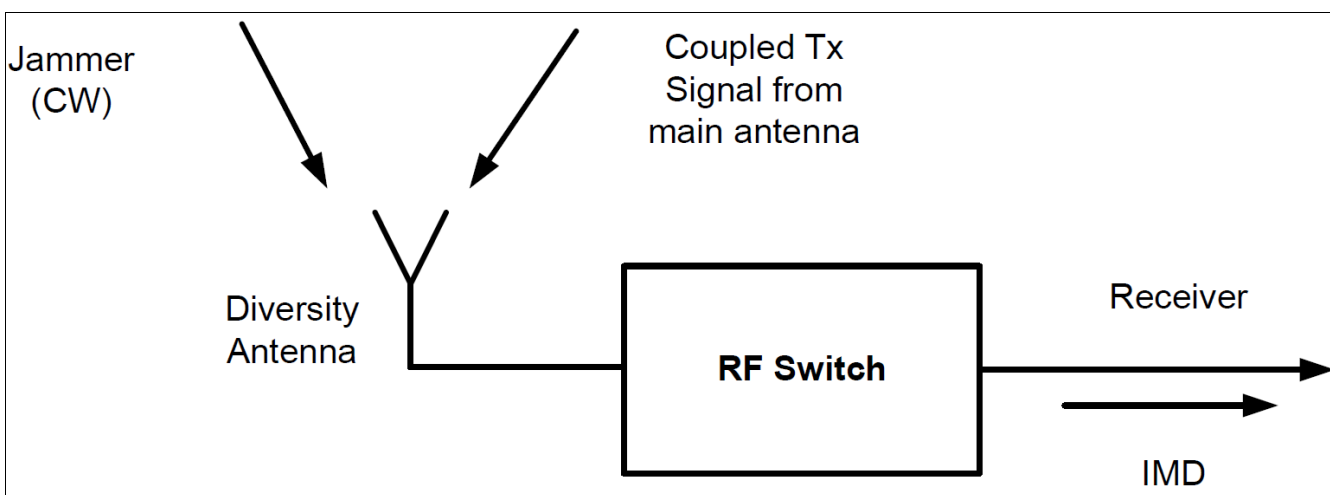
## 5.1 Test conditions

Developing the same mathematical expressions we can see that external signals matching IMDs frequencies can interfere over  $f_{Rx}$

**Table 13 IMD Mathematical definitions extended**

<b>Second Order IMD</b>	$f_{IMD2low} = f_{Rx} - f_{Tx} \rightarrow$ $f_{Rx} = f_{IMD2low} + f_{Tx}$		$f_{IMD2high} = f_{Rx} + f_{Tx} \rightarrow$ $f_{Rx} = f_{IMD2high} - f_{Tx}$
<b>Third Order IMD</b>	$f_{IMD3l} = 2f_{Tx} - f_{Rx} \rightarrow$ $f_{Rx} = 2f_{Tx} - f_{IMD3l}$	$f_{IMD3m} = 2f_{Rx} + f_{Tx} \rightarrow$ $f_{Rx} = (f_{Tx} - f_{IMD3m})/2$	$f_{IMD3h} = f_{Rx} + 2f_{Tx} \rightarrow$ $f_{Rx} = f_{IMD3h} - 2f_{Tx}$

One of the possible intermodulation scenarios is shown in Figure 18. The transmission (Tx) signal from the main antenna is coupled into the diversity antenna with high power. This signal (21 dBm or 10 dBm depending the case) and a received Jammer signal (-15 dBm) are entering the switch. Thanks to the specified application for the BGS14GA14 in between the filters and the Transceiver, the Tx signal from the main antenna loose until arriving at the switch input mostly 5 to 10 or more dB, depending of the filter and PCB structure of the RF frontend. The IMD products are measured with a Tx of 21dBm or 10dBm, which is corresponding to the IMD spec of a main antenna diversity switch like Infineon BGS14GA14. Therefore, the measured IMD products will be extremely better in the specified application circuit within the filters and transceiver as showed in the measurement results below.



**Figure 18 Block diagram of RF Switch intermodulation**

Special combinations of TX and Jammer signal are producing intermodulation products 2nd and 3rd order, which fall in the RX band and disturb the wanted RX signal.

## 5.2 Measurement Setup

The test setup for the IMD measurements has to provide a very high isolation between RX and TX signals. As an example the test set-up and the results for the high band are shown (Figure 19 and Table 11).

For the RX / TX separation a professional duplexer with 80 dB isolation is used.

For each distortion scenario there is a min and a max value given. This variation is caused by a phase shifter connected between switch and duplexer. In the test set-up the phase shifter represents a no ideal matching of the switch to 50 Ohm.

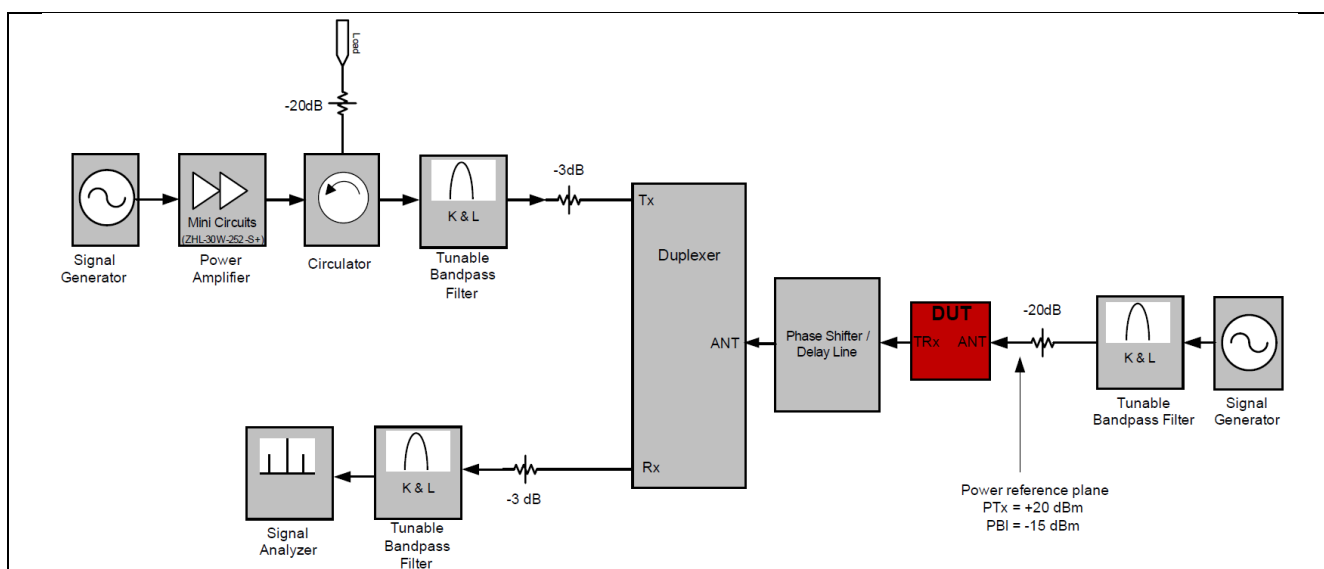


Figure 19 Block diagram of RF Switch intermodulation

### 5.3 Measurement Results

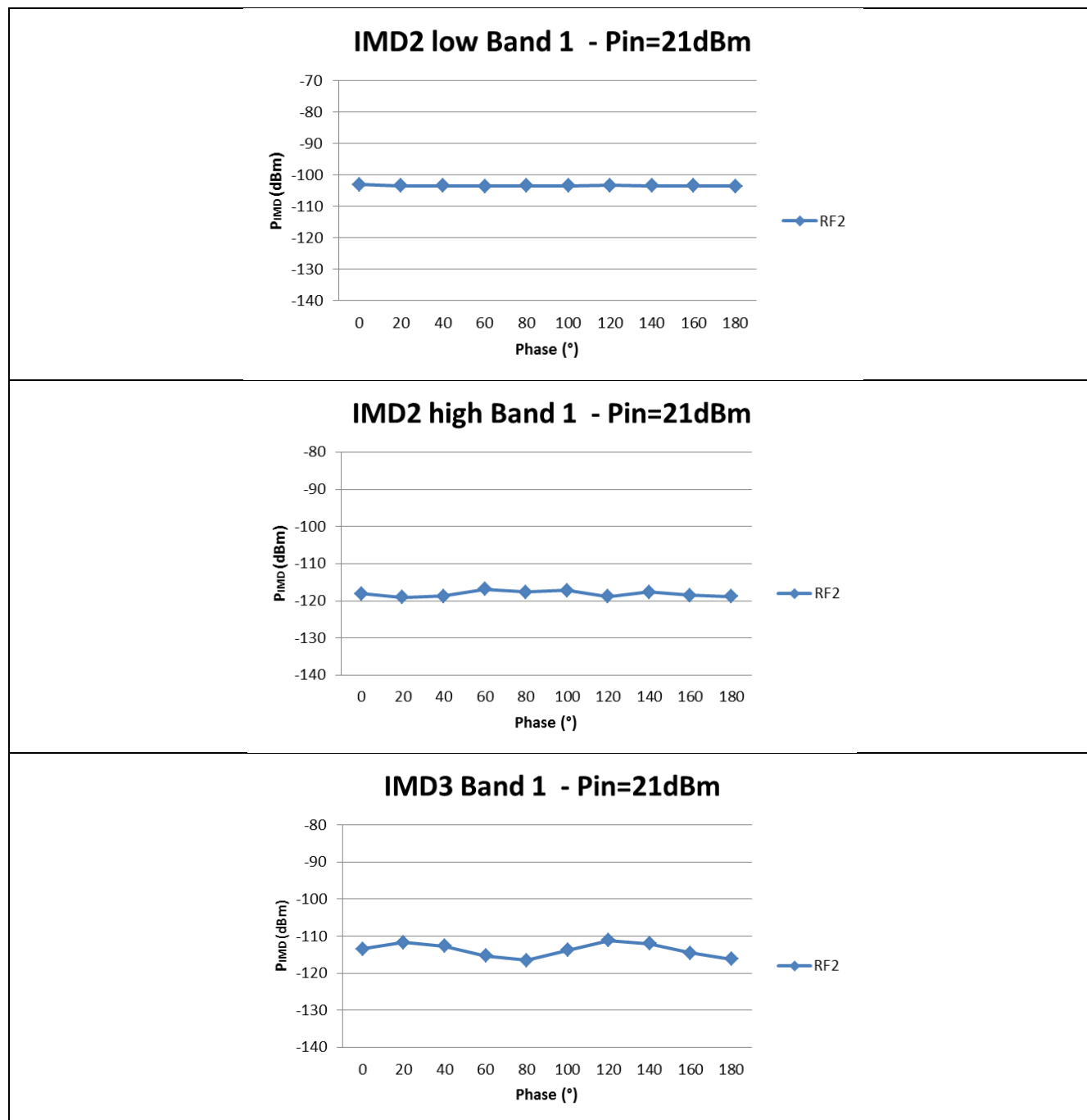


Figure 20 IMD products of Band 1 LTE and Pin=21dBm

Table 14 IMD products of Band 1 LTE

IMD Band 1 P <sub>Tx</sub> =21dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =190MHz)	-103.57	-103.10
IMD2High (f <sub>blocker</sub> =4090MHz)	-118.99	-116.84
IMD3 (f <sub>blocker</sub> =1760MHz)	-116.46	-111.19

