# BGS12PL6

## SPDT RF CMOS Switch

## For High Power Applications

## Application Note AN319

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# 1 Introduction

The BGS12PL6 general purpose RF MOS power switch is designed to cover a broad range of high power applications from 30 MHz to 4 GHz, mainly in the transmit path of WCDMA and LTE mobile phones. The symmetric design of its single pole double throw (SPDT) configuration, as shown in Figure 1 offers high design flexibility.

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 35 dBm, resulting in linear performance at all signal levels. The RF switch has a very low insertion loss of 0.33 dB in the 1 GHz, 0.42 dB in the 2 GHz and 0.6 dB in the 3 GHz range.

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

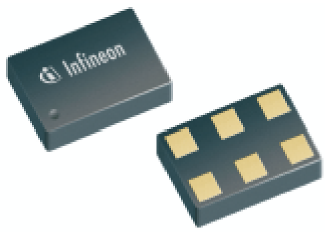
The BGS12PL6 RF switch is manufactured in Infineon's patented MOS technology, offering the performance of GaAs with the economy and integration of conventional CMOS including the inherent higher ESD robustness.

The device has a very small size of only 0.7x 1.1 $mm^2$ and a maximum height of 0.4 mm.

# 2 BGS12PL6 Features

## 2.1 Main Features

- 2 high-linearity TRx paths with power handling capability of up to 35 dBm
- All ports fully symmetrical
- No external decoupling components required
- Very low insertion loss
- Very low harmonic generation
- High port-to-port-isolation
- 0.1 to 4 GHz coverage
- High ESD robustness
- On-chip control logic
- Small lead and halogen free package TSLP-6-4 (0.7 x 1.1 $mm^2$)
- RoHS compliant package



## 2.2 Functional Diagram

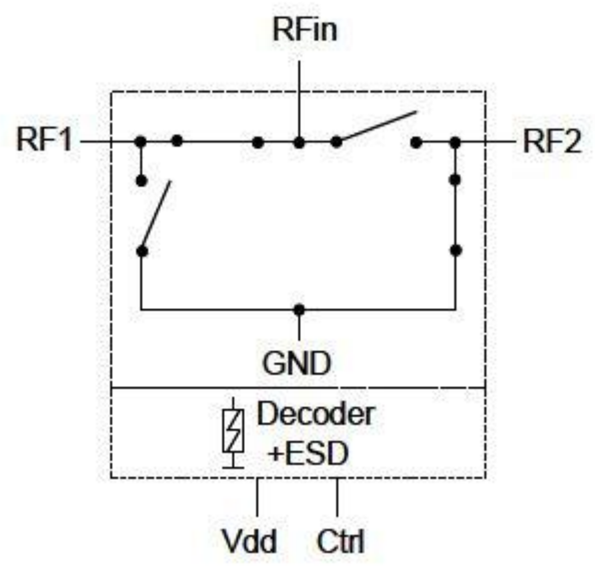



**Figure 1 BGS12PL6 Functional Diagram**

## 2.3 Pin Configuration

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

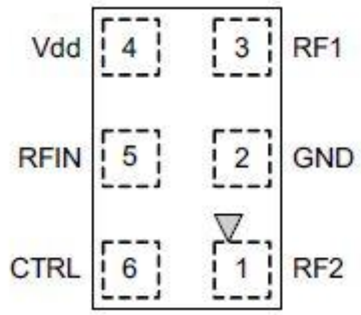



**Figure 2 Pin Configuration**

## 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 LTE Band Switch

The next generation smart phones are required to support upto 15 different frequency bands and even more number of band combinations. Often the number of pins on the transceiver is limited. An RF switch can be used to expand the number of reception bands. One of the possible applications of this high power SPDT is an LTE band switch which can be used after the Power Amplfier (PA) as shown in the figure below.

