BGS12SN6

Performance of SPDT RF Switch

Ultra Low Insertion Loss Wideband RF SPDT for UMTS, WCDMA and LTE diversity or WiFi applications

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1 Introduction

The BGS12SN6 RF MOS switch is designed for mid power and pre PA applications. Any of the 2 ports can be used as termination of the diversity antenna or Wifi application handling up to 30 dBm.

This single supply chip integrates on-chip CMOS logic driven by a simple, single-pin CMOS or TTL compatible control input signal. The 0.1 dB compression point exceeds the switch's maximum input power level of 32 dBm, resulting in linear performance at all signal levels. The RF switch has a very low insertion loss of 0.26 dB in the Low Band (LB), 0.29 dB in the Mid Band (MB) and High Band (HB) and 0.56 dB in the 5GHz range (measured directly with probes on the package).

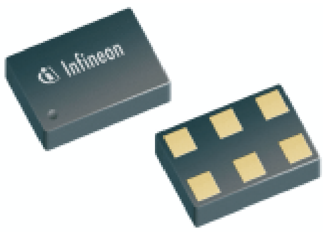
Unlike GaAs technology, external DC blocking capacitors at the RF ports are only required if DC voltage is applied externally.

The BGS12SN6 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.

2 BGS12SN6 Features

2.1 Main Features

- 2 high-linearity TRx paths with power handling capability of up to 30 dBm
- High switching speed, ideal for WLAN and Bluetooth applications
- All ports fully symmetrical
- No external decoupling components required
- Very low insertion loss up to 6 GHz
- Low harmonic generation
- High port-to-port-isolation
- 0.1 to 6 GHz coverage
- High ESD robustness
- On-chip control logic
- Very small leadless and halogen free package TSLP-6-2 (0.7x1.1mm^2) with super low height of 0.31 mm
- RoHS compliant package



2.2 Functional Diagram

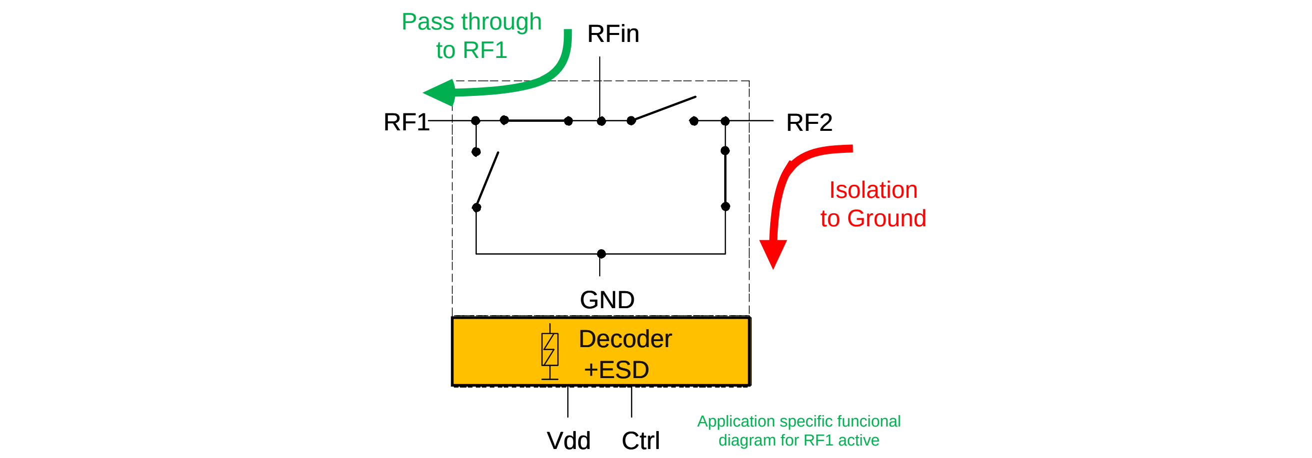


Figure 1 BGS12SN6 Functional Diagram

The functional Diagram in **Figure 1** shows a typical bahaviour of the BGS12SN6 in active state, meaning RF1 active and RF2 in isolation mode. This Daigram gives a short brief about the working princip of this SPDT. The BGS12SN6 in designed by an implementation of several series and shunt transistors to ground to optimize the RF signal parameter in points of isolations between active and non-active ports and the RF power capability of 32 dBm in maximum ratings.

2.3 Pin Configuration

In Figure 2 the pin configuration in top view is given.

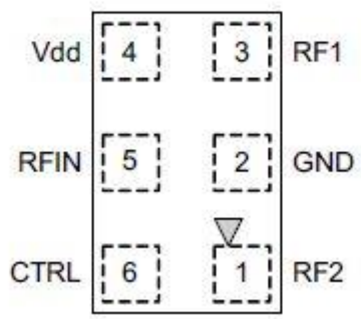


Figure 2 Pin configuration

2.4 Pin Description

Table 1 Pin Description (top view)

Pin NO	Name	Pin Type	Function
1	RF2	I/O	RF port 2
2	GND	GND	Ground
3	RF1	I/O	RF port 1
4	Vdd	PWR	Supply Voltage
5	RFIN	I/O	RF port In
6	CTRL	I	Control Pin

3 Application

3.1 Band Selection with RF CMOS Switch in Single-Ended Configuration

The number of LTE bands to support in a mobile phone is increasing rapidly worldwide. A simple way to support more bands in a mobile phone is to implement band selection function by adding a RF CMOS switch to existing transceiver/diversity ICs. Following two examples show band selection with the BGS12SN6, switching in single-ended configuration, a WiMAX FE system and a typical WLAN Dual Band application using the BGS12SN6 as RF switch.

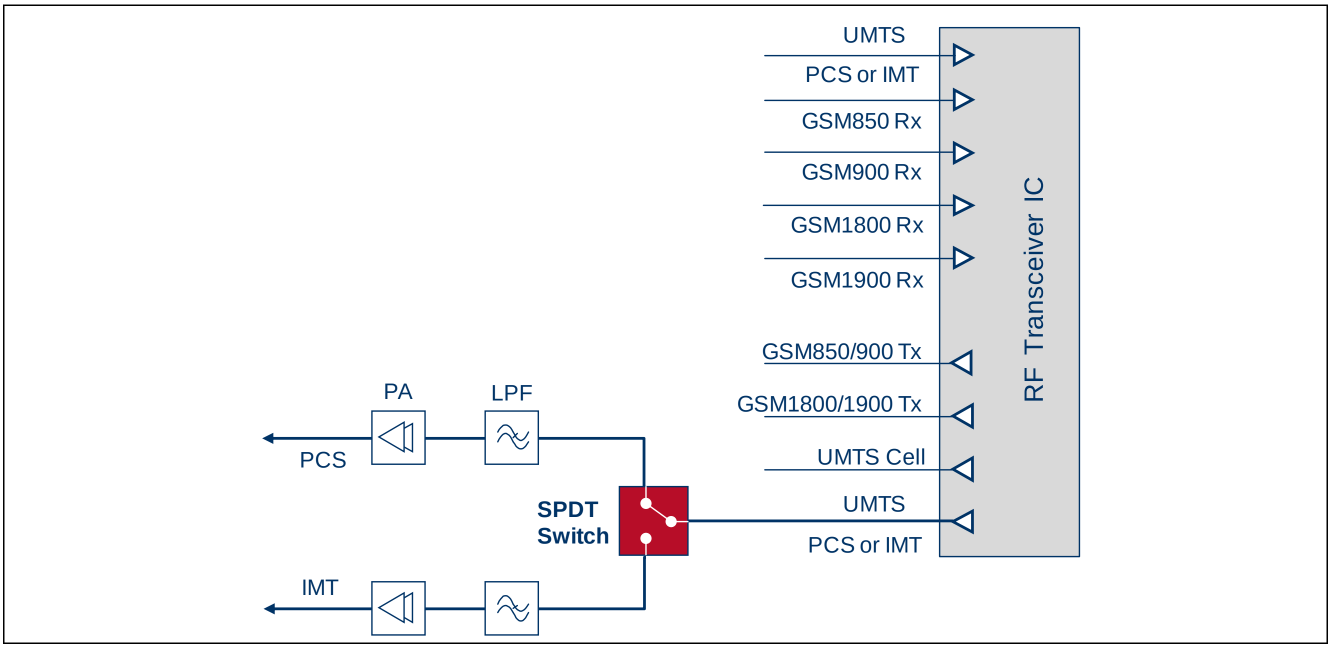


Figure 3 PCS/IMT band switching

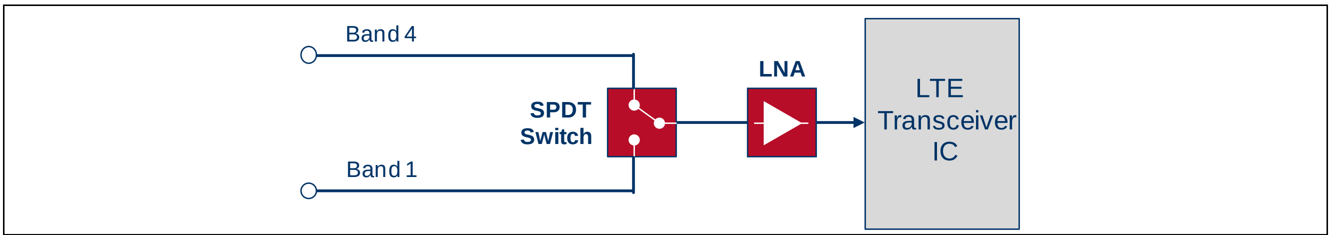


Figure 4 LTE Band -1/Band -4 switching

Figure 3 and Figure 4 are typical examples of band switching in a phone or tablet for transmitting and receivien path. Such an application, using BGS12SN6 as band selection switch supports a brider bandwith for data transfer by adding an extra band at the transceivers to overcome the bottleneck to get higher data rates and improve the system performance.