Intermodulation

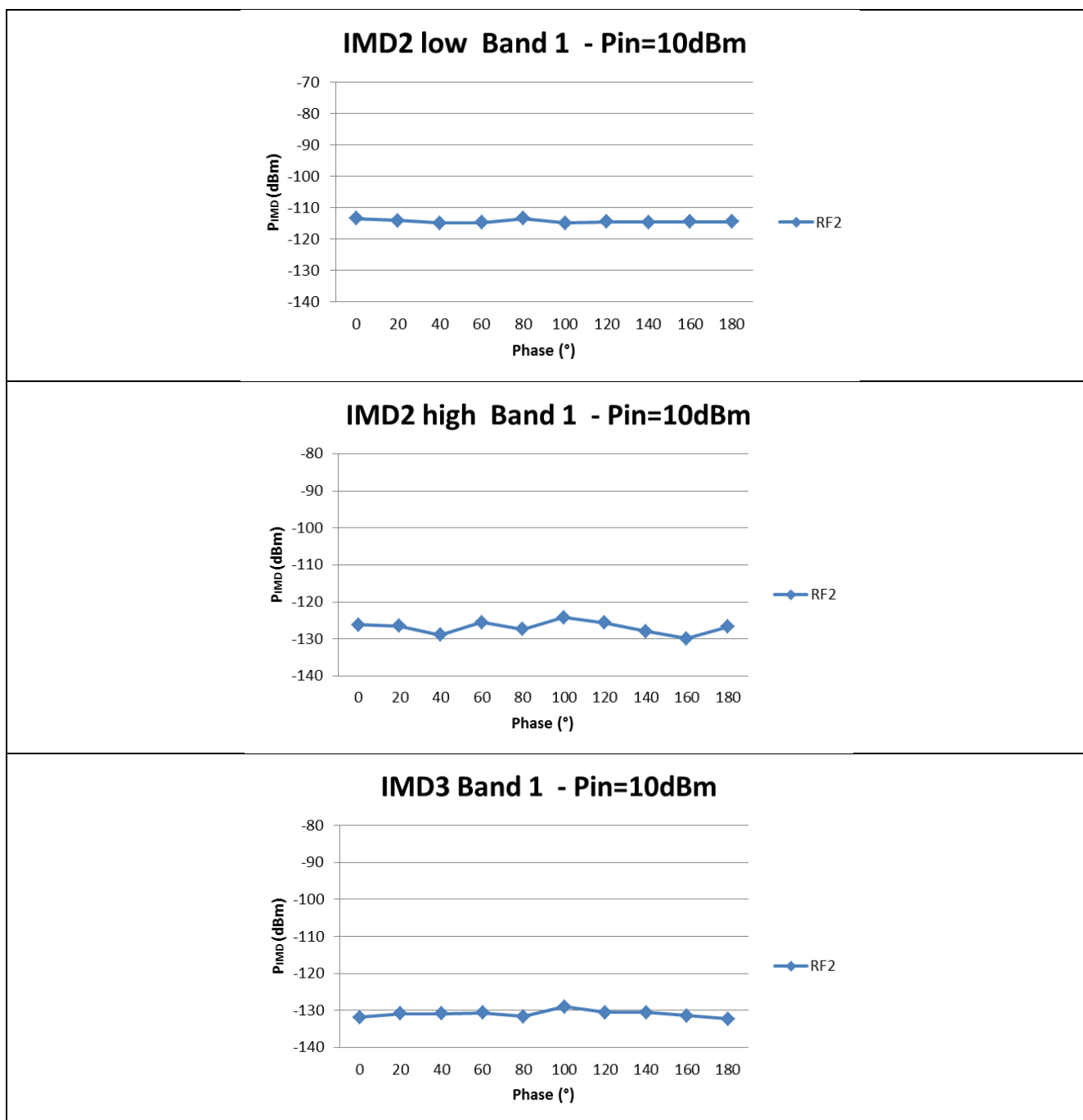


Figure 21 IMD products of Band 1 LTE and Pin=10dBm

Table 15 IMD products of Band 1 LTE

IMD Band 1 P <sub>Tx</sub> =10dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =190MHz)	-114.94	-113.39
IMD2High (f <sub>blocker</sub> =4090MHz)	-129.84	-124.20
IMD3 (f <sub>blocker</sub> =1760MHz)	-132.29	-129.05

### Intermodulation

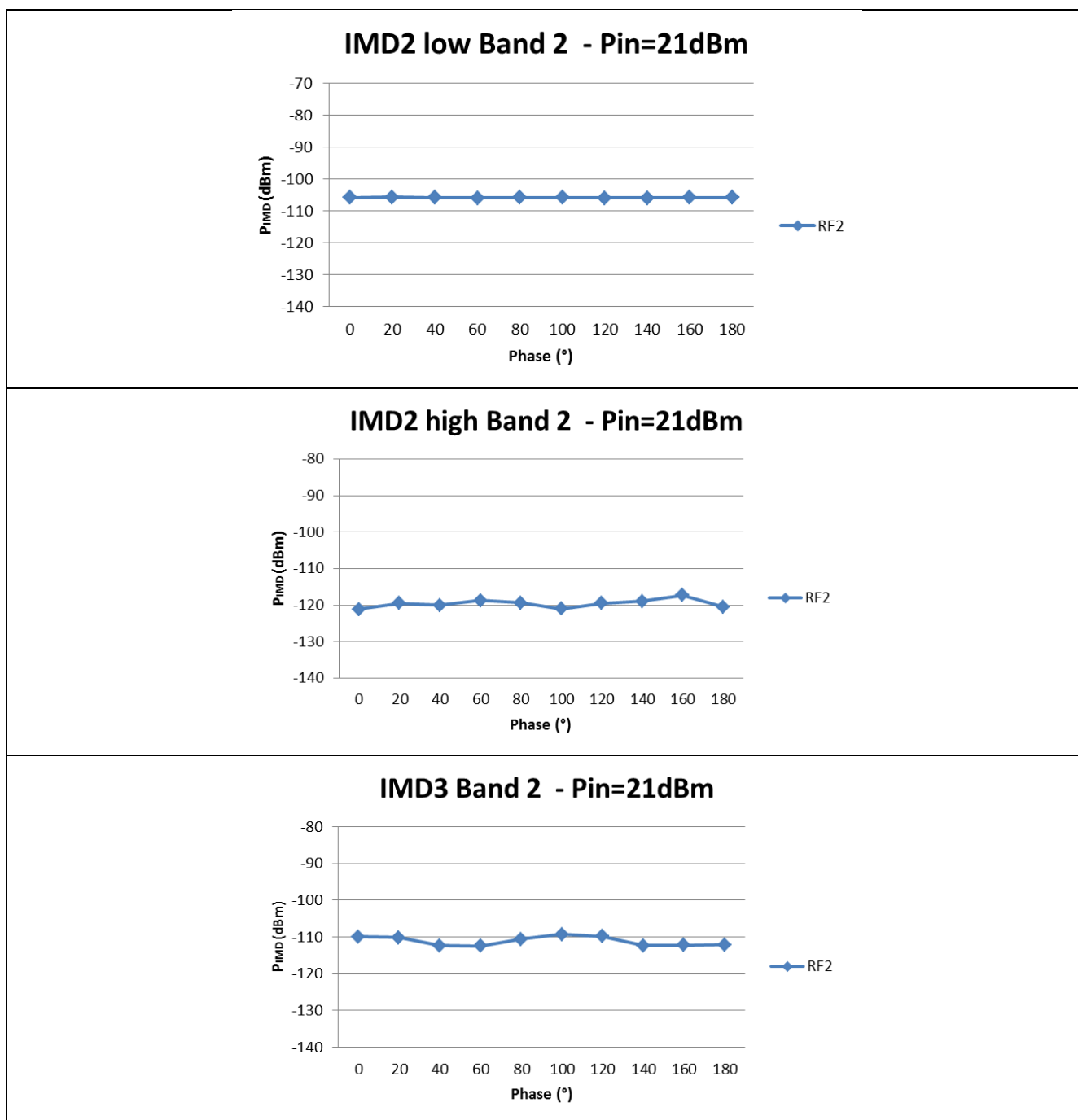


Figure 22 IMD products of Band 2 LTE and Pin=21dBm

Table 16 IMD products of Band 2 LTE

IMD Band 2 P <sub>Tx</sub> =21dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =80MHz)	-105.94	-105.63
IMD2High (f <sub>blocker</sub> =3840MHz)	-121.14	-117.31
IMD3 (f <sub>blocker</sub> =1800MHz)	-112.45	-109.24