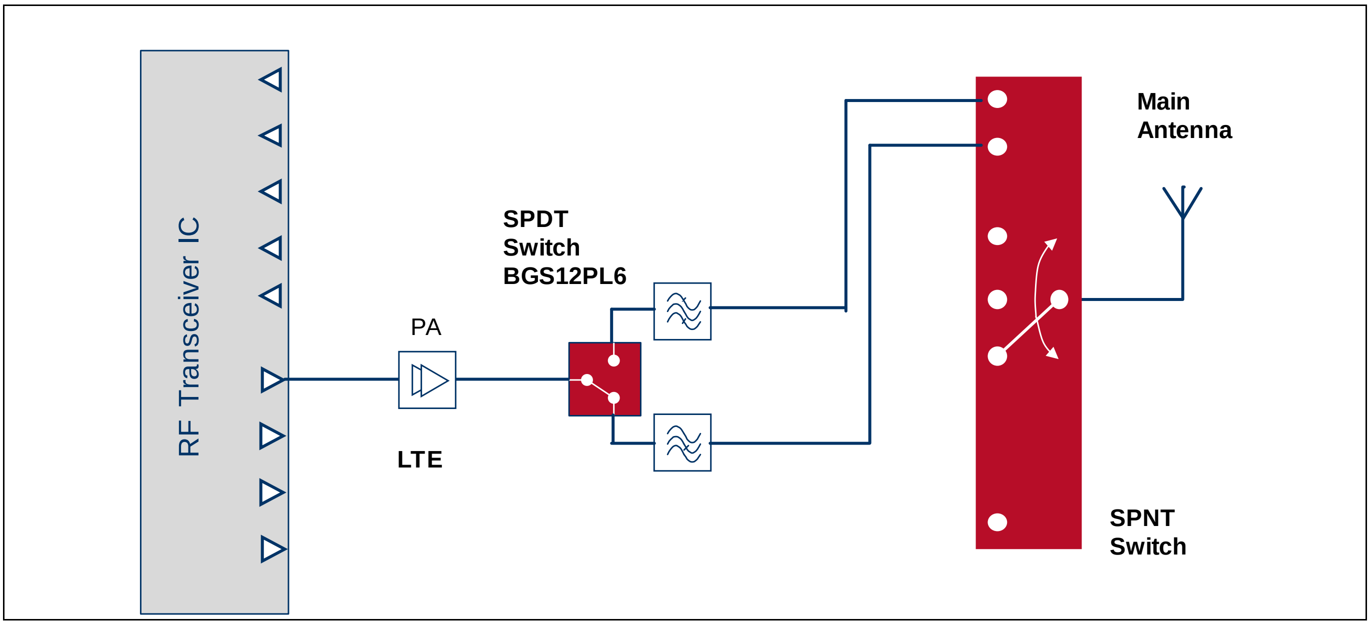



**Figure 3 Application LTE Switch**

## 3.2 Antenna switch

Another application is the antenna switch for certain bands in LTE and CDMA.

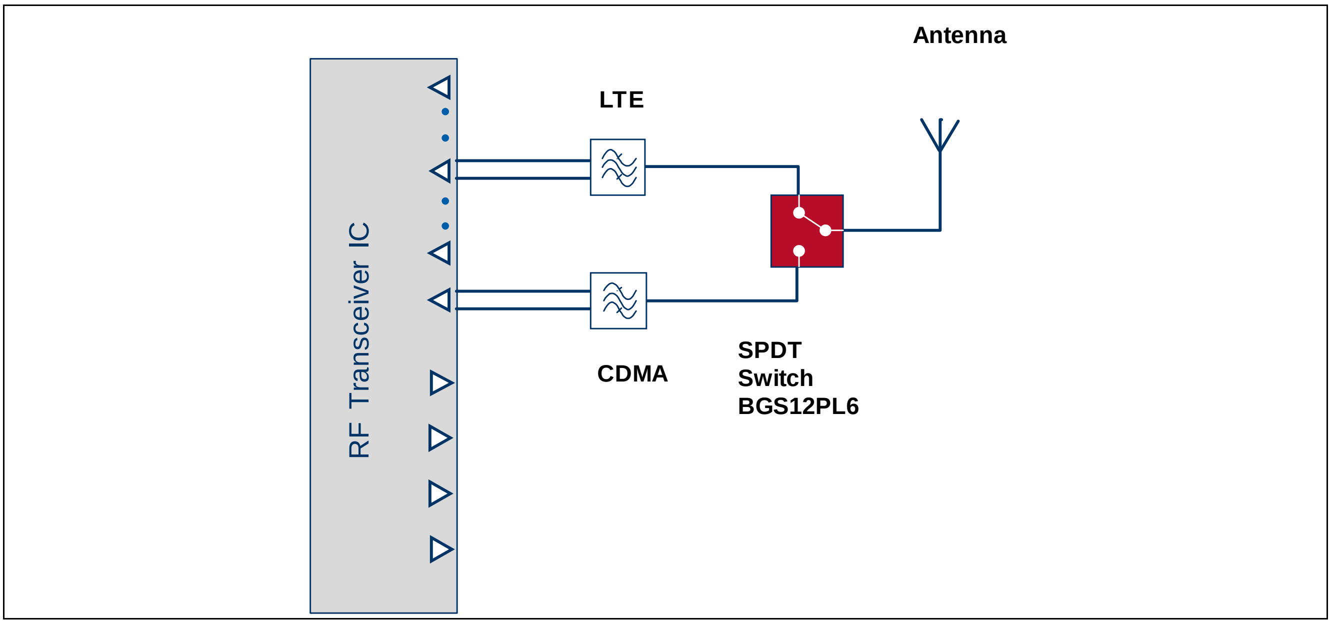



**Figure 4 Antenna Switch with BGS12PL6**

## 3.3 Application Board

Below is a picture of the evaluation board used for the measurements (Figure 5). 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).

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

- Perform full calibration on all NWA ports.
- Attach empty SMA connector at port 2 and perform “open” port extension. Turn port extensions on.
- Connect the “half” de-embedding board (Figure 6 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 6 right board)

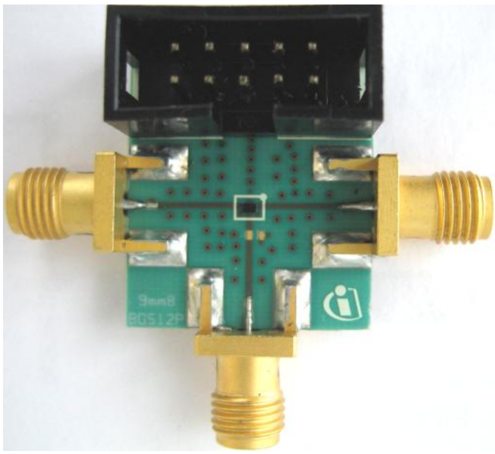


**Figure 5 Photo of the Application Board**

**Figure 6 Photos of De-embedding Boards**

The construction of the PCB is shown in Figure 7.