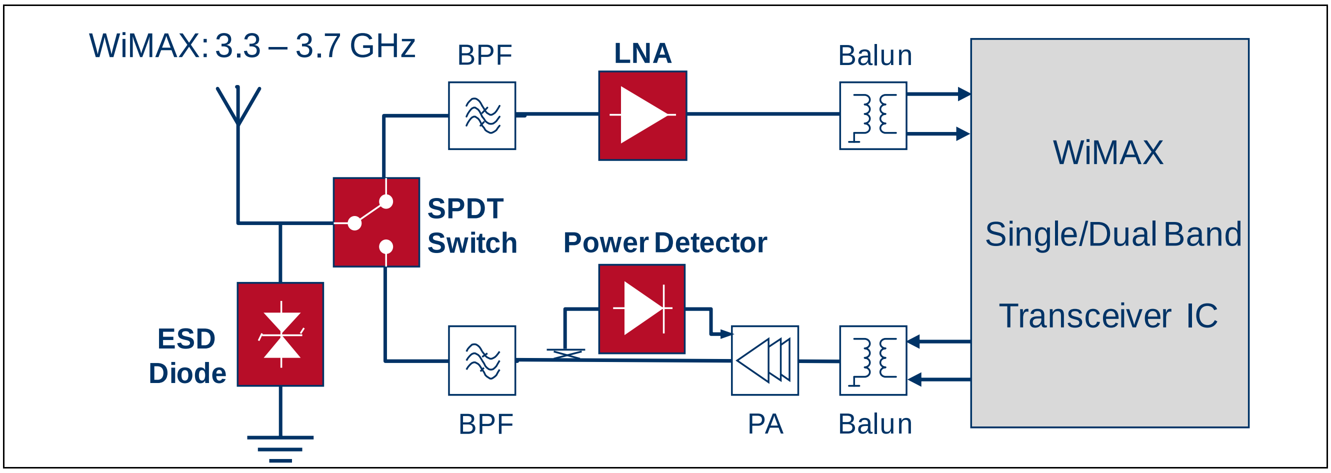


Figure 5 3.5 GHz WiMAX (IEEE 802.16e) transceiver system

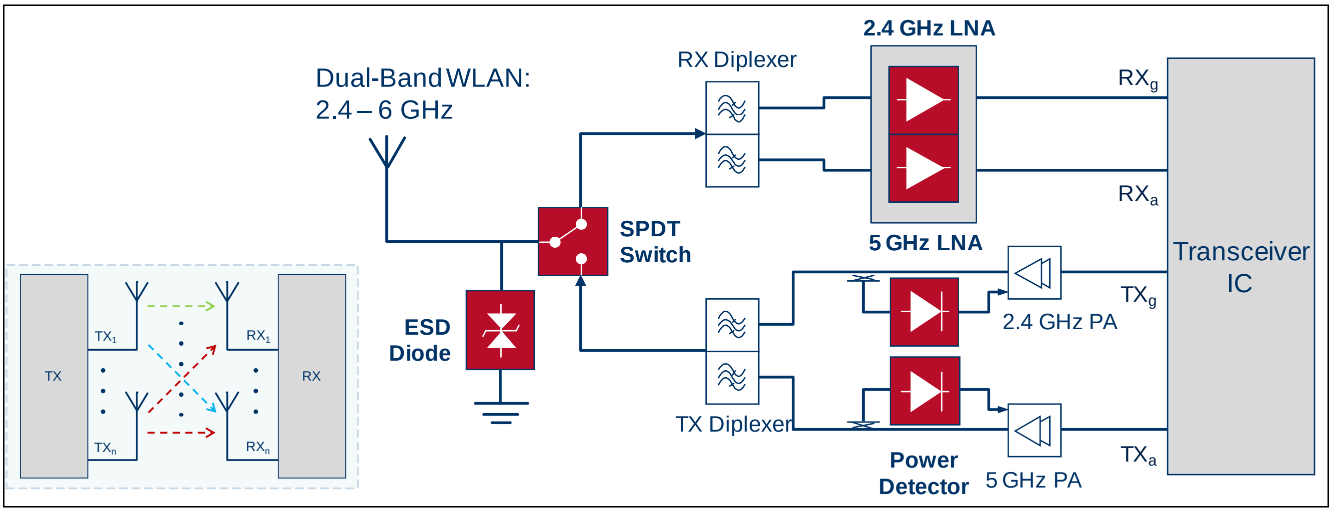


Figure 6 Dual-band (2.4–6.0 GHz) WLAN (IEEE 802.11a/b/g/n), also MIMO applications

Thanks to the BGS12SN6 wideband RF performance, supporting a very lo insertion loss of around 0.4 dB to 0.7 dB upto 6 GHz, this SPDT is highly suitable for WiMAX (**Figure 5**) and WLAN (**Figure 6**) applications. Next to this performance wise system key parameter, the BGS12SN6 has a very fast RF rise time of about 70 ns.

3.2 Application Board

Below is a picture of the evaluation board used for the measurements (Figure 7). The board is designed so that all connecting 50 Ohm lines have the same length.

In order to get accurate values for the insertion loss of the BGS12PL6 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 (Figure 6). But be aware, this calibration/deembedding method is only working in a proper way **up to 3 to 4 GHz**. Upper frequencies, and the resulting influence of the pcb transition to the coaxial line of the SMA connector can not be deembedded in such a way.

The calibration of the network analyser (NWA) is done in severall steps:

- Perform full calibration on all NWA ports.
- Attach empty SMA connector (with cutted RF line, **Figure 8**, left) at port 2 and perform "open" port extension. Turn port extensions on.
- Connect the "half" de-embedding board (**Figure 8** left board) between port1 and port2, store this as a s-parameter (s2p) file.
- Turn all port extentions off.
- Load the stored s-parameter file as de-embedding file for all used NWA ports
- Switch all port extentions on
- Check insertion loss with the de-embedding through board (**Figure 8** right board)

In case, there is no NWA including this option for the deembedding available, please use the measured s2p file as a deembedding structure in any RF simulation environment @ all ports of the measured application board itself.

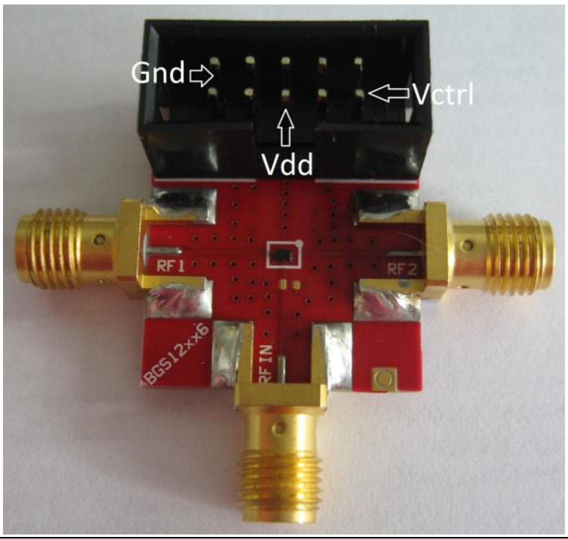


Figure 7 Layout of the application board

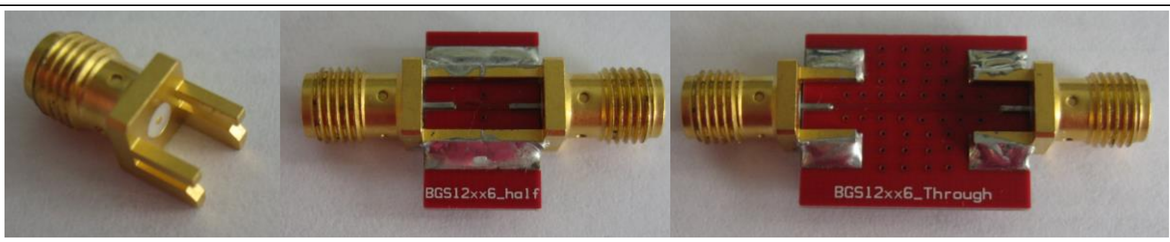


Figure 8 Layout of de-embedding boards and single SMA connector

Device level measurements above 4 GHz are not feasible with this deembeding method. The reason is a very tiny resonance between 5 and 6 GHz. Behind this behavior is the transmission between the pcb RF trace and the SMA coaxial line. The capacitance and the inductance are not sufficient enough to reproduce with the deembedding method. A better way to improve the compensation of the pcb losses and phase shifts is to perform a full open port extension with an empty application board including phase **and** losses. But, this is a trade of for insertion loss measurement accuracy over frequency bandwith. That means, for lower frequencies up to 3 or 4 Ghz the deembedding method is more ecactly, for higher frequencies the open port extension method is more accurate, shown in **Figure 9**, because of fewer losses in kind of quality characteristics of the connector to pcb transition, but limited by the number of points and the NWA's interpolation.

As reference for the BGS12SN6 performance, probe measurements direclty on the package (brown and red curve) pads are show the graph below.

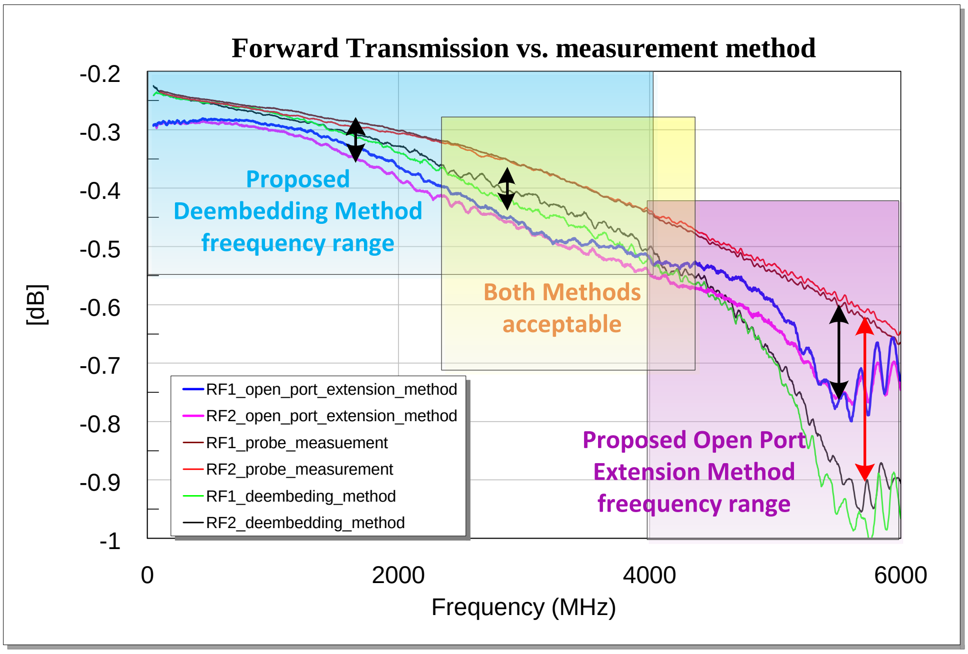


Figure 9 Forward transmission in order to measurement method

These small differences, depending on the measurement method, are only necessary for higly precise insertion loss measurement concerning the neededcorrectness of some 1/10 rather 1/100 of dB.

The construction of the PCB is shown in **Figure 10** and contains of 3 layers (35µm copper), one Signal RF layer, and two ground layers meaning RF ground DC ground. The Rodgers material defines the RF performance, the FR4 material is just use as a mechanical carrier in order to stability of the pcb.