Intermodulation

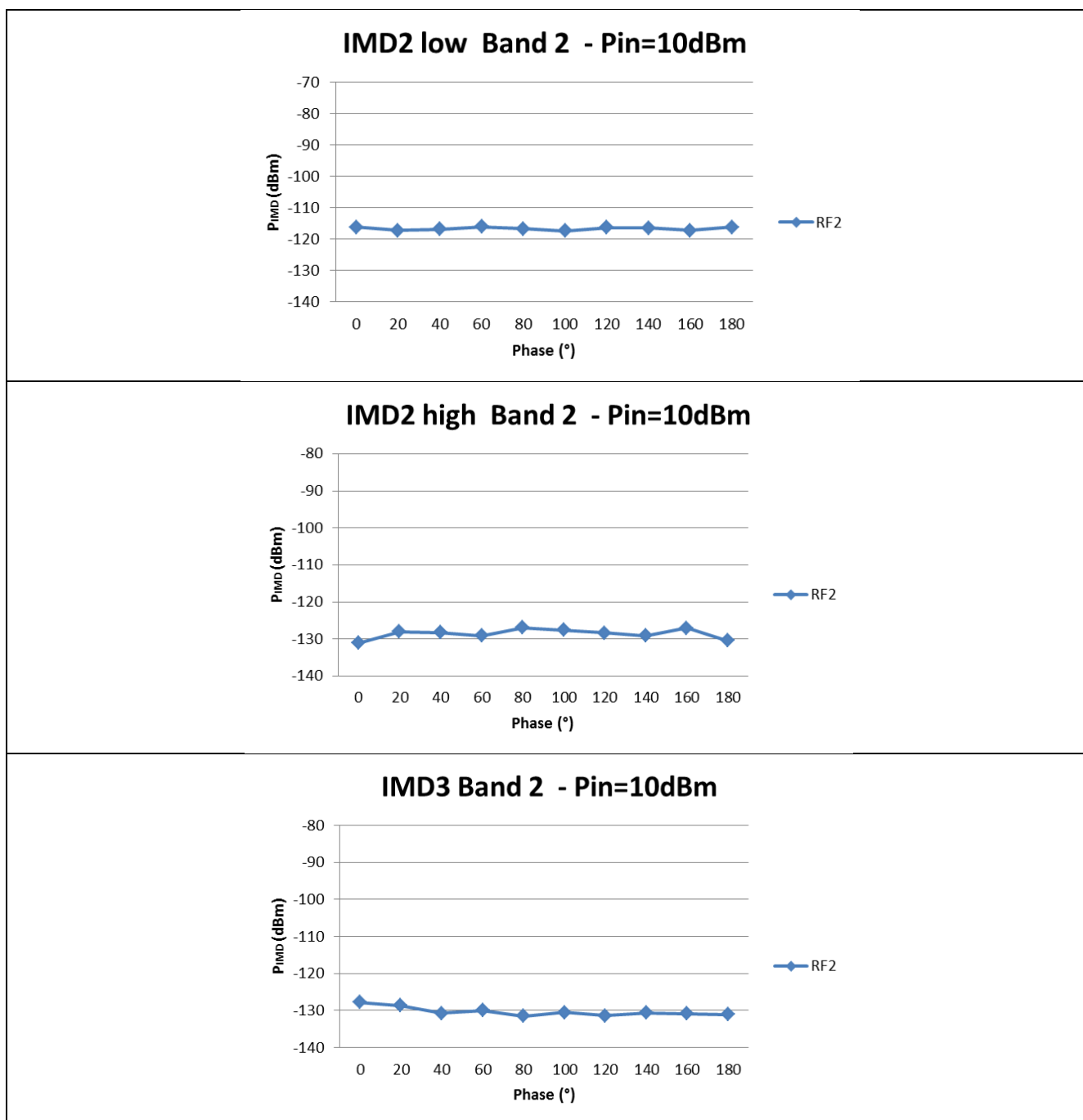
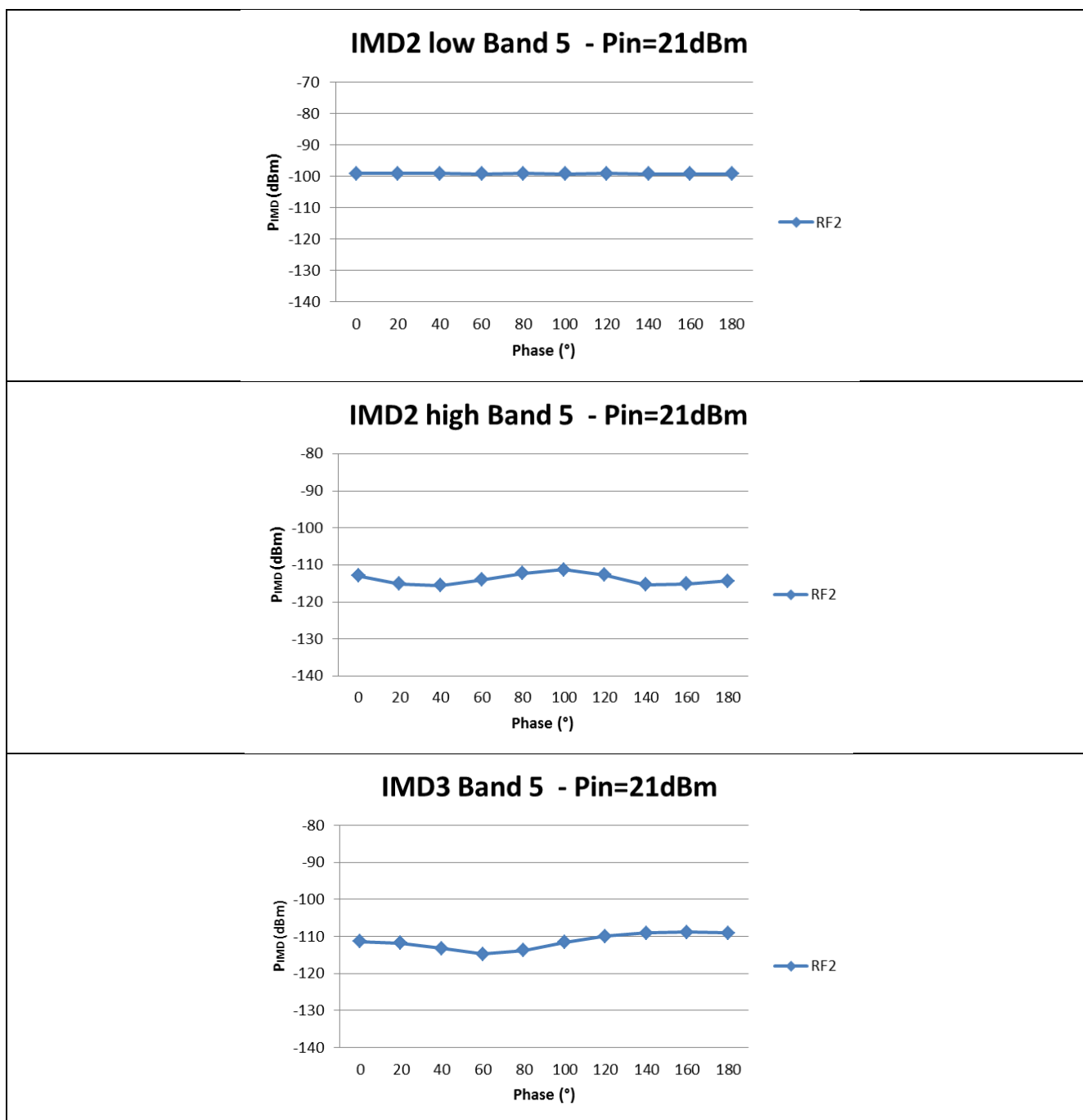


Figure 23 IMD products of Band 2 LTE and Pin=10dBm

Table 17 IMD products of Band 2 LTE

IMD Band 2 P <sub>Tx</sub> =10dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =80MHz)	-117.35	-116.07
IMD2High (f <sub>blocker</sub> =3840MHz)	-131.05	-126.89
IMD3 (f <sub>blocker</sub> =1800MHz)	-131.56	-127.82

### Intermodulation

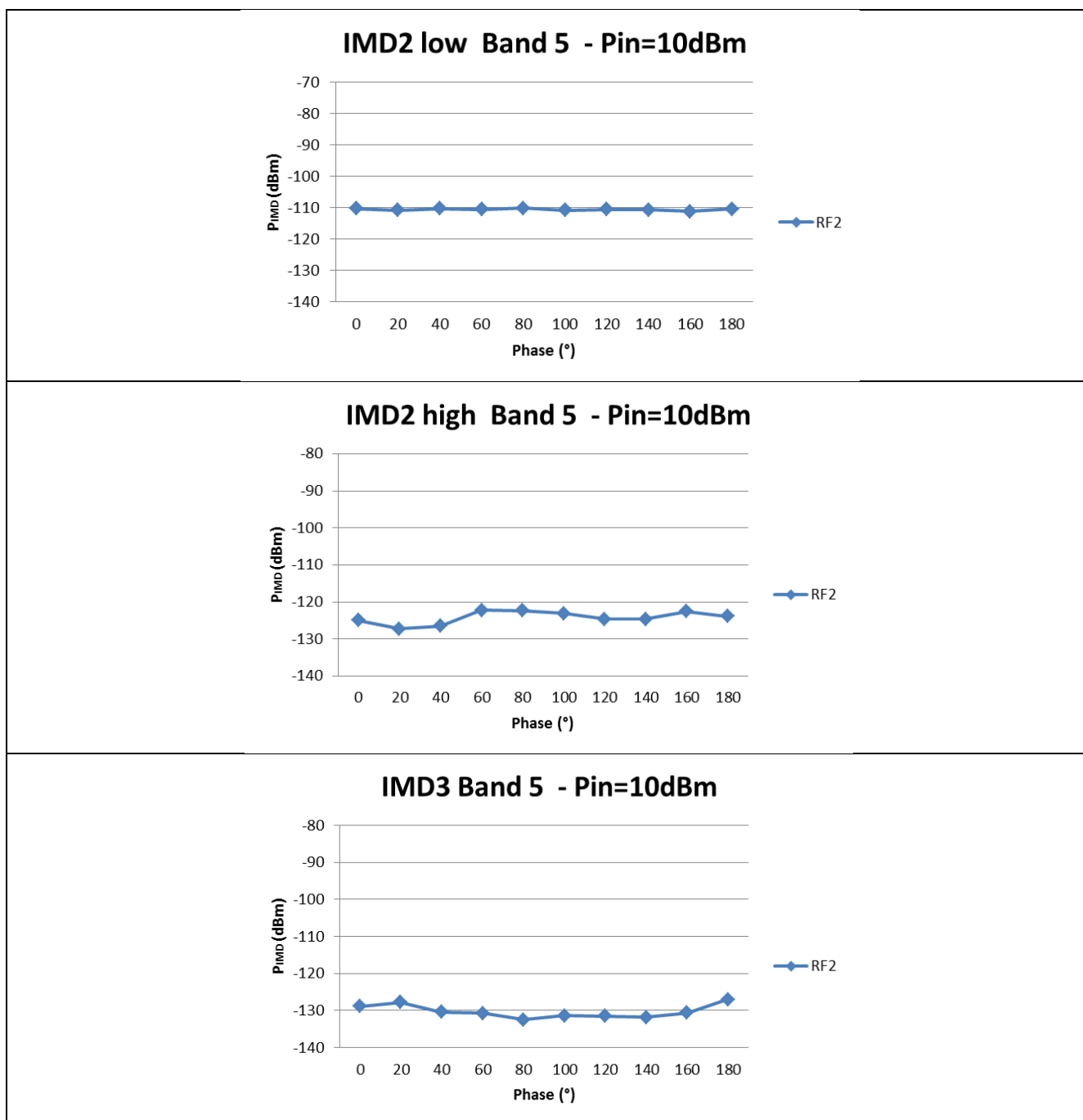


**Figure 24** IMD products of Band 5 LTE and Pin=21dBm

**Table 18** IMD products of Band 5 LTE

IMD Band 5 P <sub>Tx</sub> =21dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =45MHz)	-99.29	-99.05
IMD2High (f <sub>blocker</sub> =1718MHz)	-115.54	-111.26
IMD3 (f <sub>blocker</sub> =791,5MHz)	-114.76	-108.89

### Intermodulation



**Figure 25** IMD products of Band 5 LTE and Pin=10dBm

**Table 19** IMD products of Band 5 LTE

IMD Band 5 P <sub>Tx</sub> =10dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =45MHz)	-111.16	-110.2
IMD2High (f <sub>blocker</sub> =1718MHz)	-127.21	-122.23
IMD3 (f <sub>blocker</sub> =791,5MHz)	-132.52	-127.03