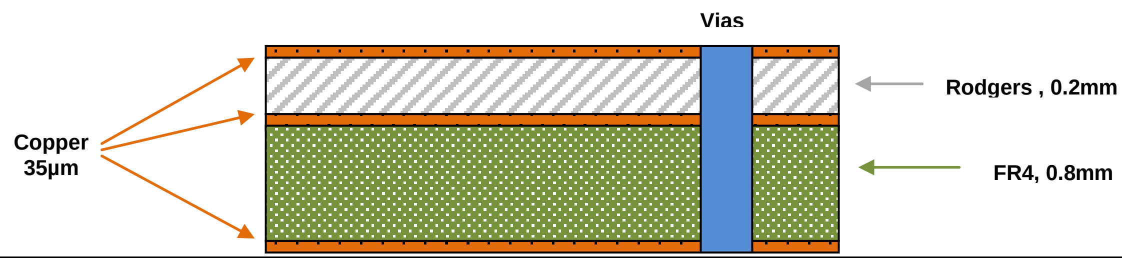



**Figure 7 PCB layer information**

# 4 Small Signal Characteristics

The small signal characteristics are measured at 25 °C with a 4-port Network Analyzer.

## 4.1 Measurement Results

In the following tables and graphs the most important RF parameters of the BGS12SL6 are shown. The markers are set to the most important frequencies of the WDCDMA system.

**Table 2 Forward Transmission from RFIN Port to the Respective RF Port with All Other Ports Terminated with 50Ω**

| Frequency (MHz) / RF Path | 824 | 915 | 1000 | 1710 | 1910 | 2170 | 2690 |
|---|---|---|---|---|---|---|---|
| RF1 | -0.38 | -0.39 | -0.39 | -0.46 | -0.47 | -0.51 | -0.58 |
| RF2 | -0.37 | -0.38 | -0.38 | -0.44 | -0.46 | -0.49 | -0.57 |

**Table 3 Reflection RFin Port to the Respective RF Port with All Other Ports Terminated with 50Ω**

| Frequency (MHz) / RF Path | 824 | 915 | 1000 | 1710 | 1910 | 2170 | 2690 |
|---|---|---|---|---|---|---|---|
| RF1 | -29.1 | -27.8 | -27.7 | -25.3 | -24 | -22.2 | -20 |
| RF2 | -29.2 | -28.1 | -27.9 | -25.4 | -23.9 | -22 | -19.6 |

**Table 4 Reflection RF Port to the Respective RF Port with All Other Ports Terminated with 50Ω**

| Frequency (MHz) / RF Path | 824 | 915 | 1000 | 1710 | 1910 | 2170 | 2690 |
|---|---|---|---|---|---|---|---|
| RF1 | -29.8 | -29.4 | -29.3 | -26.2 | -25.3 | -23.7 | -20.2 |
| RF2 | -30.8 | -30.2 | -30.3 | -26.6 | -25.4 | -23.2 | -19.3 |