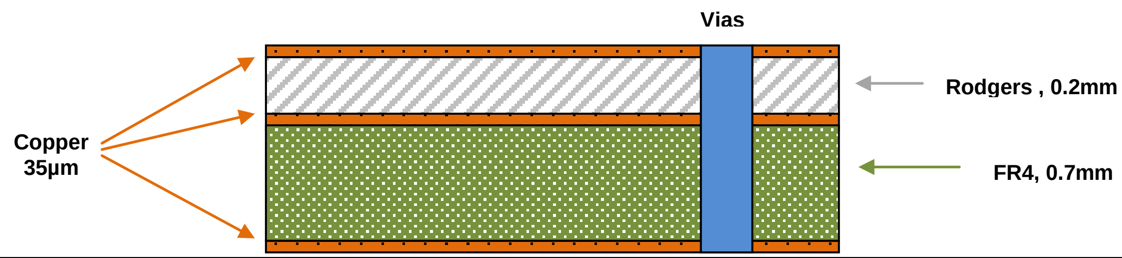


Figure 10 PCB layer information

4 Small Signal Characteristics

The small signal characteristics are measured at room temperature (~25°C) with a Network analyzer including a Multiport System on application board. The NWA is set to an input Power of 0dBm, a 50 MHz to 4 GHz (measuring LB and MB) or 50 MHz to 6 GHz (measuring HB and WLAN) frequency range with an IF bandwith of 15 kHz. All ports are terminated with a 50 Ω load (provided from the measurement system directly) during the measurement. Device specific, the Vdd is set to 3.3 volts and the Vctrl to 3 volts.

4.1 Measurement Results

In the following tables and graphs the most important RF parameter of the BGS12SN6 are shown. The markers are set to the most important frequencies in Low Band (up to 1 GHz), Mid Band (over 1 GHz up to 3 GHz) and High Band (3 GHz to 4 GHz)[1] for mobile communication applications and Wireless LAN (5 GHz)[2].

Table 2 Forward Transmission from RFIN Port to the Respective RF Port (dB)

Frequency (MHz)	Low Band			Mid Band						High Band		WLAN		
	824	915	1000	1575	1710	1910	2170	2400	2690	3400	3600	5200	5500	5800
RF1	-0.26	-0.27	-0.27	-0.3	-0.31	-0.32	-0.34	-0.37	-0.38	-0.49	-0.5	-0.68	-0.77	-0.67
RF2	-0.27	-0.27	-0.28	-0.31	-0.32	-0.33	-0.36	-0.38	-0.41	-0.5	-0.52	-0.69	-0.76	-0.71

Table 3 Reflection RFin Port to the Respective RF Port (dB)

Frequency (MHz)	Low Band			Mid Band						High Band		WLAN		
	824	915	1000	1575	1710	1910	2170	2400	2690	3400	3600	5200	5500	5800
RF1	-25.4	-24.8	-23.9	-20.6	-19.8	-19	-18.2	-17.6	-17	-15.4	-15.4	-18	-19.7	-20.9
RF2	-25.7	-24.9	-24.3	-21	-20.4	-19.8	-18.9	-18.4	-17.8	-16.1	-15.9	-17.9	-19.2	-20.1

Table 4 Reflection RF Port to the Respective RF Port (dB)

Frequency (MHz)	Low Band			Mid Band						High Band		WLAN		
	824	915	1000	1575	1710	1910	2170	2400	2690	3400	3600	5200	5500	5800
RF1	-26.2	-25.6	-24.7	-21	-20.2	-19.3	-18.3	-17.6	-16.9	-14.9	-14.9	-17.4	-18.7	-20.7
RF2	-25.4	-24.7	-24	-20.7	-20.2	-19.6	-18.8	-18.1	-17.4	-15.6	-15.6	-16.8	-17.7	-19

Table 5 Isolation RF1 (off state) to RF2 and RFin (dB)

Frequency (MHz)	Low Band			Mid Band						High Band		WLAN		
	824	915	1000	1575	1710	1910	2170	2400	2690	3400	3600	5200	5500	5800
RF2	-46.5	-45.8	-44.7	-39.3	-38.7	-38.5	-35.3	-34.5	-33.5	-31	-29.3	-20.9	-20.8	-22.7
RFin	-41	-39.9	-39.2	-34.1	-33.5	-32.7	-30.6	-29.8	-28.9	-26.8	-25.6	-18.3	-18	-19.9

Table 6 Isolation RF2 (off state) to RF1 and RFin (dB)

Frequency (MHz)	Low Band			Mid Band						High Band		WLAN		
	824	915	1000	1575	1710	1910	2170	2400	2690	3400	3600	5200	5500	5800
RF1	-46.1	-45.1	-44.2	-39.6	-38.6	-37.4	-36.1	-34.5	-34.2	-30.9	-29.2	-20.9	-21.4	-24.1
RFin	-40.5	-39.5	-38.7	-34.1	-33.1	-31.9	-30.3	-29	-27.7	-25.6	-24.9	-17.8	-17.2	-18.7

[1] Measured with open port extension deembedding method
[2] Measured with open port extension deembedding method

4.2 Forward Transmission (measured on application board)

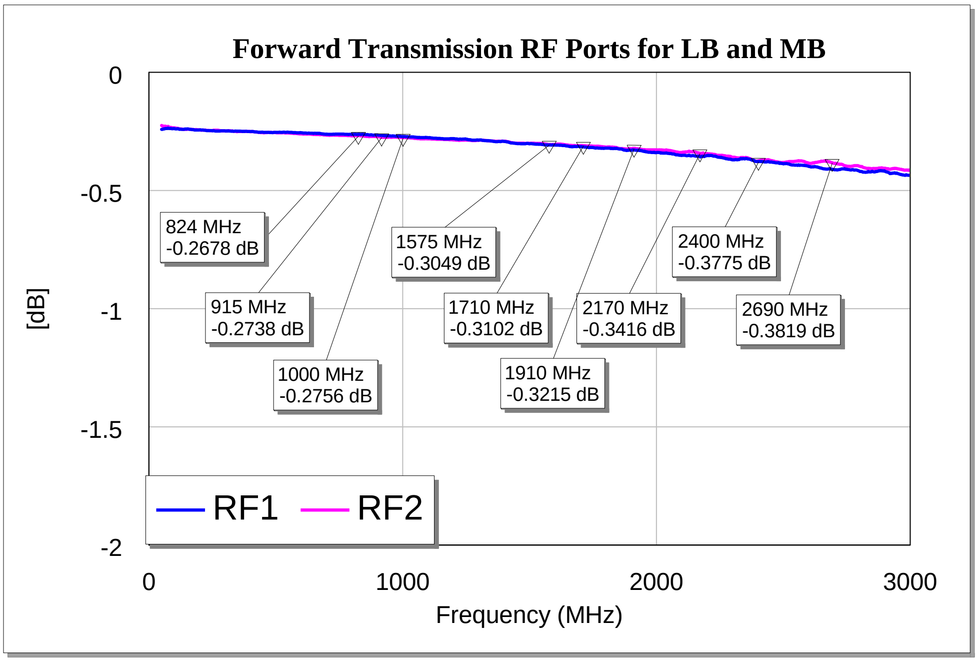


Figure 11 Forward Transmission Curves of all RF Ports for LB and HB frequency range

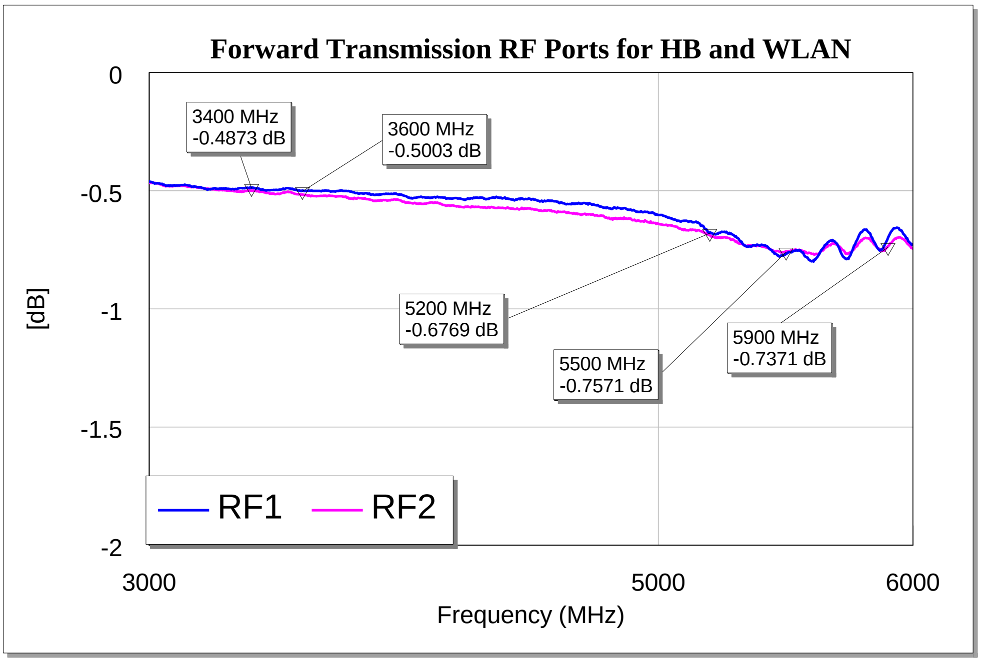


Figure 12 Forward Transmission Curves of all RF Ports for HB and WLAN frequency range