Intermodulation

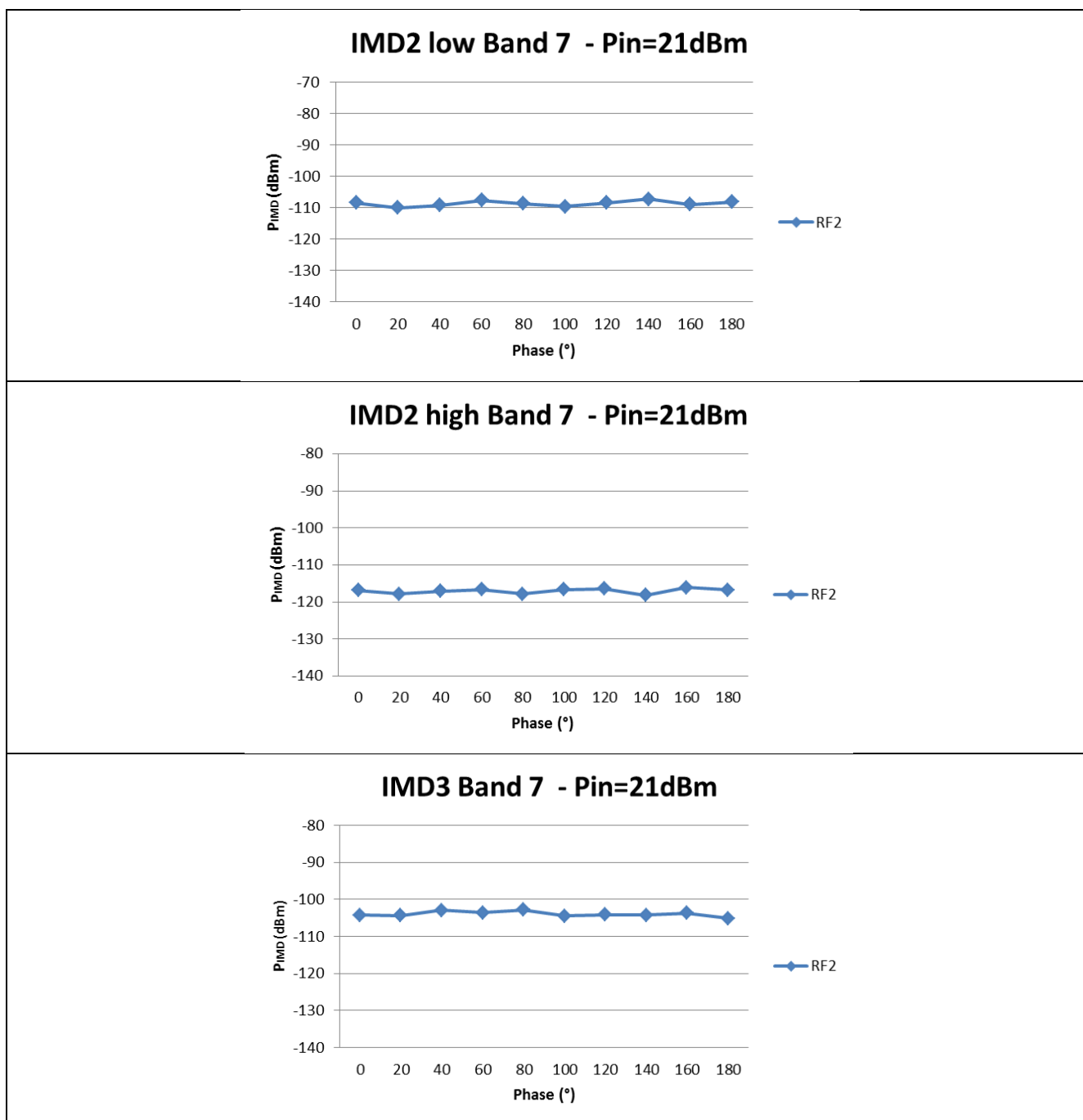


Figure 26 IMD products of Band 7 LTE and Pin=21dBm

Table 20 IMD products of Band 7 LTE

IMD Band 7 P <sub>Tx</sub> =21dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =120MHz)	-109.98	-107.28
IMD2High (f <sub>blocker</sub> =5190MHz)	-118.17	-116.08
IMD3 (f <sub>blocker</sub> =2415MHz)	-105.13	-102.81

Intermodulation

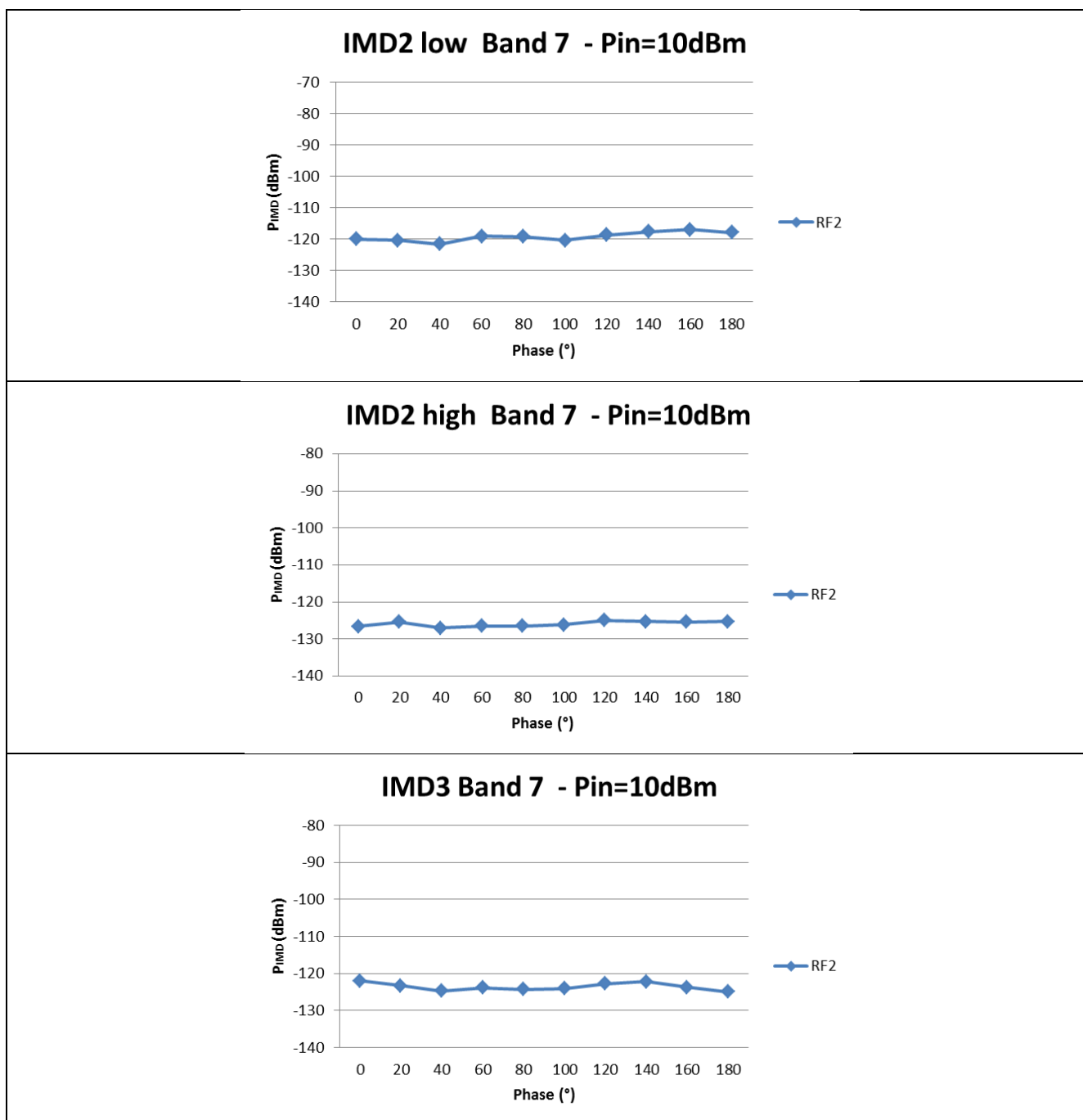


Figure 27 IMD products of Band 7 LTE and Pin=10dBm

Table 21 IMD products of Band 7 LTE

IMD Band 7 P <sub>Tx</sub> =10dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =120MHz)	-121.58	-116.98
IMD2High (f <sub>blocker</sub> =5190MHz)	-126.99	-124.96
IMD3 (f <sub>blocker</sub> =2415MHz)	-124.97	-122.02