## 4.2 Forward Transmission

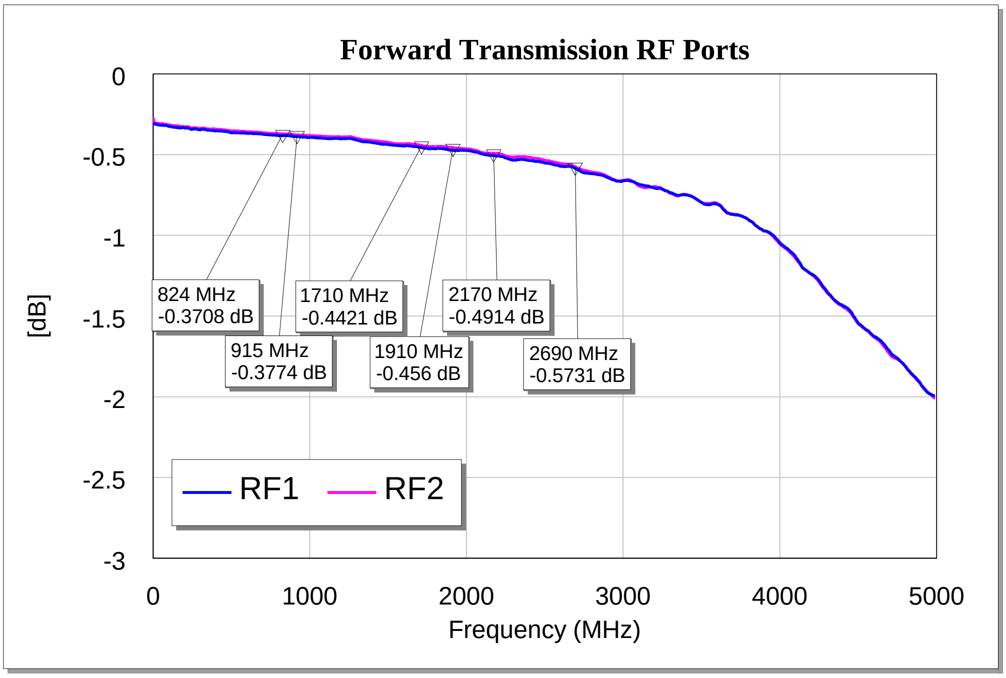



**Figure 8 Forward Transmission Curves for RF Ports**

## 4.3 Reflection RFin Port

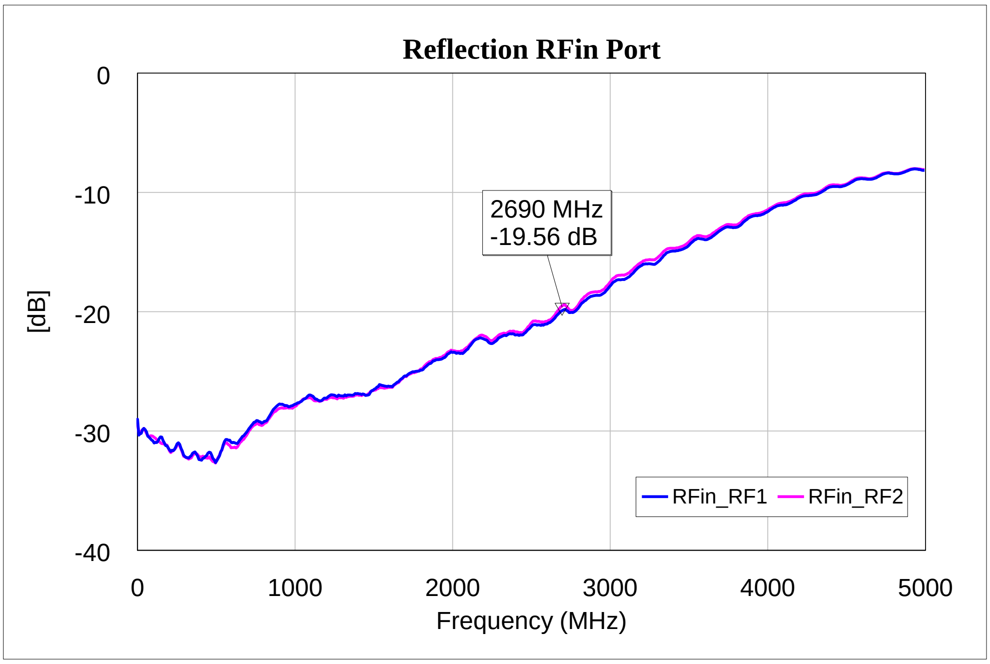



**Figure 9 Reflection RFin Port**

## 4.4 Isolation RF1

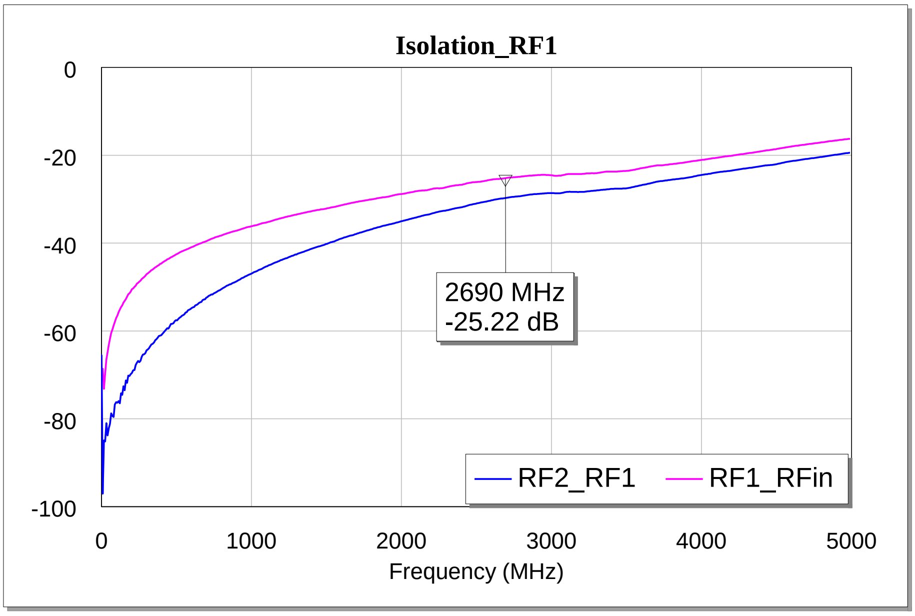



**Figure 10 Isolation RF1**

## 4.5 Isolation RF2

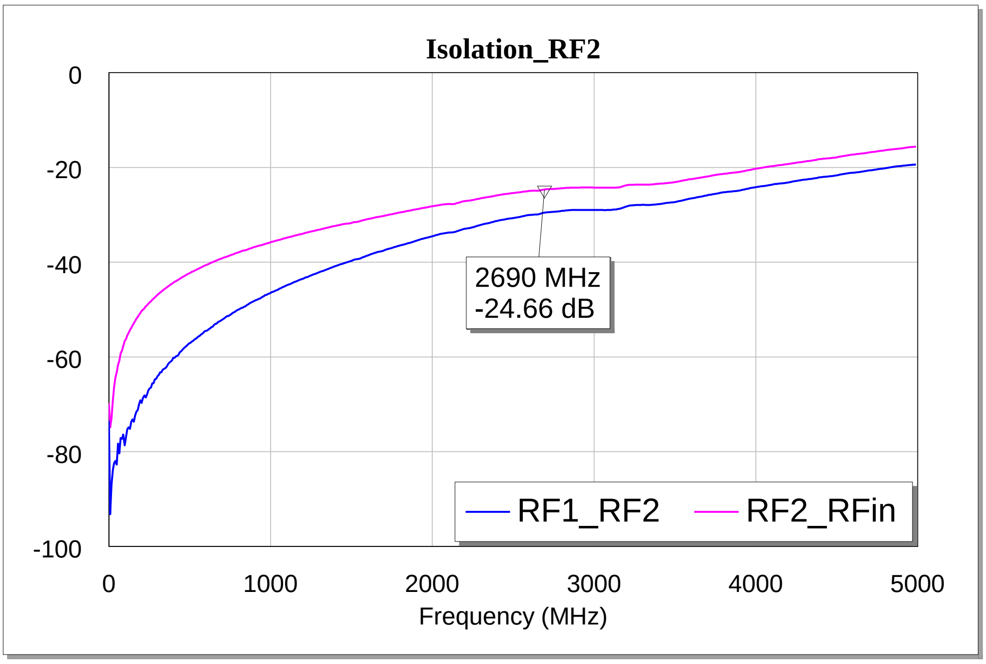



**Figure 11 Isolation RF2**

# 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 12. The transmission (Tx) signal from the main antenna is coupled into the diversity antenna with high power.This signal (20 dBm) and a received Jammer signal (-15 dBm) are entering the switch.

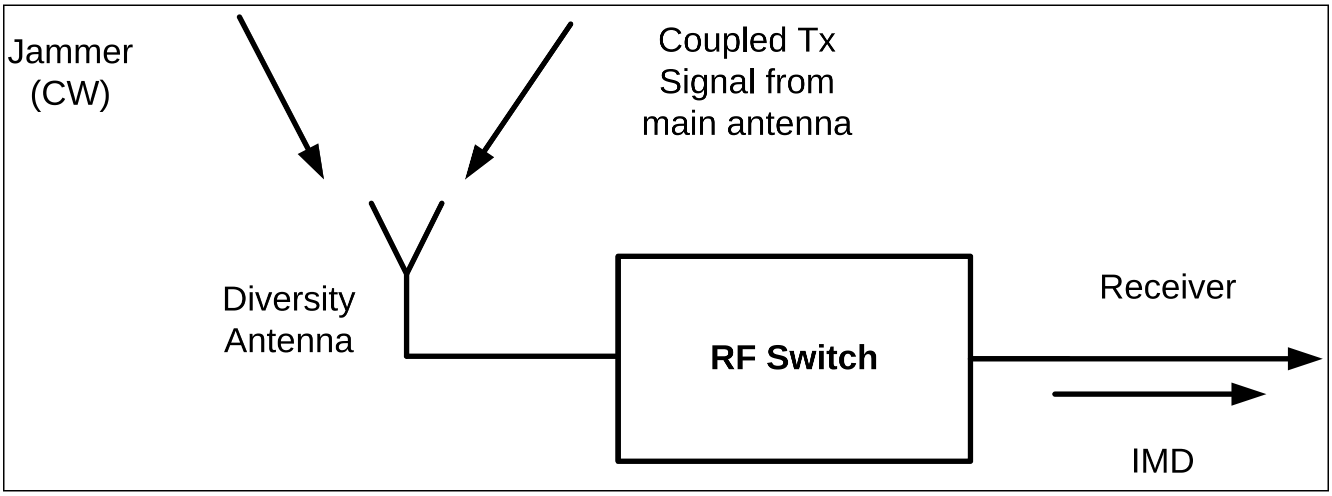



**Figure 12 Block Diagram of Intermodulation Measurement of RF Switch**

Special combinations of TX and Jammer signals produce 2$^{nd}$ and 3rd order intermodulation products, which fall in the RX band and interfere with the wanted RX signal.

In Table 5 frequencies for 3 bands and the intermodulation specifications for an undisturbed communication are given.

**Table 5 Test Conditions and Specifications of IMD Measurements**

| Test Conditions (Tx = +20dBm, BI = -15dBm,freq.in MHz,@25°C) | | | | | | Intermodulation Specification | | | |
|---|---|---|---|---|---|---|---|---|---|
| Band (MHz) | Tx Freq. (MHz) | Rx Freq. (MHz) | IMD2 Low Jammer 1 (MHz) | IMD3 Jammer 2 (MHz) | IMD2 High Jammer 3 (MHz) | IMD2 (dBm) | IIP2 (dBm) | IMD3 (dBm) | IIP3 (dBm) |
| 850 | 836.5 | 881.5 | 45 | 791.5 | 1718 | **-105** | 110 | **-105** | 65 |
| 1900 | 1880 | 1960 | 80 | 1800 | 3840 | **-105** | 110 | **-105** | 65 |
| 2100 | 1950 | 2140 | 190 | 1760 | 4090 | **-105** | 110 | **-105** | 65 |

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 13 and Figure 14).