4.3 Forward Transmission (probe measurements on device pads)

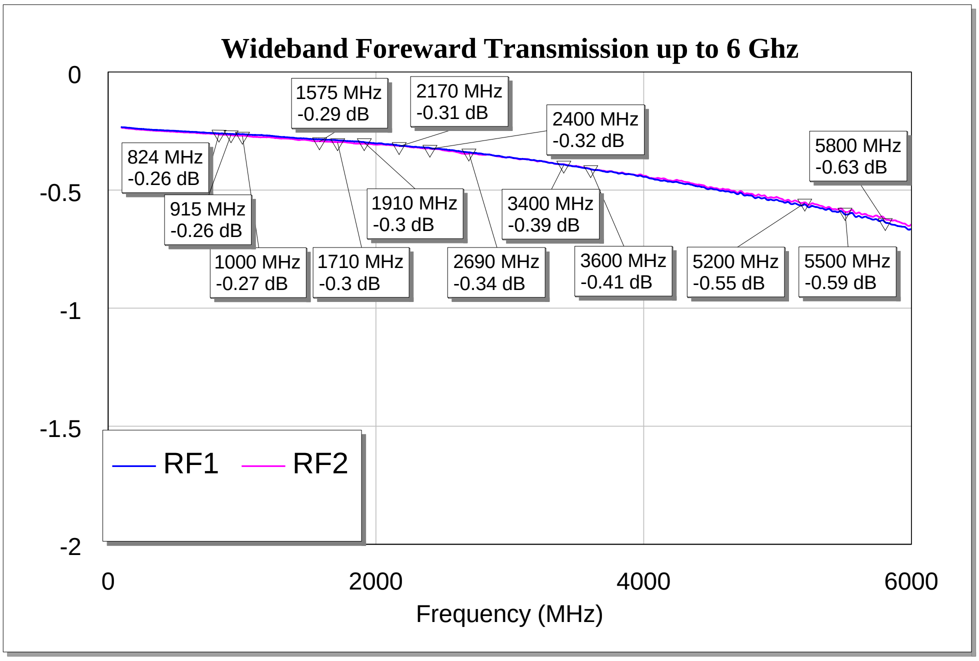


Figure 13 Wideband Forward Transmission Curves of all RF Ports

4.4 Wideband reflection RFin Port

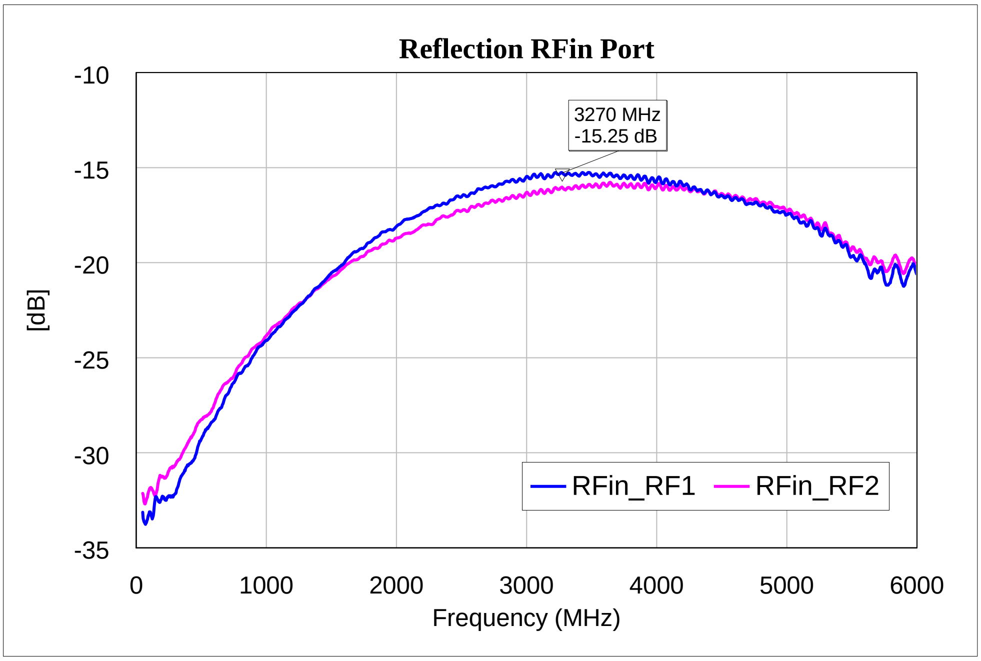


Figure 14 Reflction RFin Port (50 MHz to 6 GHz)

4.5 Wideband reflection RF Ports

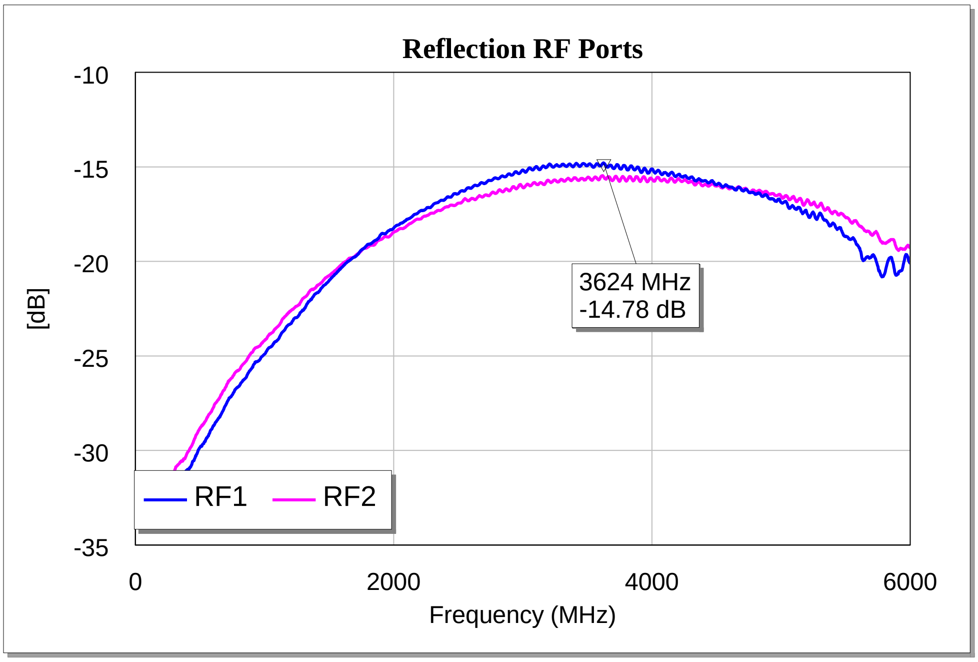


Figure 15 Reflction RFin Port (50 MHz to 6 GHz)

4.6 Wideband isolation RF1

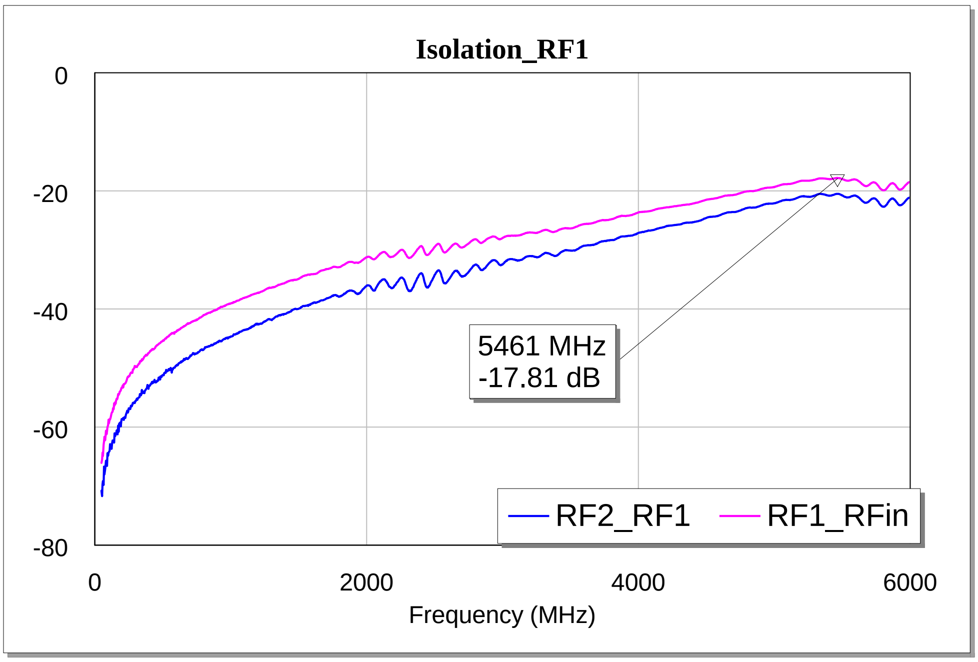


Figure 16 Isolation RF1 (50 MHz to 6 GHz)

4.7 Wideband isolation RF2

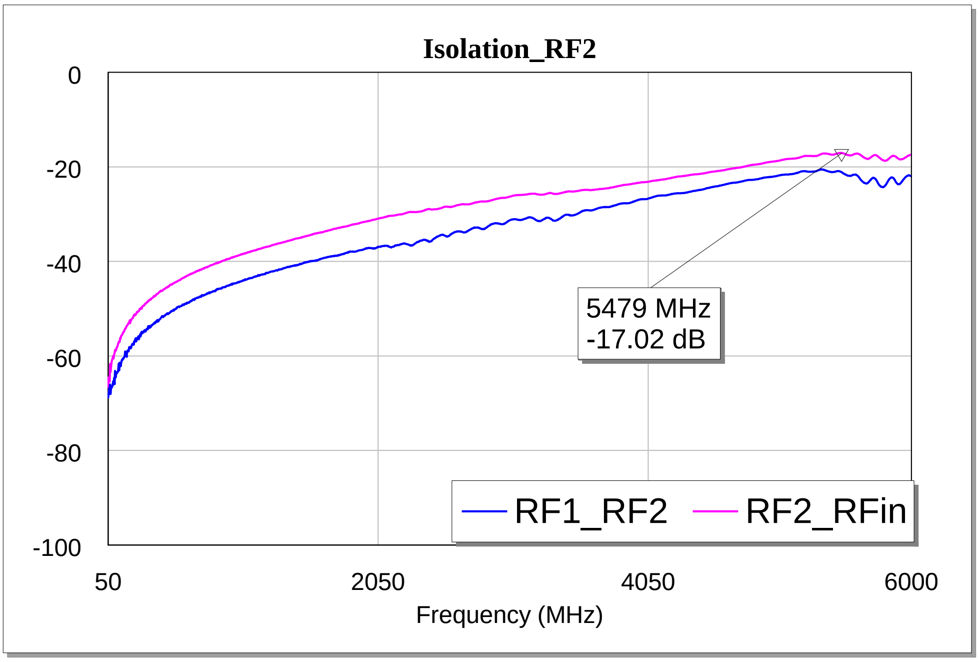


Figure 17 Isolation RF2 (50 MHz to 6 GHz)

5 Intermodulation

Another very important parameter of a RF switch is the large signal capability. 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 with high power.This signal (20 dBm) and a received Jammer signal (-15 dBm) are entering the switch.

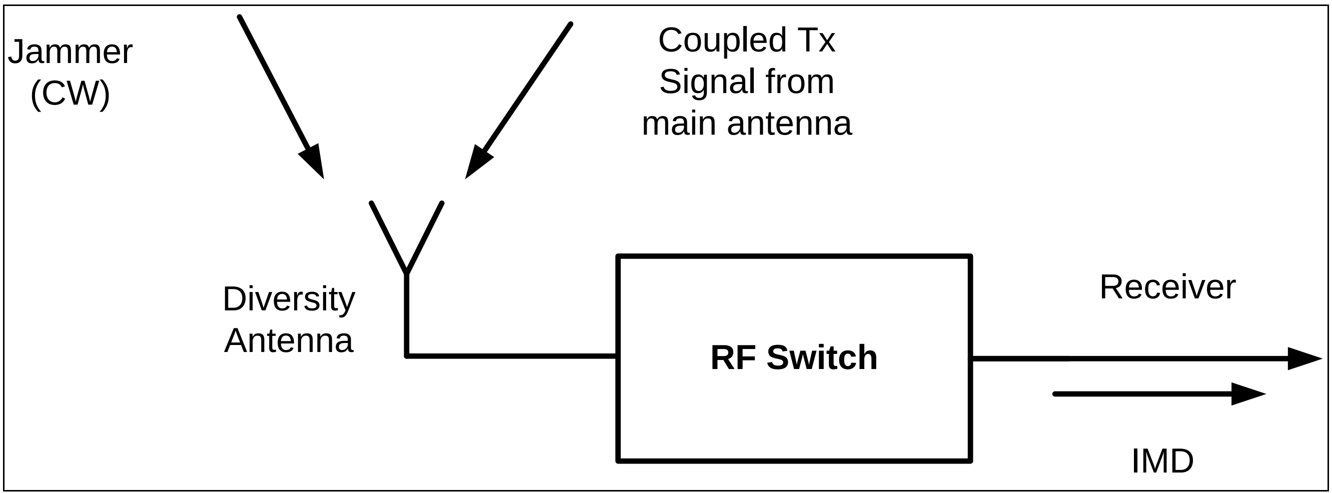


Figure 18 Block diagram of RF Switch intermodulation

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.