Intermodulation

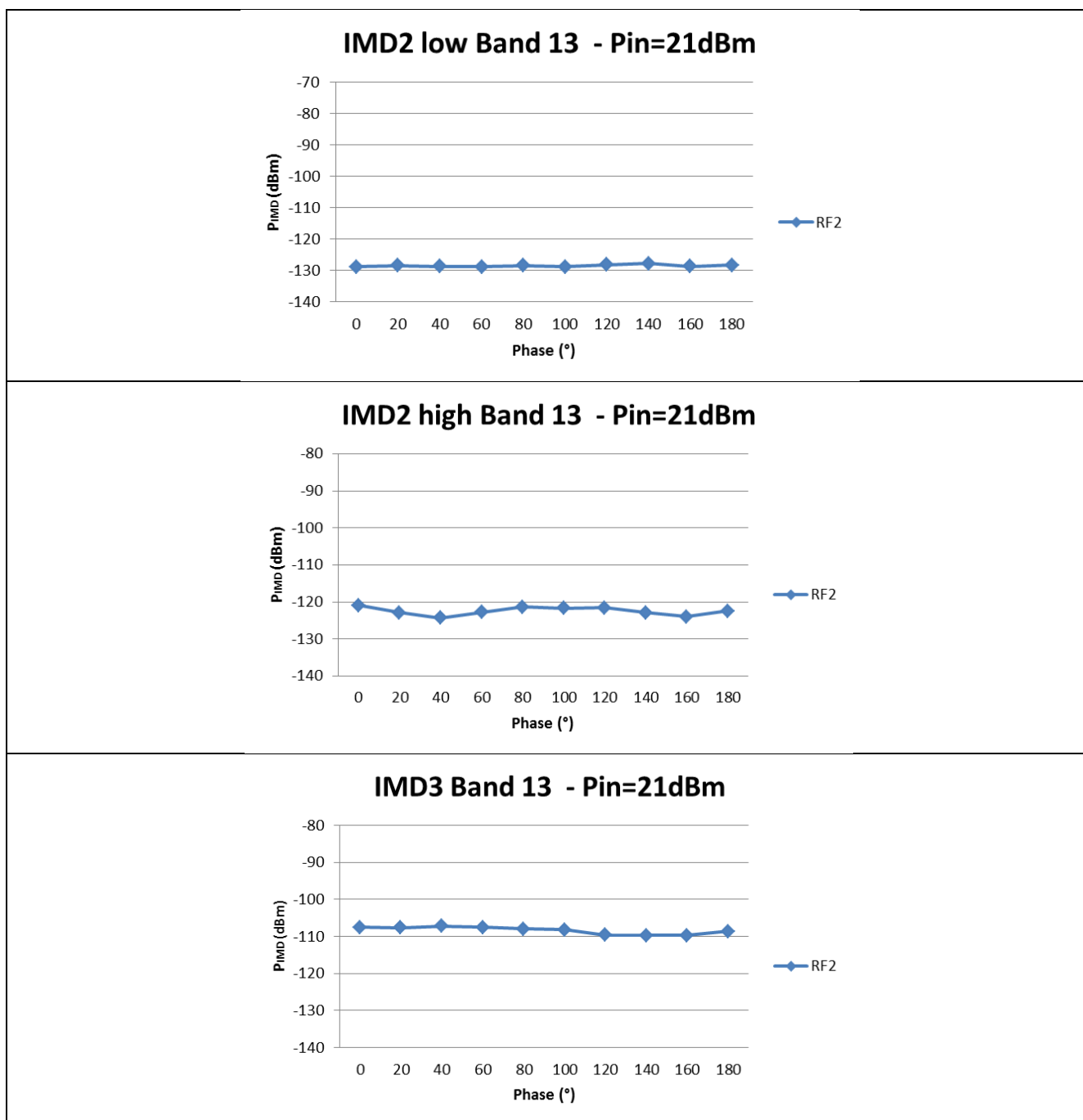
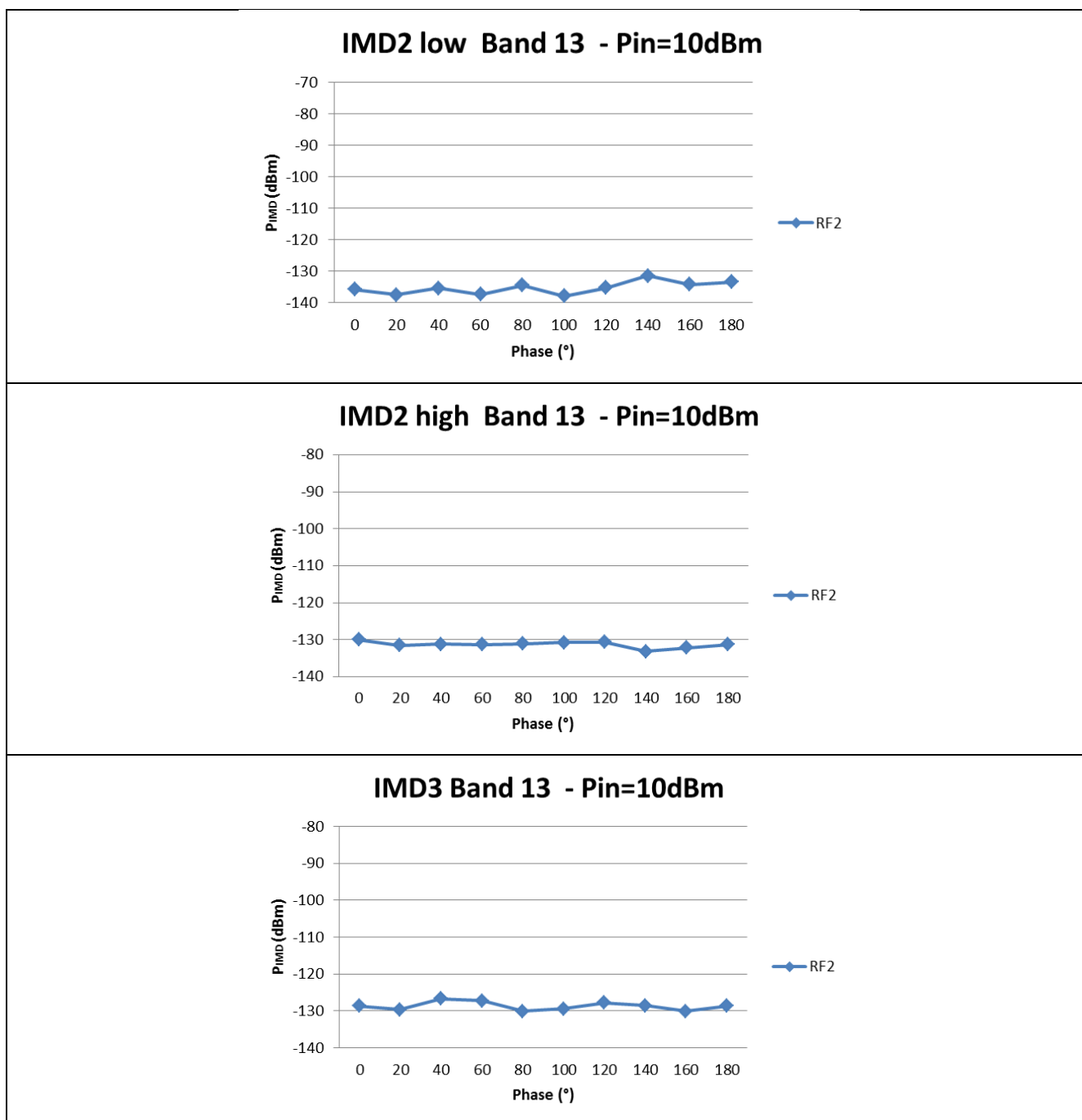


Figure 28 IMD products of Band 13 LTE and Pin=21dBm

Table 22 IMD products of Band 13 LTE

IMD Band 13 P <sub>Tx</sub> =21dBm	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =31MHz)	-128.87	-127.77
IMD2High (f <sub>blocker</sub> =1533MHz)	-124.32	-120.89
IMD3 (f <sub>blocker</sub> =813MHz)	-109.76	-107.16

### Intermodulation



**Figure 29** IMD products of Band 13 LTE and Pin=10dBm

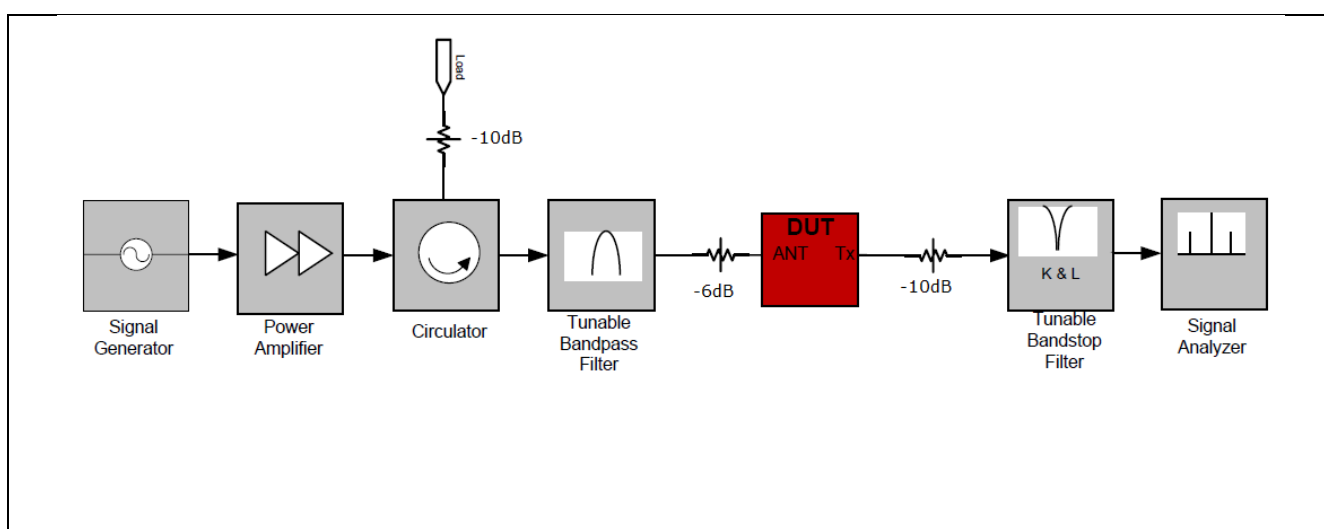
**Table 23** IMD products of Band 13 LTE

IMD Band 13 <b>P<sub>Tx</sub>=10dBm</b>	RF2	
	Min	Max
IMD2Low (f <sub>blocker</sub> =31MHz)	-137.87	-131.5
IMD2High (f <sub>blocker</sub> =1533MHz)	-133.11	-130.02
IMD3 (f <sub>blocker</sub> =813MHz)	-130.14	-126.7

## 6 Harmonic Generation

Harmonic generation is another important parameter for the characterization of a RF switch. RF switches have in such a Differential Band select Switching application to deal with high RF levels, up to 24 dBm. With this high RF power at the input of the switch harmonics are generated. This harmonics (2nd and 3rd) can disturb the other reception bands or cause distortion in other RF applications (GPS, WLAN) within the mobile phone.

### 6.1 Measurement Setup



**Figure 30 Setup for harmonics measurement**

The results for the 2<sup>nd</sup> and 3<sup>rd</sup> order harmonic generation at different Bands are shown from for all RF ports on the following points.

The x-axis show the input power and the y-axis show the generated harmonics in dBm.