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

Figure 14 and Figure 15 show the results for Band I and Band V. For each distortion scenario there is a min. and a max. value given. This variation is caused by a phase shifter connected between the switch and the duplexer. In the test set-up the phase shifter represents a non-ideal matching of the switch to 50 Ohm.

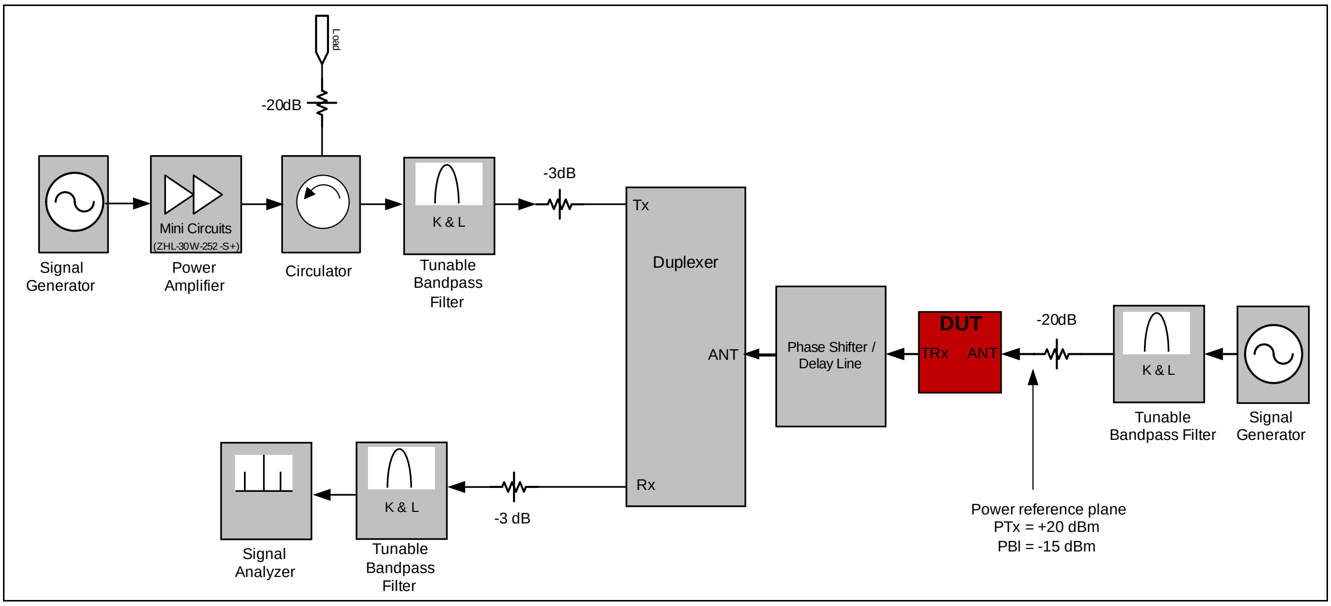



**Figure 13 Test Set-Up for IMD Measurements**

| | | IMD Band - I | | | | | |
|---|---|---|---|---|---|---|---|
| | | IMD2 low | | IMD2 High | | IMD3 | |
| | | $f_b$ = 190 MHz | | $f_b$ = 4090 MHz | | $f_b$ = 1760 MHz | |
| Power | RF-port | Min | Max | Min | Max | Min | Max |
| $P_{Tx}$ = +10dBm | RF1 | -113,46 | -102,93 | -118,42 | -113,63 | -133,97 | -125,14 |
| $P_{int}$ = - 15dBm | RF2 | -112,95 | -102,45 | -117,31 | -113,76 | -134,87 | -126,04 |
| $P_{Tx}$ = +20dBm | RF1 | -105,52 | -96,24 | -111,64 | -107,45 | -118,05 | -106,35 |
| $P_{int}$ = - 15dBm | RF2 | -105,22 | -95,58 | -109,22 | -106,19 | -121,13 | -108,86 |

**Figure 14 IMD Results for Band I**

| | | IMD Band - V | | | | | |
|---|---|---|---|---|---|---|---|
| | | IMD2 low | | IMD2 High | | IMD3 | |
| | | $f_b$ = 45 MHz | | $f_b$ = 1718 MHz | | $f_b$ = 791.5 MHz | |
| Power | RF-port | Min | Max | Min | Max | Min | Max |
| $P_{Tx}$ = +10dBm | RF1 | -116,31 | -106,04 | -119,20 | -110,94 | -124,54 | -116,64 |
| $P_{int}$ = - 15dBm | RF2 | -115,84 | -106,67 | -116,66 | -111,30 | -126,02 | -121,25 |
| $P_{Tx}$ = +20dBm | RF1 | -106,54 | -97,06 | -111,53 | -105,13 | -105,18 | -98,54 |
| $P_{int}$ = - 15dBm | RF2 | -107,77 | -98,87 | -108,43 | -103,60 | -108,59 | -102,33 |

**Figure 15 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 35 dBm. Harmonics are generated with such high RF power levels at the input of the switch. These harmonics ($2^{nd}$ and $3^{rd}$) can disturb the reception of other bands or cause distortion in other RF applications (GPS, WLAN…) within the mobile phone.