In **Error! Reference source not found.** frequencies for 3 bands and the linearity specifications for an undisturbed communication are given.

Table 7 Test conditions and specifications of IMD measurements

Band 1					
	TX		Interferer		IMD product
Testcase	F_{IN} (MHz)	P_{IN} (dBm) CW	F_{IN} (MHz)	P_{IN} (dBm) CW	F_{IMD} (MHz)
IMD3	1950	10	1760	-15	2140
IMD2 low			190		
IMD2 high			4090		
Band 5					
Testcase	F_{IN} (MHz)	P_{IN} (dBm) CW	F_{IN} (MHz)	P_{IN} (dBm) CW	F_{IMD} (MHz)
IMD3	835	10	790	-15	880
IMD2 low			45		
IMD2 high			1715		

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 Figure 21).

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

In Figure 21 the results for High band are given. 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.

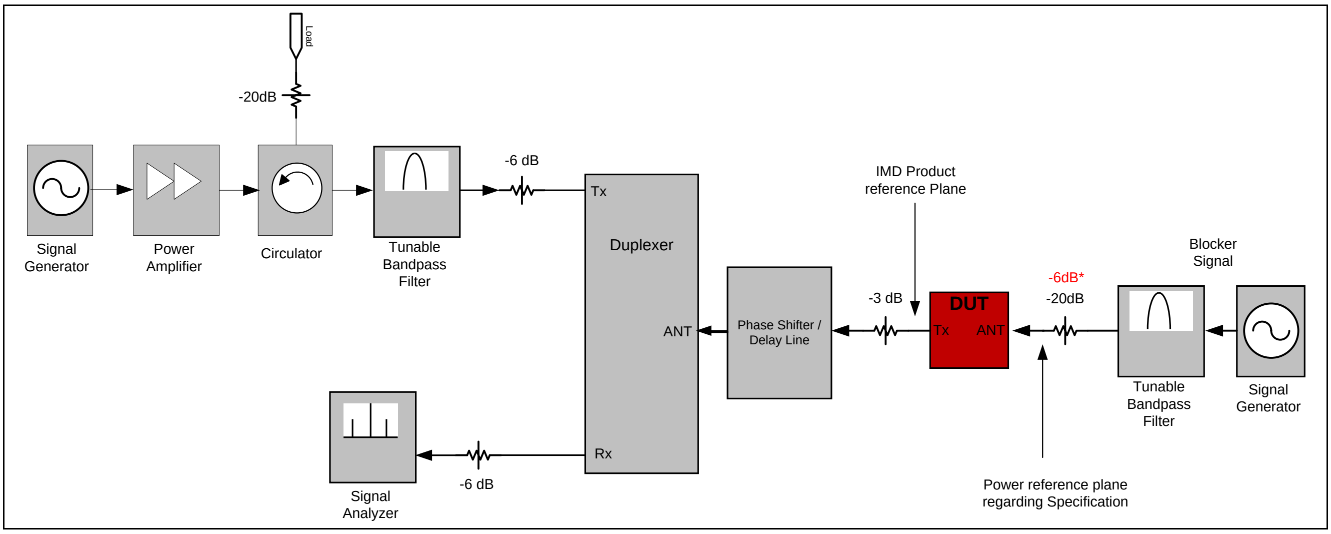


Figure 19 Test set-up for IMD Measurements for low power blocker signals

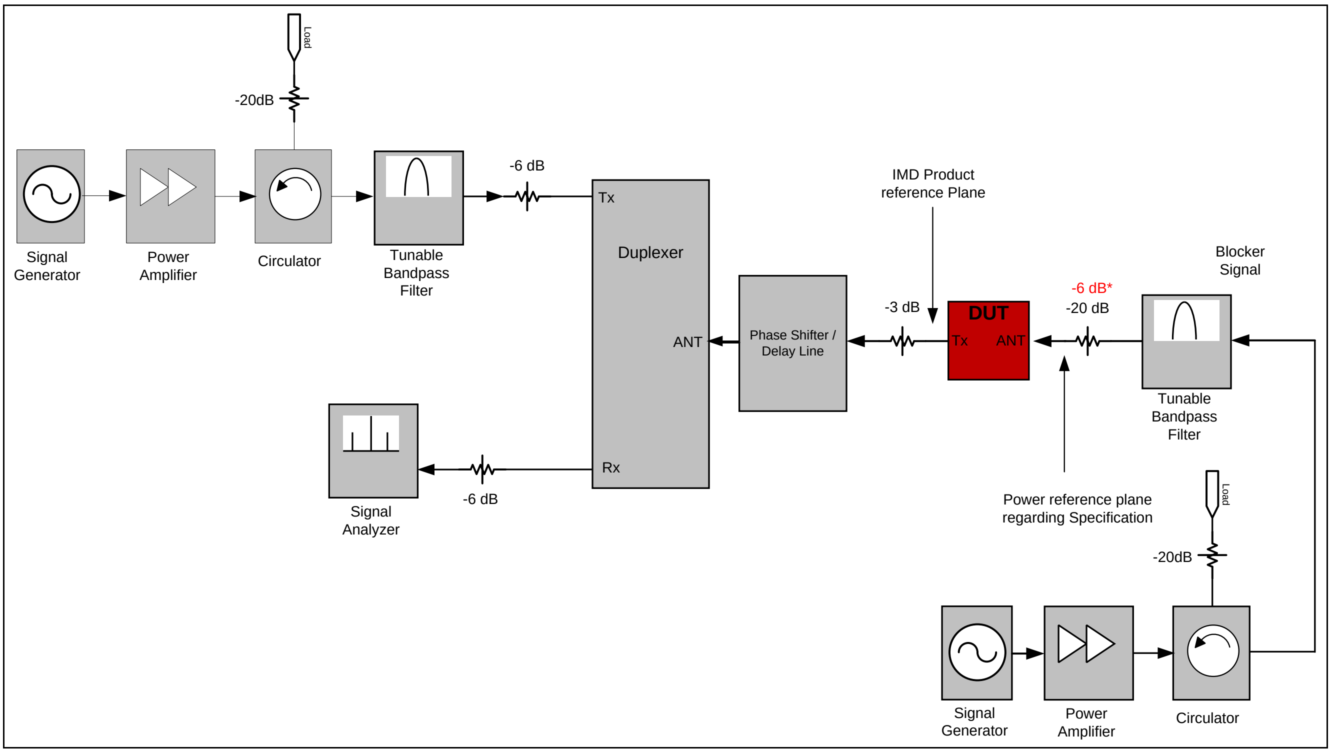


Figure 20 Test set-up for IMD Measurements for medium and high power blocker signals