## 6.2 Measurement results

### 6.2.1 Harmonics for Band 1

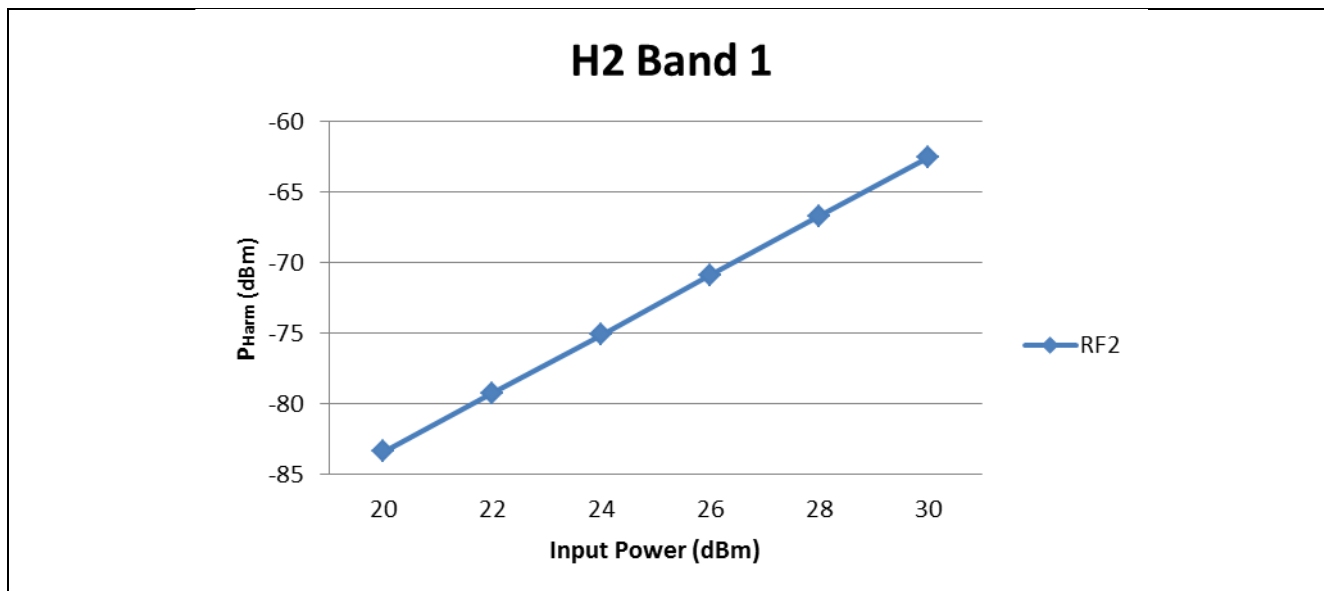


Figure 31 2<sup>nd</sup> harmonics at fc=1950MHz

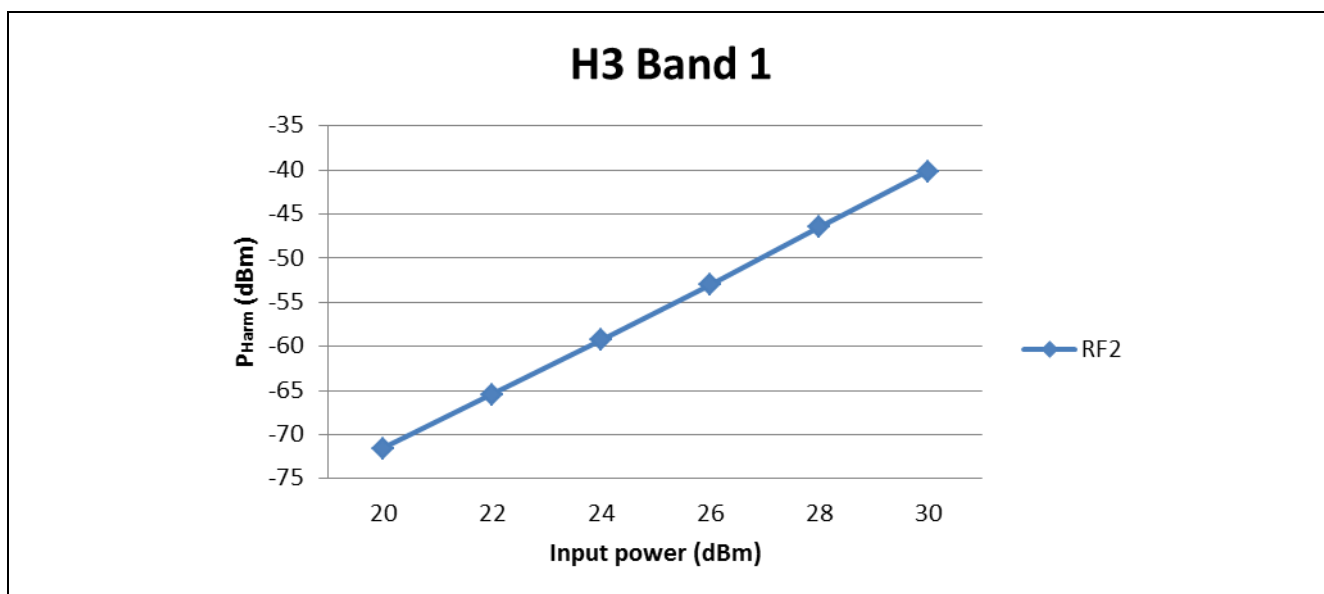


Figure 32 3<sup>rd</sup> harmonics at fc=1950MHz

fc=1950MHz		H2	H3
		RF2 (dBm)	RF2 (dBm)
RFin (dBm)	20	-83.36	-71.6
	22	-79.22	-65.44
	24	-75.07	-59.28
	26	-70.87	-53.06
	28	-66.67	-46.51
	30	-62.53	-40.16

## 6.2.2 Harmonics for Band 2

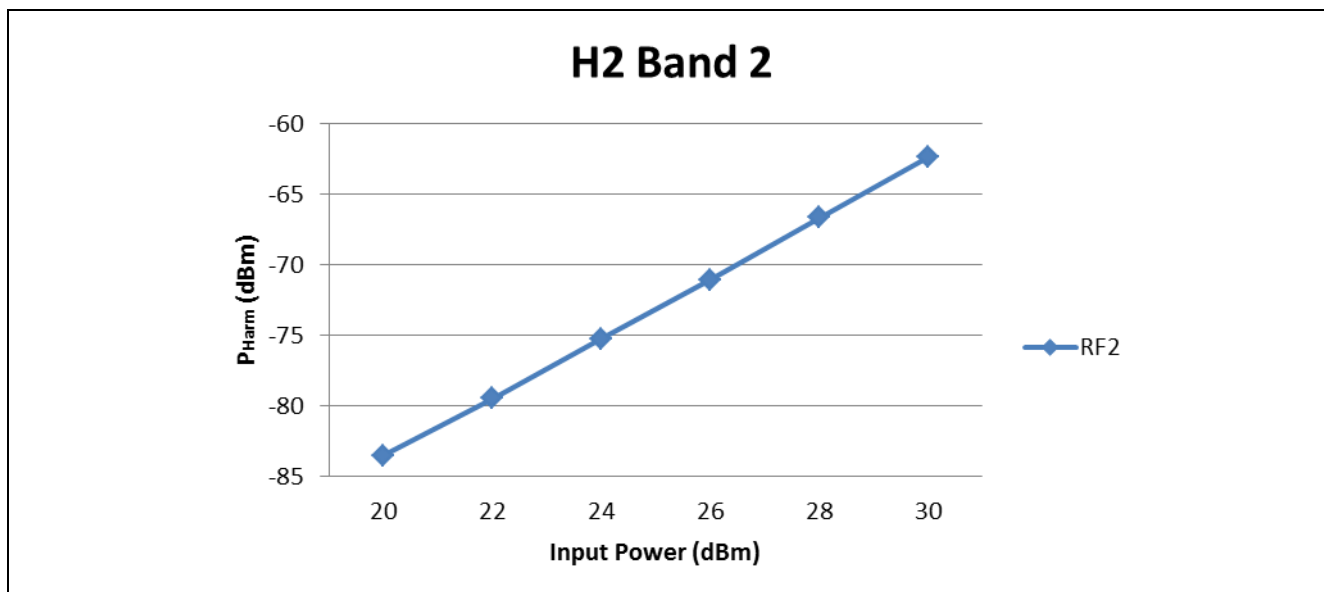


Figure 33 2<sup>nd</sup> harmonics at fc=1880MHz

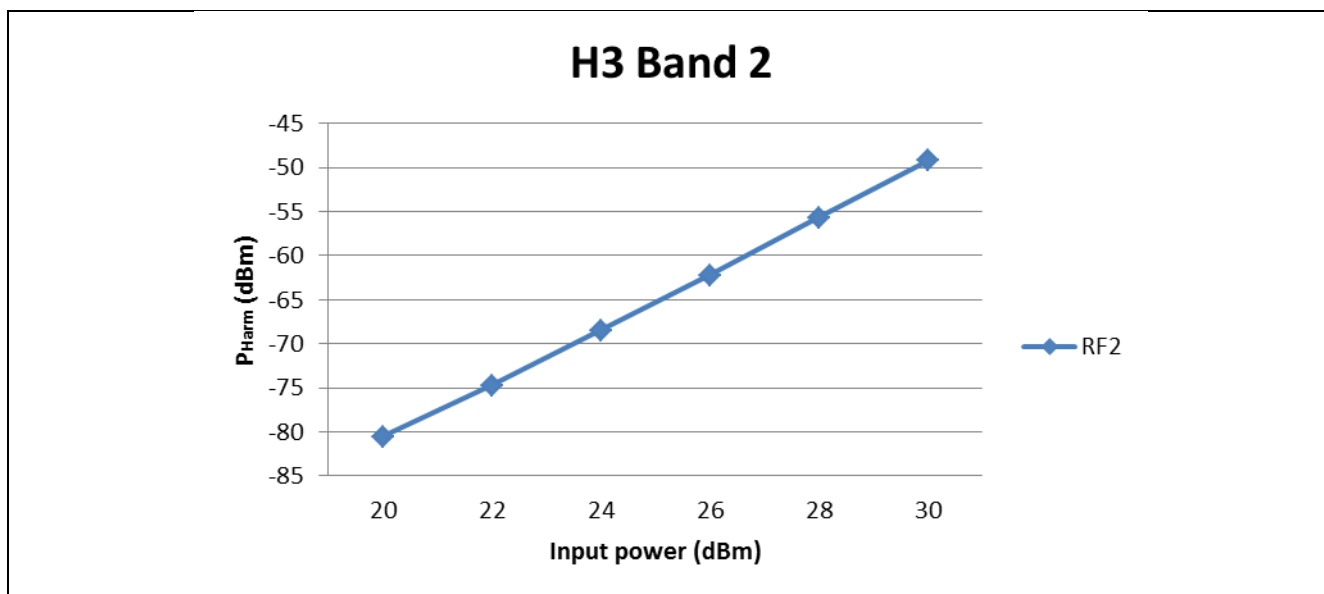


Figure 34 3<sup>rd</sup> harmonics at fc=1880MHz

fc=1880MHz		H2	H3
		RF2 (dBm)	RF2 (dBm)
RFin (dBm)	20	-83.48	-80.59
	22	-79.44	-74.76
	24	-75.23	-68.52
	26	-71.03	-62.26
	28	-66.66	-55.72
	30	-62.37	-49.24