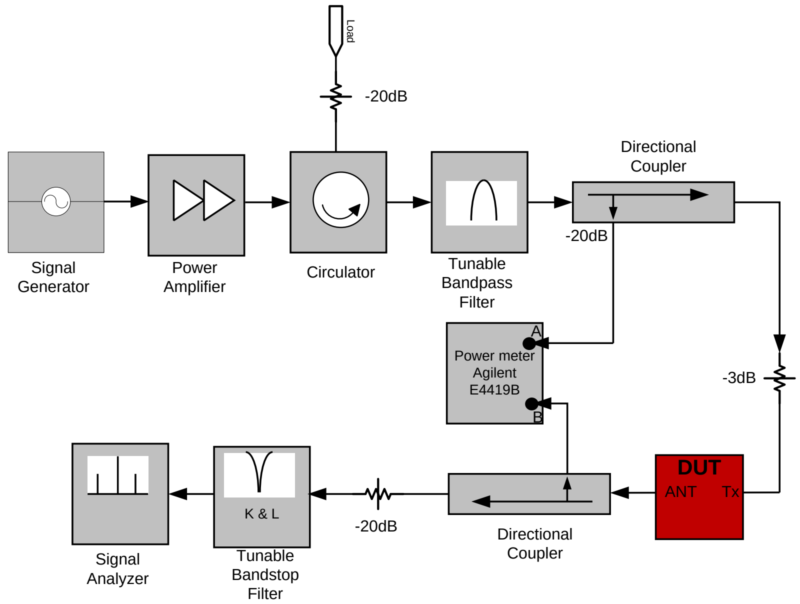



**Figure 16 Set-Up for Harmonics Measurement**

The results for the harmonic generation at 830 MHz are shown in Figure 17 ($2^{nd}$ harmonic) and Figure 18 ($3^{rd}$ harmonic) for all RF ports. In Figure 19 and Figure 20 the results for 1800 MHz are given.

On the x-axis the input power is plotted and on the y- axis the generated harmonics in dBm.