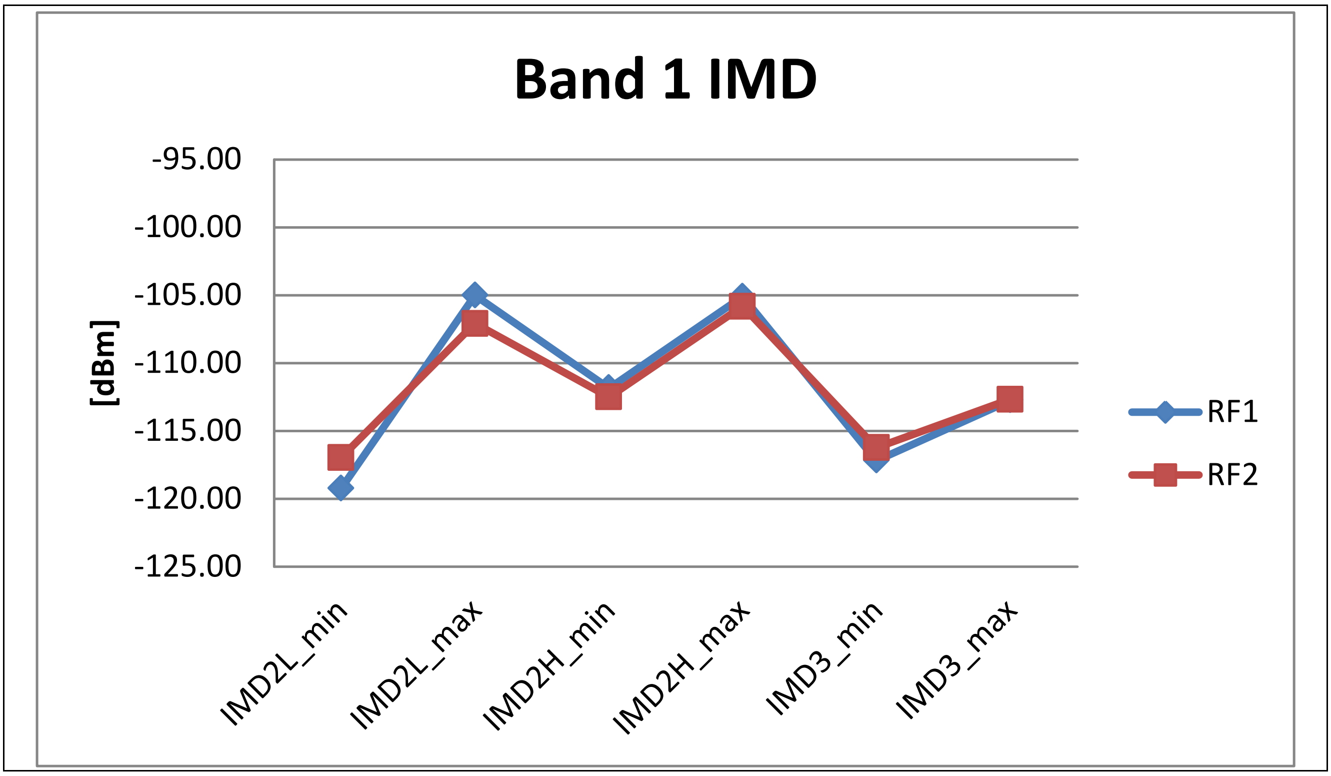


Figure 21 IMD2 and IMD3 results for Band I

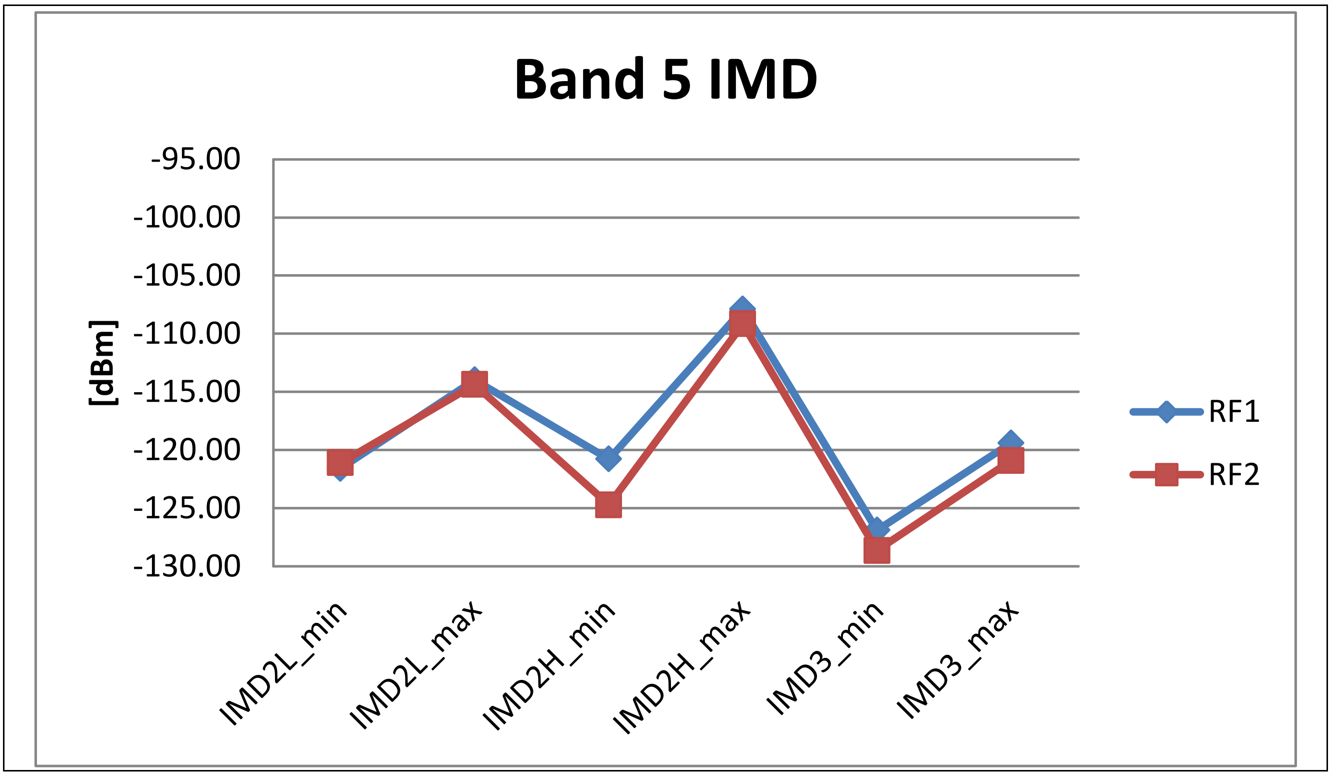


Figure 22 IMD Results for Band V

6 Harmonic Generation

Harmonic generation is another important parameter for the characterization of a RF switch. RF switches have to deal with high RF levels, up to 33 dBm. With this high RF power at the input of the switch harmonics are generated. These harmonics (2nd and 3rd) can disturb the other reception bands or cause distortion in other RF applications (GPS, WLan) within the mobile phone.

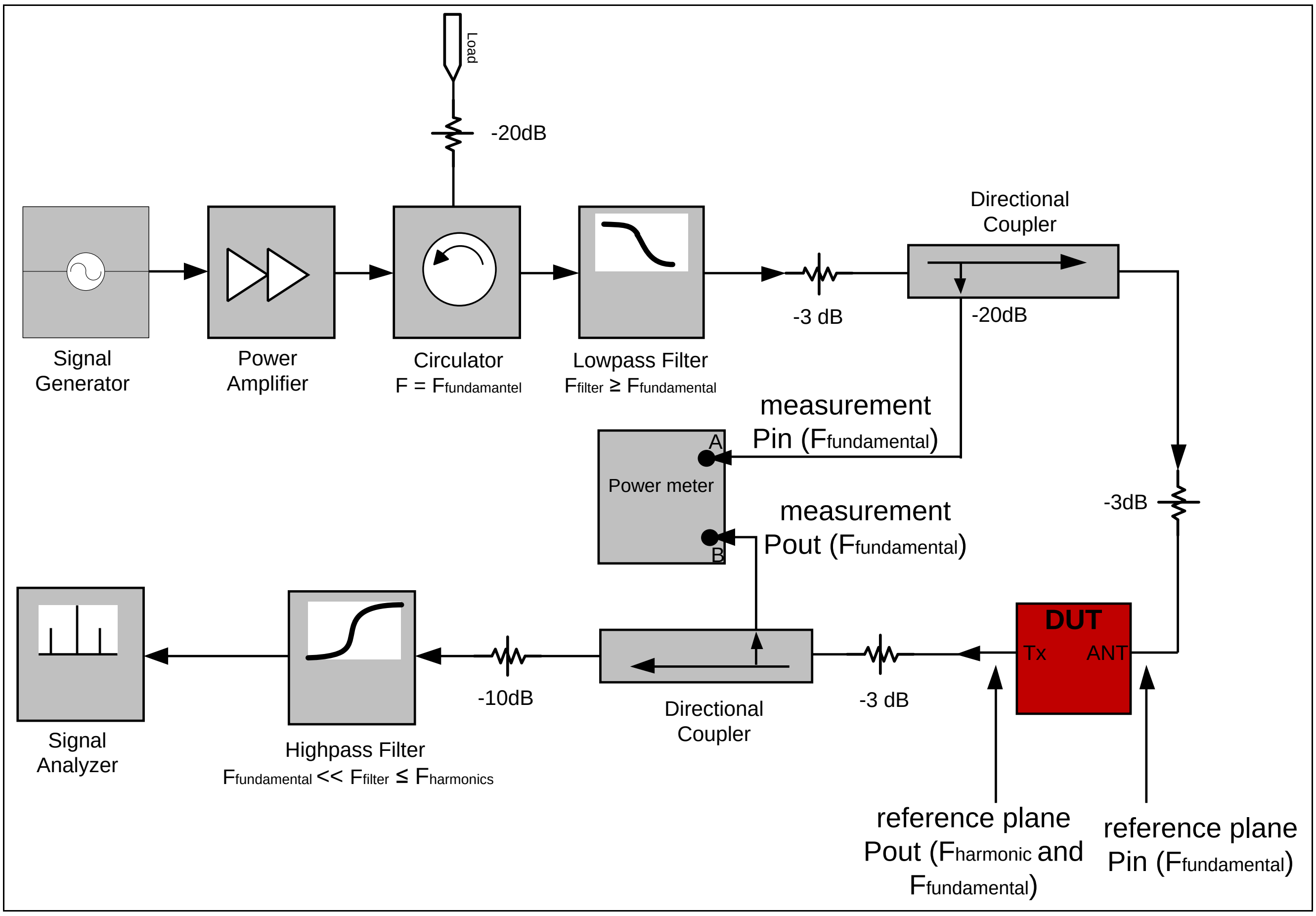


Figure 23 Set-up for harmonics measurement

The results for the harmonic generation at 824 MHZ are shown in Figure 24 (2nd harmonic) and Figure 25 (3rd harmonic) for all RF ports.

At the x-axis the input power is plotted and at the y- axis the generated harmonics in dBm.