### 6.2.3 Harmonics for Band 5

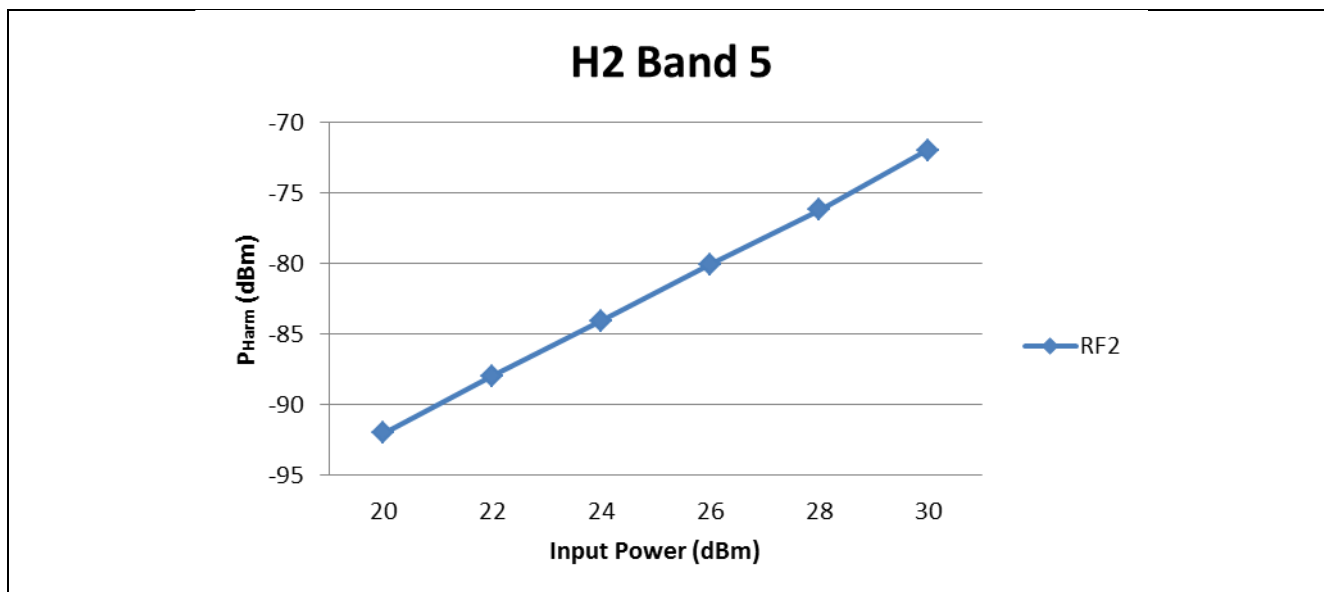


Figure 35 2<sup>nd</sup> harmonics at  $f_c=836,5\text{MHz}$

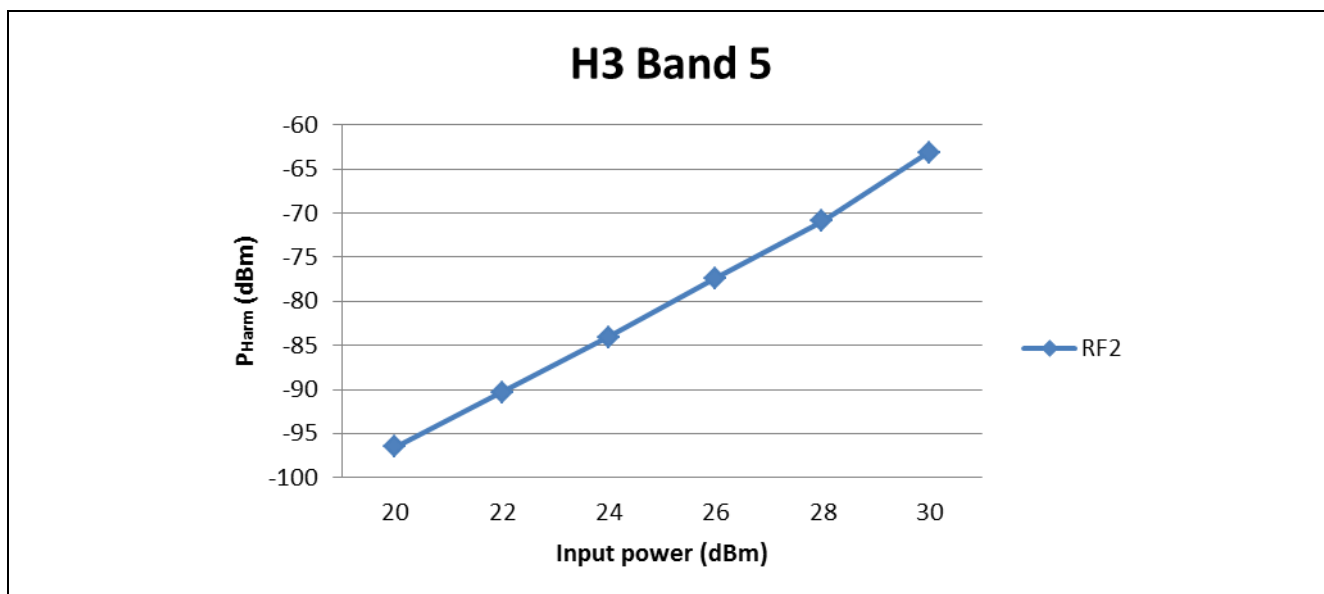


Figure 36 3<sup>rd</sup> harmonics at  $f_c=836,5\text{MHz}$

$f_c=836,5\text{MHz}$		H2	H3
		RF2 (dBm)	RF2 (dBm)
RFin (dBm)	20	-92.01	-96.51
	22	-87.97	-90.32
	24	-84.06	-84.05
	26	-80.04	-77.36
	28	-76.17	-70.88
	30	-71.94	-63.17



## 6.2.4 Harmonics for Band 7

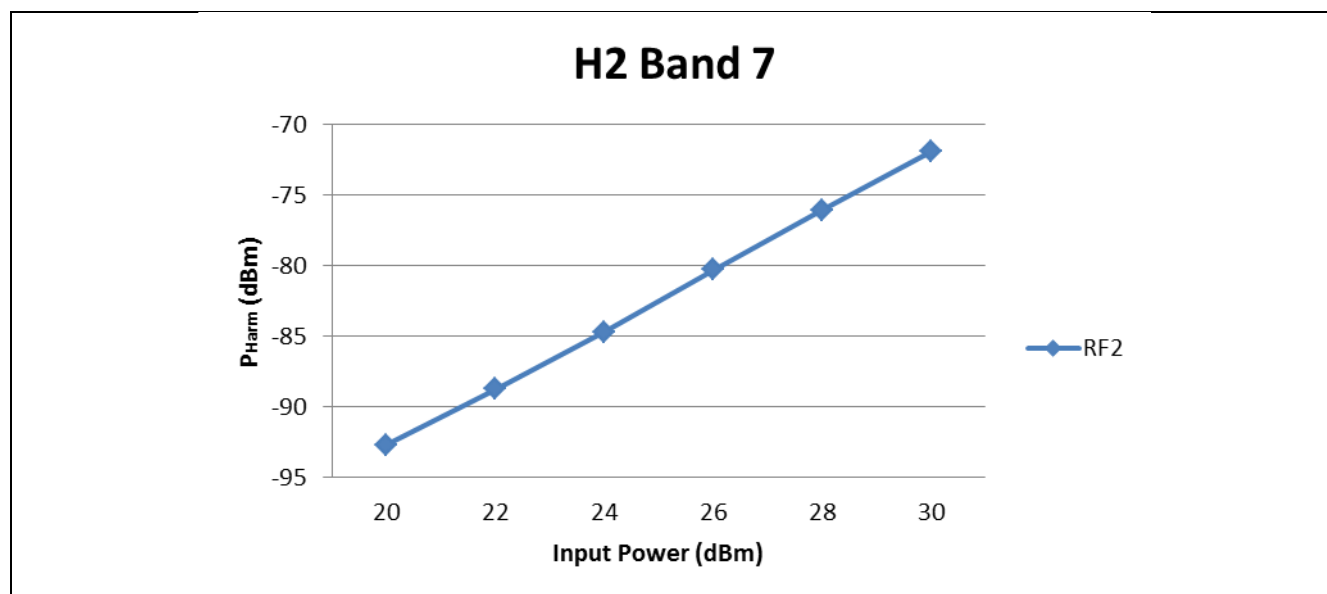


Figure 37 2<sup>nd</sup> harmonics at fc=2535MHz

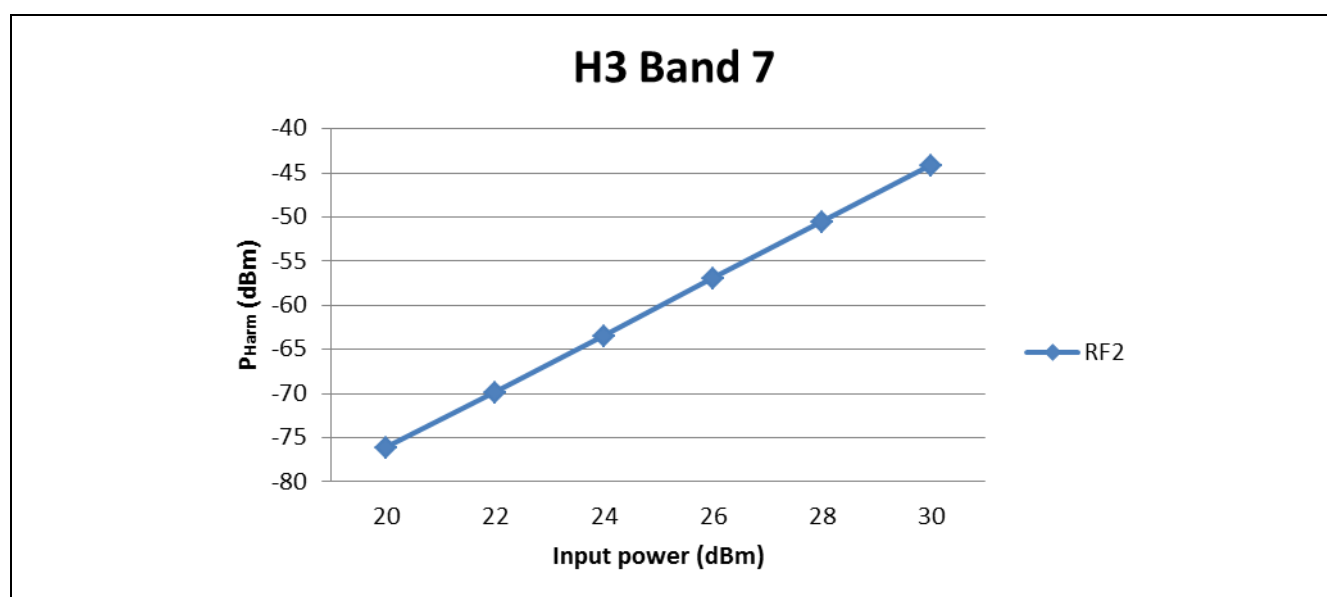


Figure 38 3<sup>rd</sup> harmonics at fc=2535MHz

fc=2535MHz		H2	H3
		RF2 (dBm)	RF2 (dBm)
RFin (dBm)	20	-92.69	-76.13
	22	-88.74	-69.89
	24	-84.67	-63.52
	26	-80.27	-56.94
	28	-76.04	-50.57
	30	-71.93	-44.12