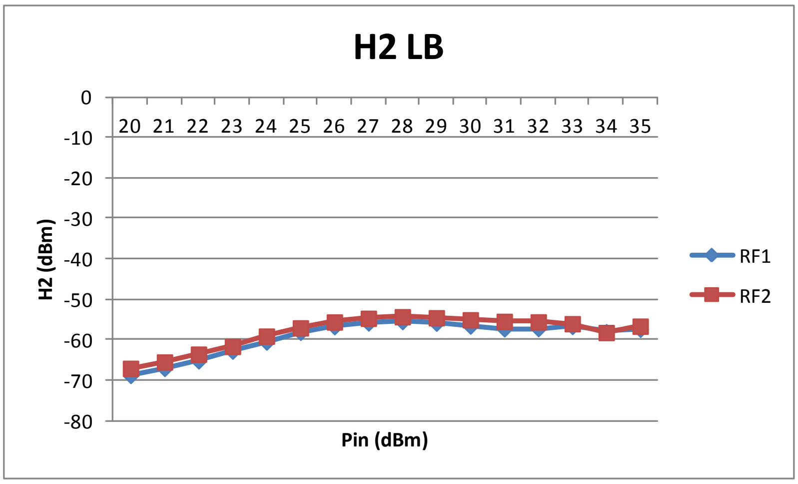



**Figure 17 $2^{nd}$ Harmonic at $f_c$=830 MHz**

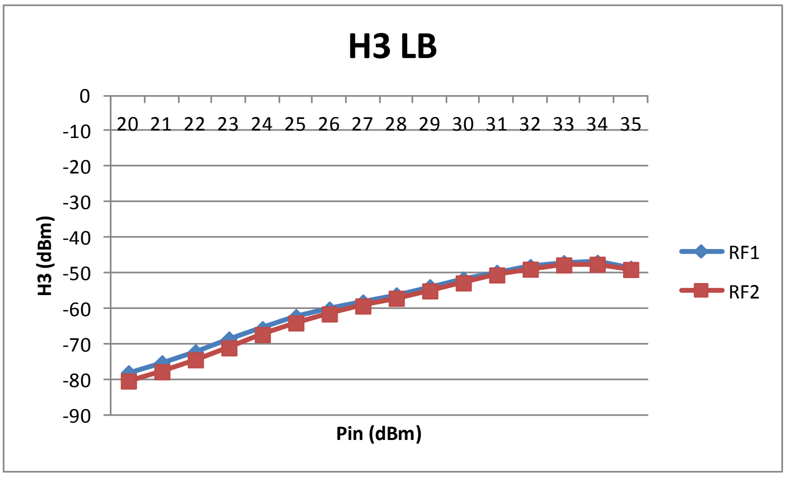



**Figure 18** 3rd Harmonic at $f_c$=830 MHz

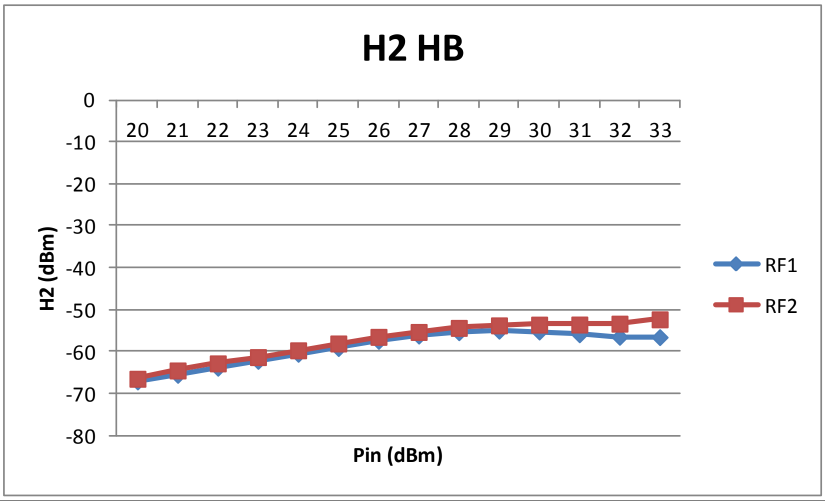



**Figure 19** 2nd Harmonic at $f_c$=1800 MHz

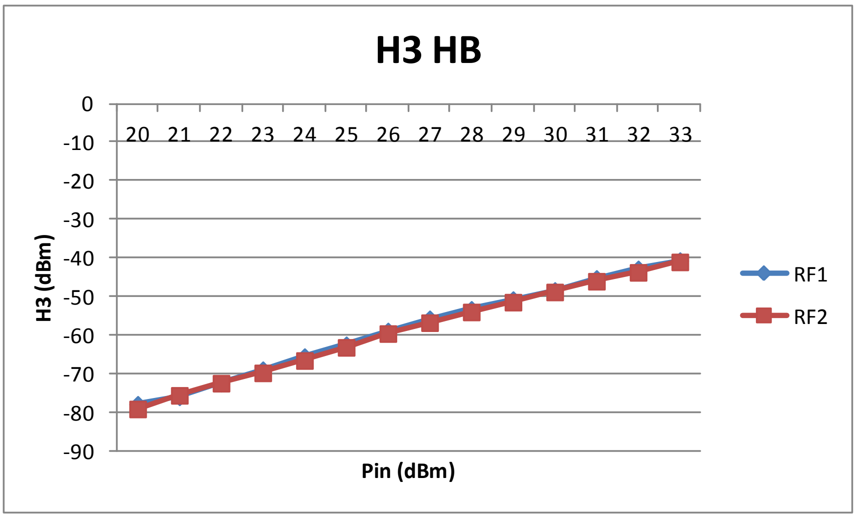



**Figure 20** 3rd Harmonic at $f_c$=1800 MHz

# 7 Power Compression Measurements on all RF Paths

To judge the large signal capability of a switch, ‘power compression’ is a widely used measurement.The output power is measured while the input power increasing gradually. At a certain point the output power does not follow the input power and the switch compresses the RF signal. In the diagram below (Figure 21) the IL is plotted versus the injected input power. The input power can be increased up to 38 dBm and there is no compression visible on any of the RF ports.

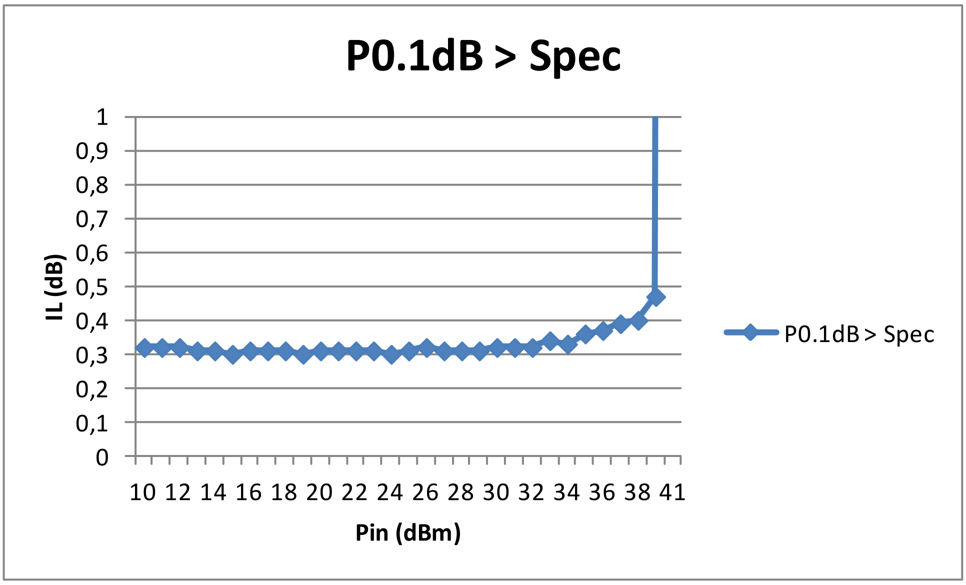



**Figure 21 Power Compression Measurement Results at $f_c$=830 MHz**

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 Authors

Ralph Kuhn, Senior Staff Application Engineer of the Business Unit “RF and Protection Devices”
Andre Dewai, Application Engineer of the Business Unit “RF and Protection Devices”