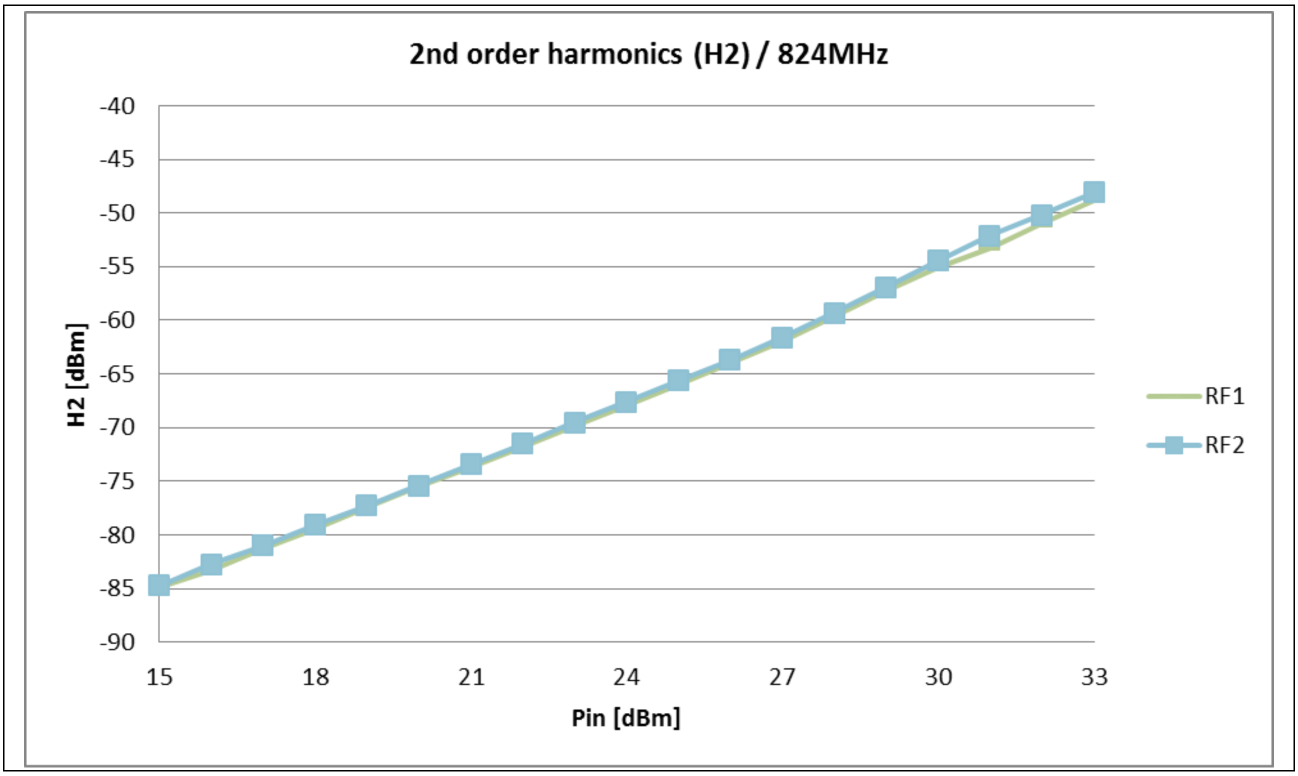


Figure 24 2nd harmonic at f_c=824 MHz

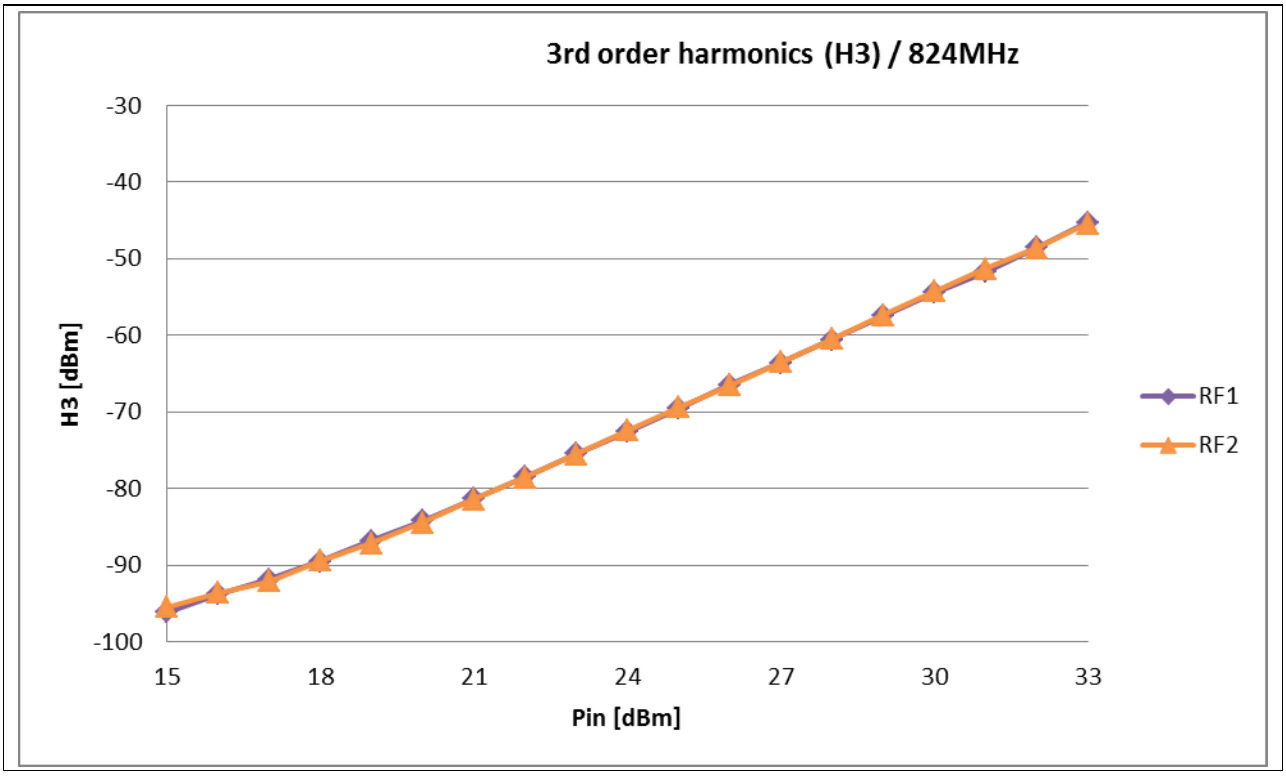


Figure 25 3rd harmonic at f_c=824 MHz

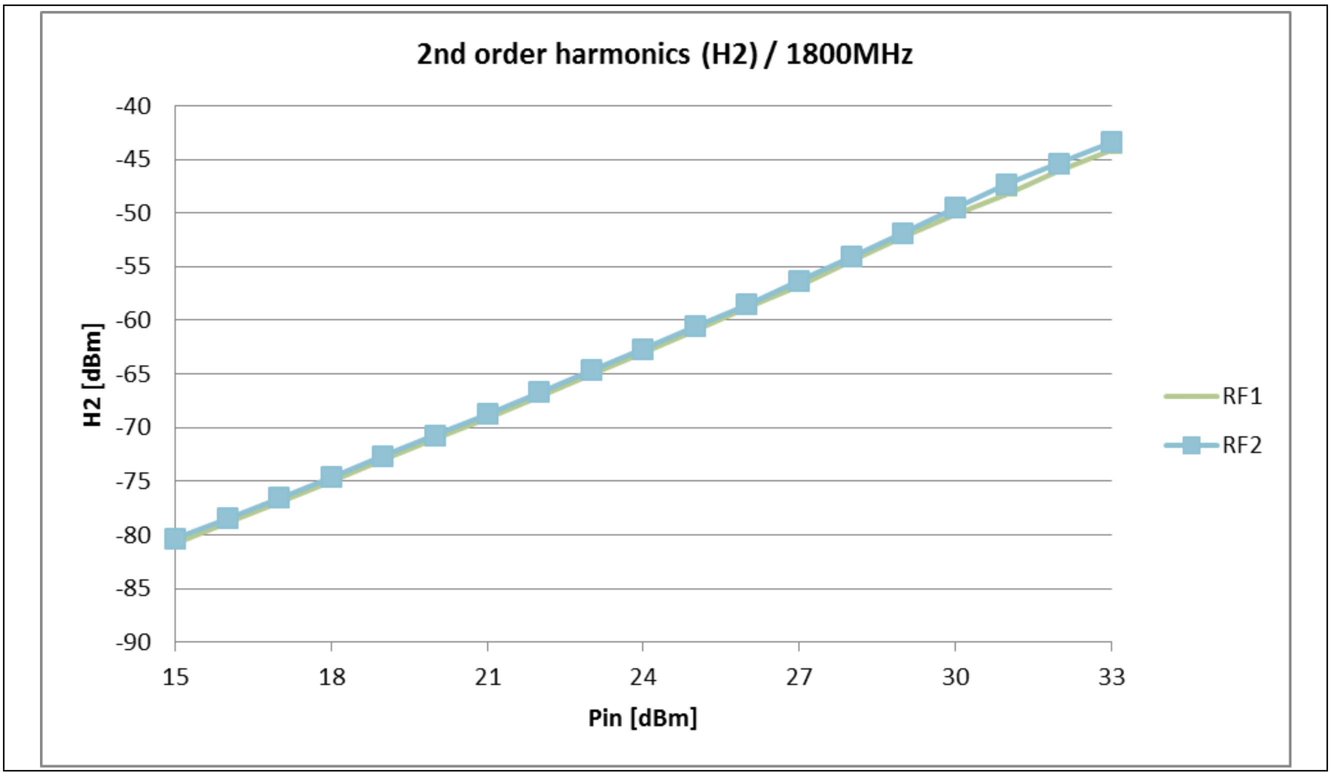


Figure 26 2nd Harmonic at f_c=1800 MHz

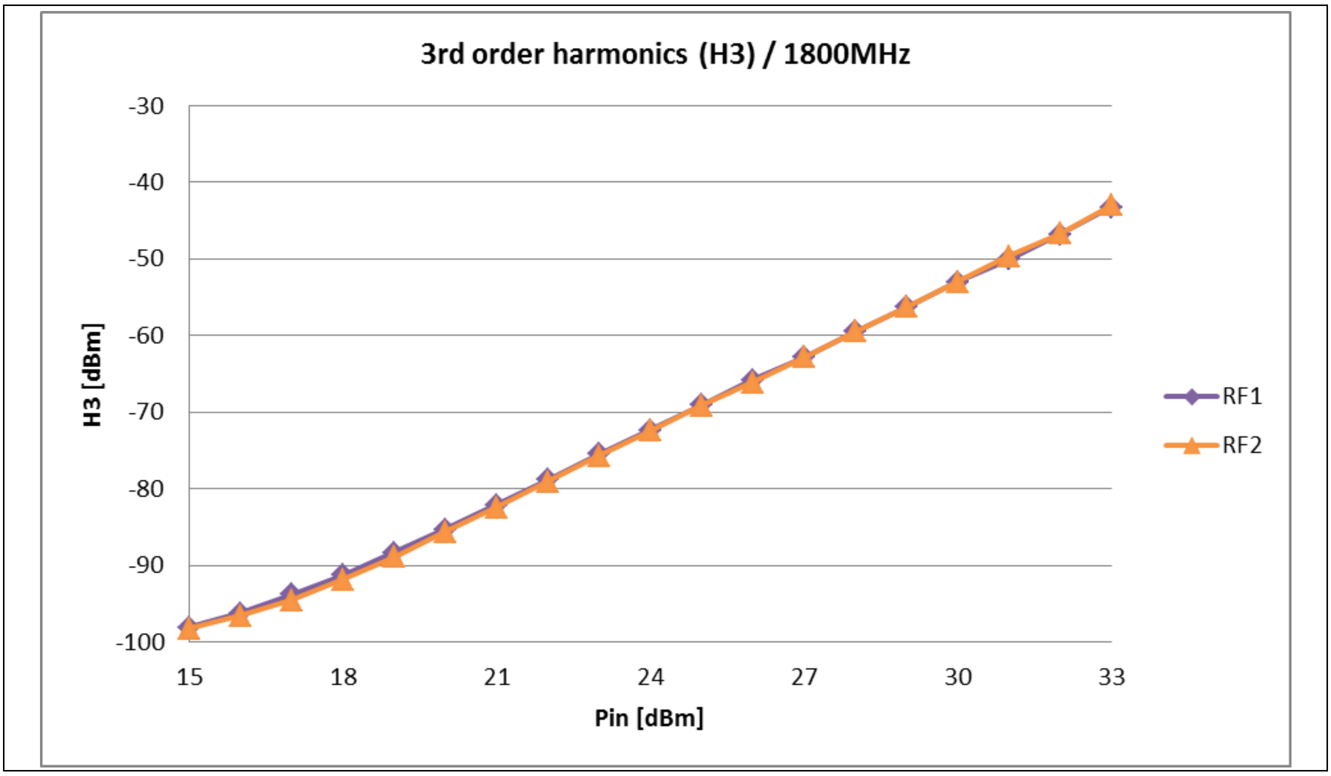


Figure 27 3rd Harmonic at f_c=1800 MHz

7 Power Compression Measurements on all RF Paths

To judge the large signal capability the power compression is a usual measurement tool. The output the power is measured while increasing the input power. At a certain point the output power does not follow the input and the switch compresses the RF signal. In the diagram below (Figure 28) the IL is plotted versus the injected input power. The input power can be increased to 30 dBm and there is no compression visible on none of the RF ports.