## 6.2.5 Harmonics for Band 13

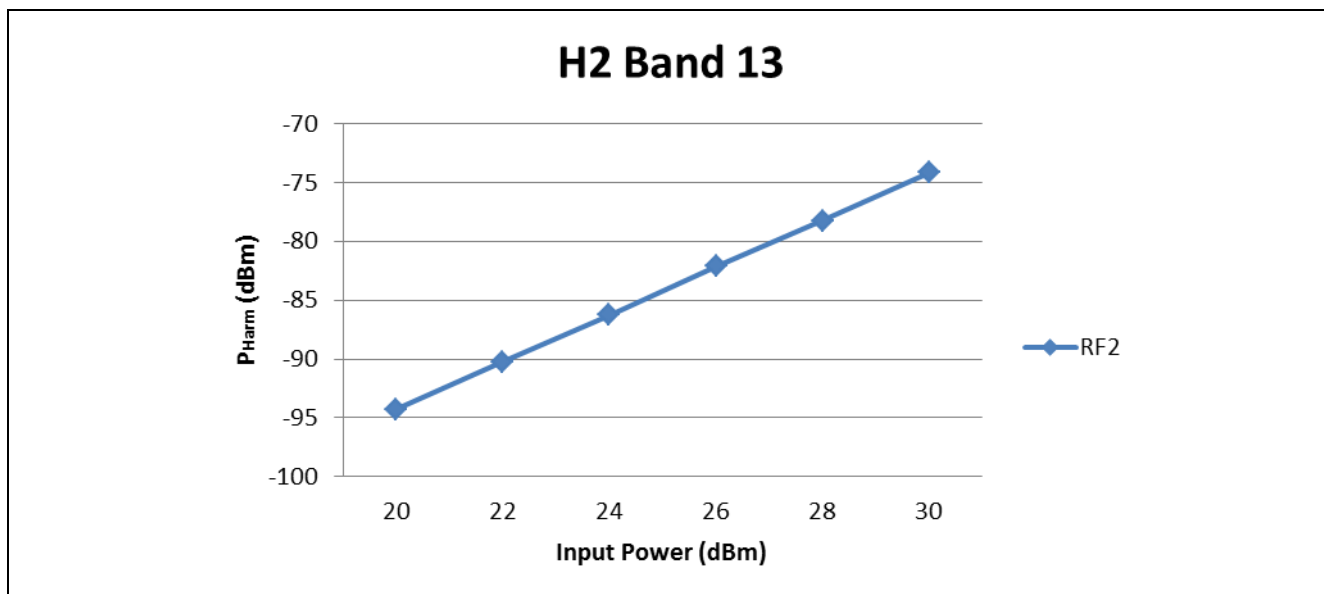


Figure 39 2<sup>nd</sup> harmonics at fc=782MHz

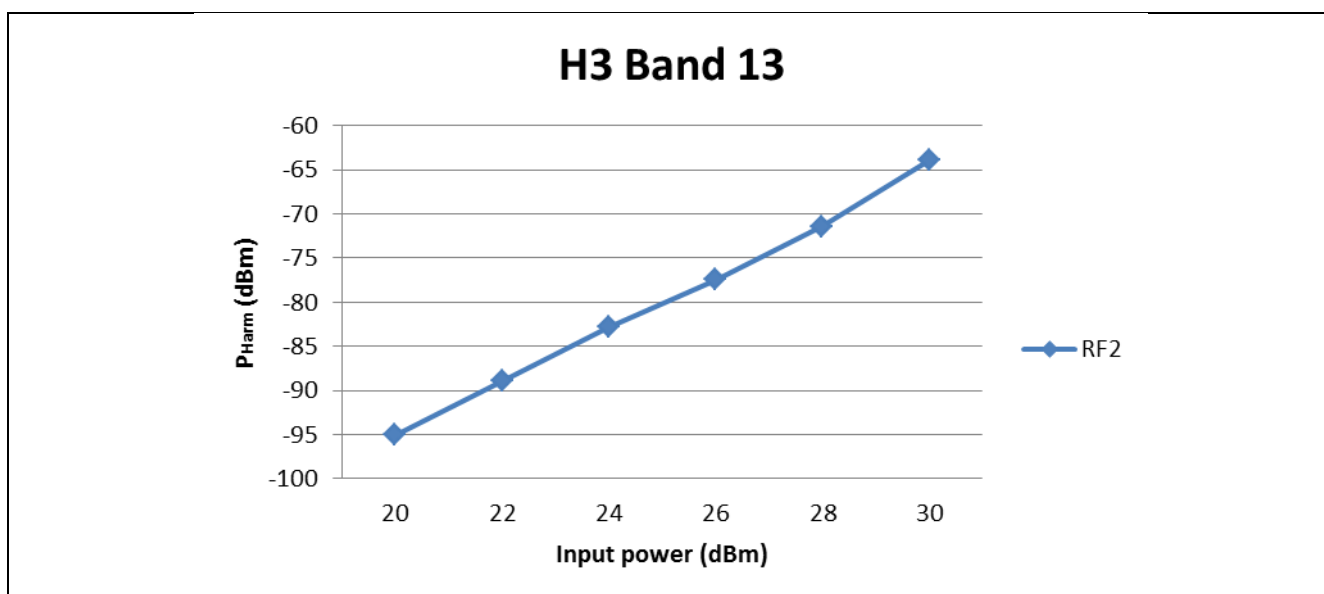


Figure 40 3<sup>rd</sup> harmonics at fc=782MHz

fc=782MHz		H2	H3
		RF2 (dBm)	RF2 (dBm)
RFin (dBm)	20	-94.27	-95.02
	22	-90.21	-88.96
	24	-86.25	-82.84
	26	-82.12	-77.45
	28	-78.26	-71.46
	30	-74.16	-63.93

## 7 Evaluation Board and Layout Information

### 7.1 Evaluation Board

In this application note, the following PCB is used:

PCB Marking: **BGS1xGA14**

PCB material: **Rogers**

$\epsilon_r$  of PCB material: **3.55**

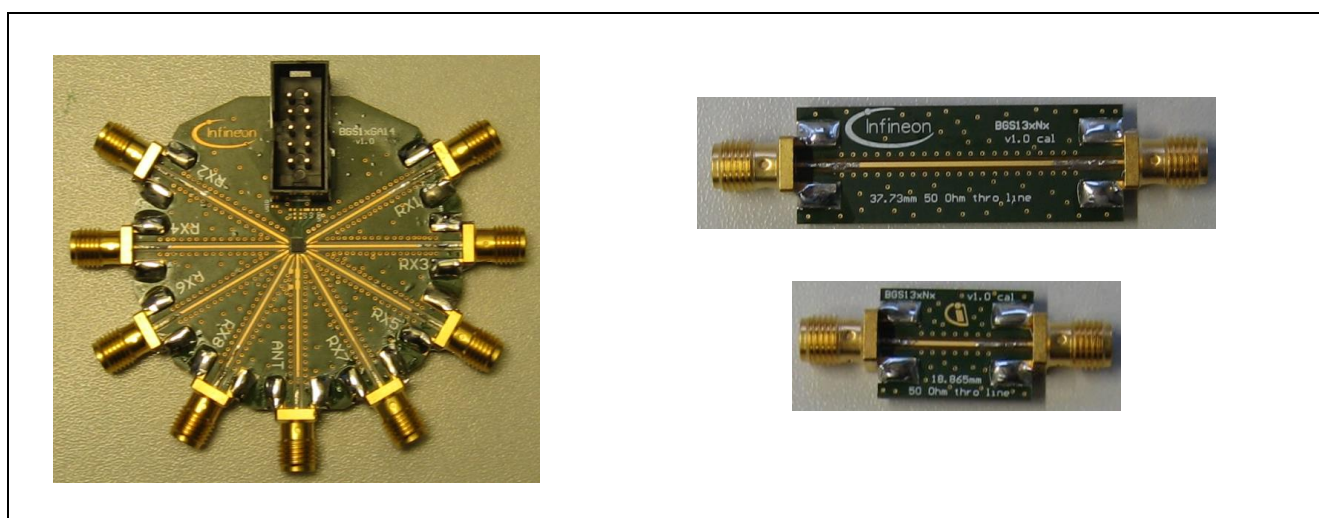


Figure 41 BGS14GA14 Application Board and deembedding kit

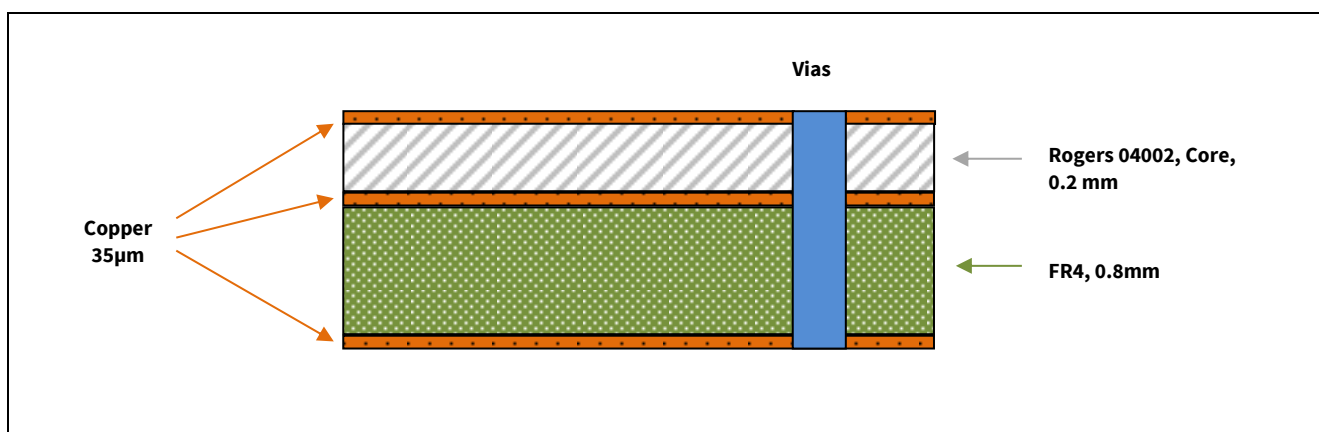


Figure 42 PCB cross-section of the evaluation board for BGS14GA14

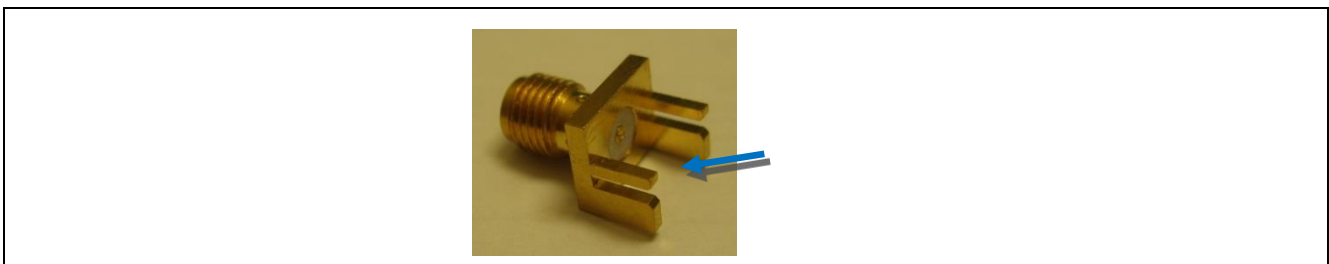
## 7.2 Measurement description and deembedding

Below is a picture of the evaluation board used for the measurements (Figure 43). The board is designed in the way that all connecting 50 Ohm lines have the same length.

To get correct called “device level” measurement values for the insertion loss of the BGS14GA14 all influences and losses of the evaluation board, lines and connectors have to be eliminated. Therefore a separate de-embedding board, representing the line length is necessary.

After full port calibration of the network analyzer (NWA) a deembedding has to be done in several steps:

- Use an SMA connector whose inner conductor has been removed to tune out one of the SMA to PCB transitions using the port extension on one port (Figure 43). Turn port extensions on.
- Measure S21 of the half-thru structure (Figure 41, smallest board) with port extension enabled. The result is the de-embedding of S21 including only one SMA connector and the transmission line to the chip. Store this as S-parameter (s2p) file.
- Turn all port extension off.
- Load the stored s-parameter file as de-embedding on all used NWA ports
- Check insertion loss with the de-embedding through board (Figure 41 right upper board)



**Figure 43 SMA connector for deembedding procedure**

If the check of the deembedding shows an insertion loss of the through about  $\pm 0.04$  dB (depending on the measurement setup accuracy, e.g. NWA) then the Device itself can be measured.

## **8 Authors**

Renat Rius, Application Engineer of Business Unit “RF and Protection Devices”

André Dewai, Senior Application Engineer of the Business Unit “RF and Protection Devices”

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