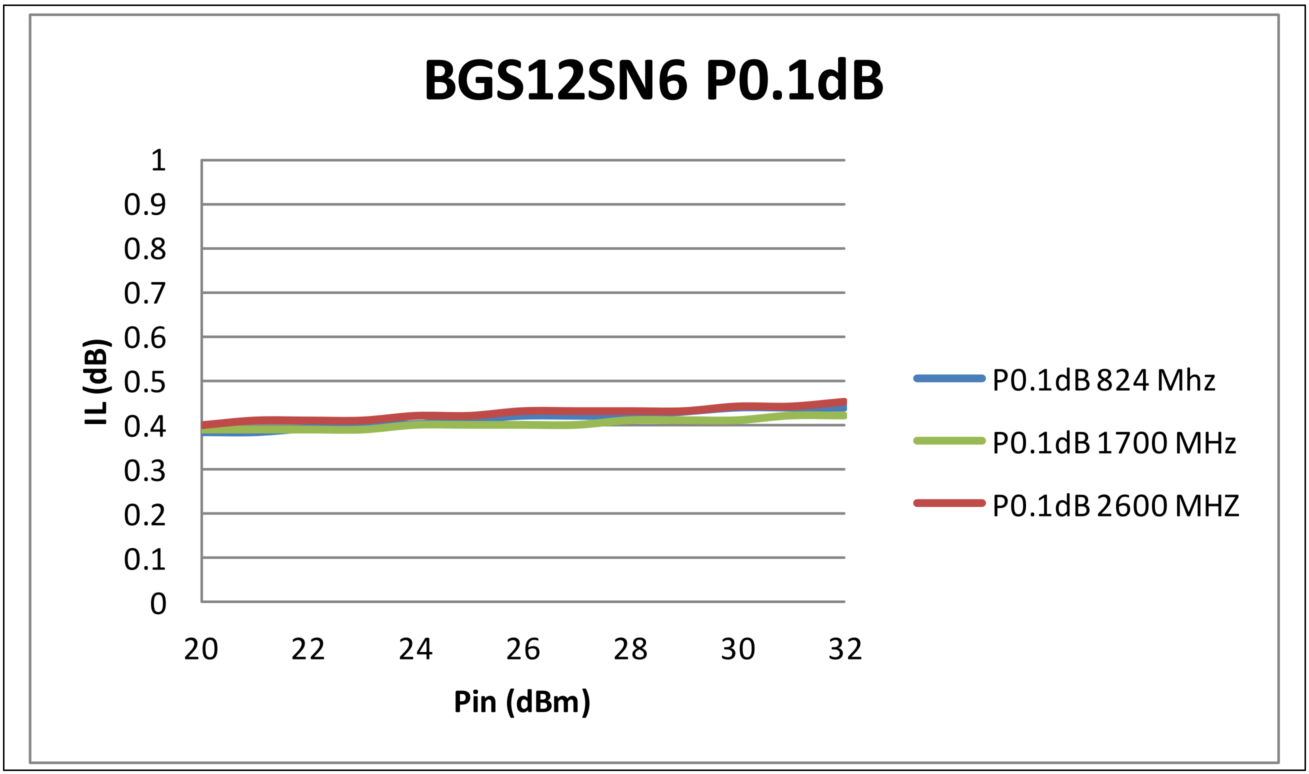


Figure 28 Power Compression Measurement Results at f_c=824 MHz, 1700 MHz and 2600MHz

The measurements are done on Large Signal measurement setup which is not calibrated for Insertion Loss with high precision. So the values here may differ with the actual IL values earlier in this report.

8 Switching time

8.1 Measurement Specifications

Switching On/ Off Time: 50% Trigger signal to 90 % RF Signal / 50% Trigger signal to 10% RF Signal

Rise time / Fall time: 10% to 90% RF Signal / 90% to 10% RF Signal

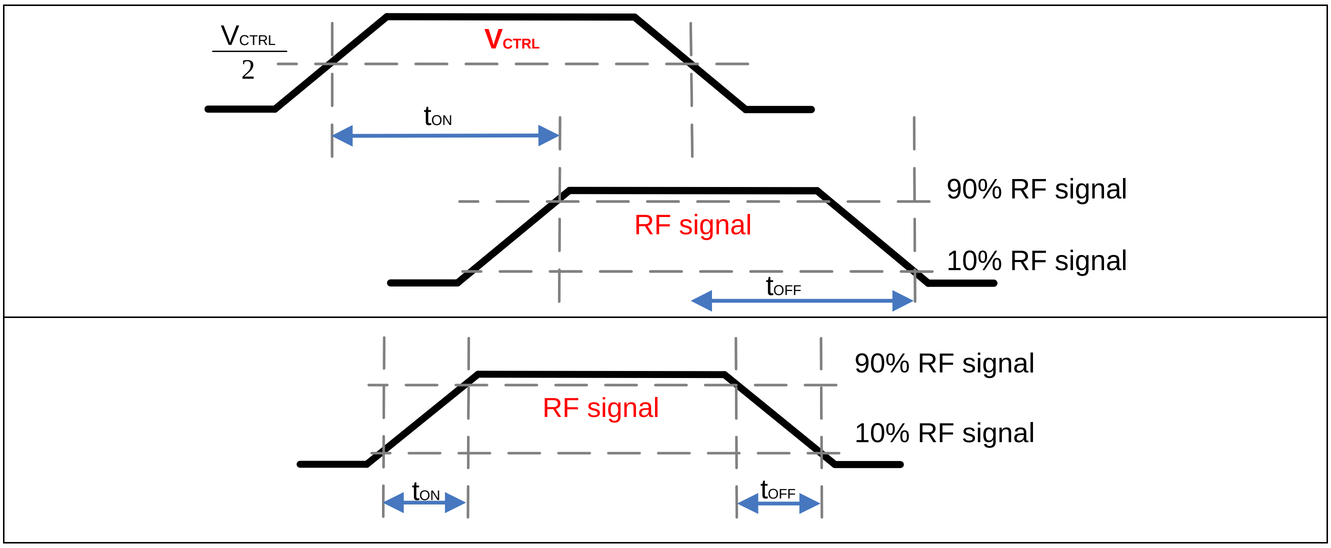


Figure 29 Switching Time and Rise/Fall Time

8.2 Measurement Setup

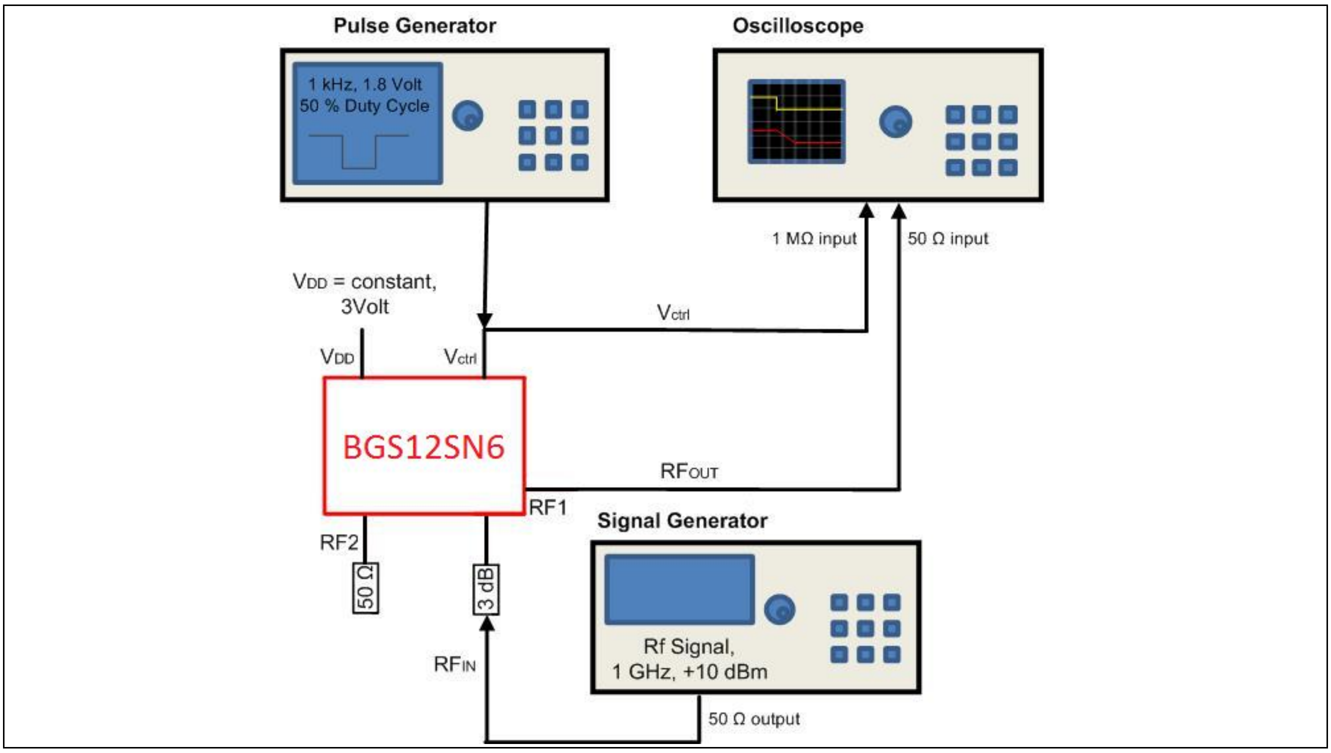


Figure 30 Switching Time Measurement Setup

8.3 Measurement results

The switching Time measurement setup consist of one pulse generator which generates a sqare 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 cannot detect the 1 GHz signal of the RF path, due to small bandwith, it is possible to use a crystal oscillator in front of the oscilloscope (such a device detects any RF signal present at input and commutates that) so that the RF signal can be detected.

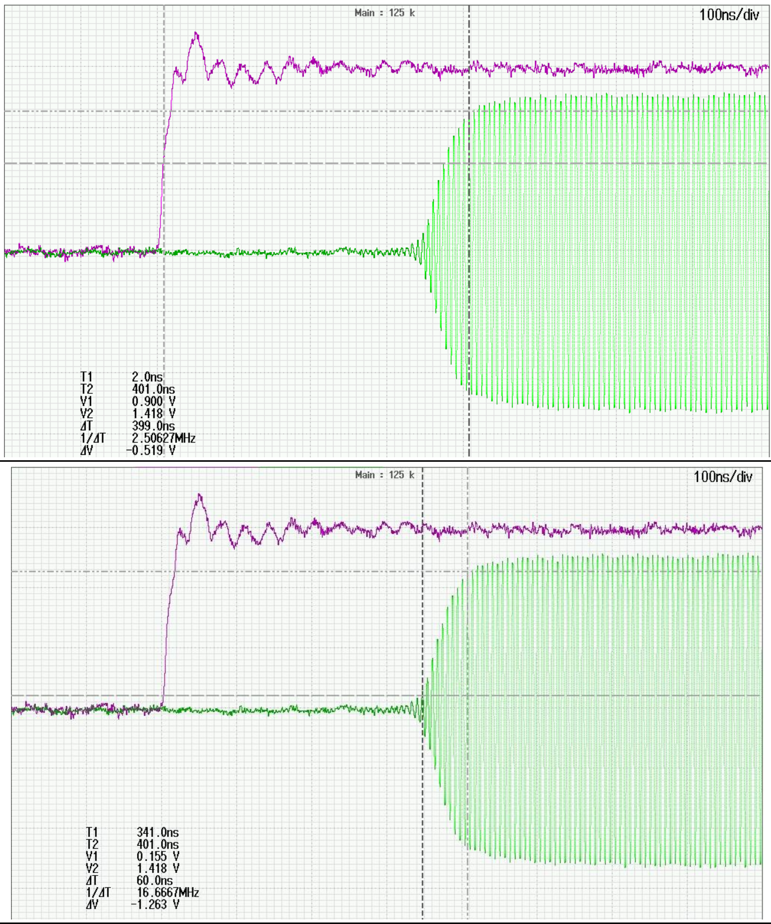


Figure 31 Screenshots of Switching Time Measurement BGS12SN6

Table 8 Switching time measurement results

BGS12SN6	RF rise time (ns)	Switching time (ns)
	60	400

9 Authors

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