

# Application Note No. 175

RF CMOS SPDT Switches

BGS12xx for Applications up to 3GHz

Small Signal Discretes



Never stop thinking

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<b>Page</b>	<b>Subjects (major changes since last revision)</b>
7	Insertion Loss values updated

## 1 Introduction

The word “Switch” needs little introduction as each one of us is well versed with the word and its function. A simple switch toggles between two states e.g. On and OFF. Such a switch is called a Single Pole Single Throw (SPST) switch which has a single input and a single output. More complex switches can have multiple inputs or multiple outputs. This application note deals with a Single Pole Double Throw or SPDT switch.

A radio frequency or RF switch is no different in its functionality but a lot of parameters are involved in its characterization. RF Switches form a major building block in today’s complex front-end systems for various applications to perform numerous functions including Tx/Rx switching, diversity switching, band switching etc. However, the location of the switch in the system architecture poses great demands on its performance, mainly concerning insertion loss, power handling capability, ESD robustness, switching time and isolation between different ports.

Infineon uses a proprietary CMOS based process on Silicon substrate for its RF Switches. These switches can also be realized using other technologies like Gallium Arsenide (GaAs) or the more classical PIN diodes. However, using CMOS design on Si substrate offers many advantages over its counterparts. A quick and informative comparison of the different technologies offering RF switches is given in [Table 1](#).

The classical approach of using PIN diodes as switches is getting extinct due to their high current consumption, slow switching speeds and the requirement of too many external components. The GaAs switches come with the disadvantage of the need to use blocking capacitors on all RF ports which results in increased PCB area, additional cost, reduced bandwidth (limiting the minimum operating frequency), more insertion loss and increased noise. Also, the GaAs switches in some cases require higher voltages (>3 V) to achieve the desired performance, which is not feasible in most battery powered devices. The manufacturers of GaAs switches overcome the problem by using a multichip package with a CMOS die together with the GaAs switch. The CMOS die integrates the control logic together with level shifters. But this approach increases the size of the package and also adds up to the cost due to an additional die. CMOS is thus the technology of choice for RF Switches due to their small size, low cost, control logic integration capability and zero external components. With all the above advantages, CMOS switches offer virtually the same performance as their GaAs counterparts.

**Table 1 Comparison of RF Switch solutions**

	<b>CMOS with integrated logic</b>	<b>GaAs pHEMT with integrated logic</b>	<b>PIN Diode without logic</b>
Substrate	bulk Silicon	GaAs Epi	Silicon Epi
Technology complexity	medium	medium	low
Current consumption in ON-state	low	low	high
PCB area	small	small-medium	medium
ESD robustness	good	low	excellent
Insertion Loss	low	low	low
Isolation	good	good	excellent
Harmonic generation	low	low	low
Switching time	medium-fast	fast	medium
Integration capability	excellent	low	low
Cost	low	high	low
External components	none	some	many

## 2 Infineon solutions

Infineon offers a wide variety of switches ranging from simple to complex configurations and low to high power switches. This application note is focused on the SPDT switches. Infineon offers the BGS12xx family of SPDT switches comprising of three members, differing in their packaging.

### 2.1 BGS12A

The BGS12A comes as a CSP or Chip Scale Package SPDT switch as shown in [Figure 1](#). With its super small size of only 0.79 mm x 0.54 mm, it is a perfect solution for modules and scenarios where size has a top priority. It has 110  $\mu\text{m}$  bumps with a pitch of 200  $\mu\text{m}$ .



Figure 1 BGS12A

### 2.2 BGS12AL7-4

BGS12AL7-4 is a packaged variant of the SPDT switch with a size of 2.3 mm x 1.5 mm. The thin leadless package TSLP7-4 is easy to handle and compatible to most of the assembly design rules with its pad pitch of 0.55 mm.

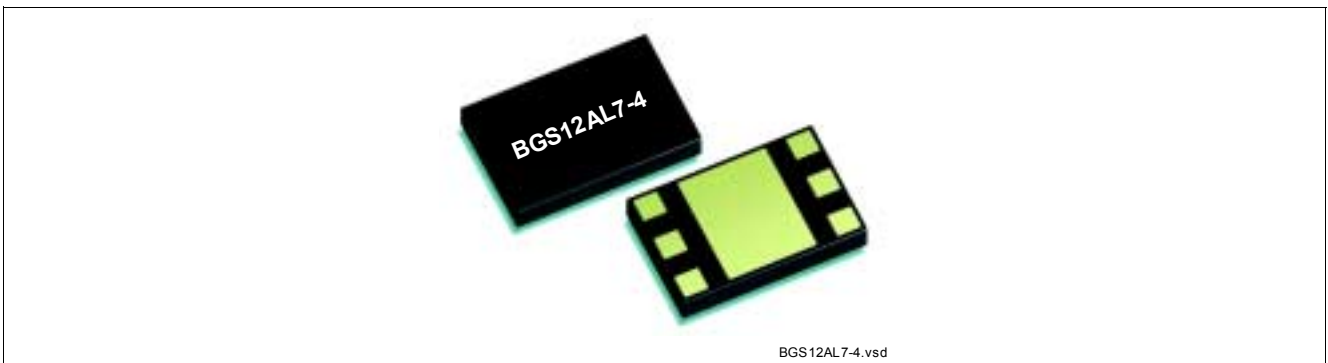


Figure 2 BGS12AL7-4

### 2.3 BGS12AL7-6

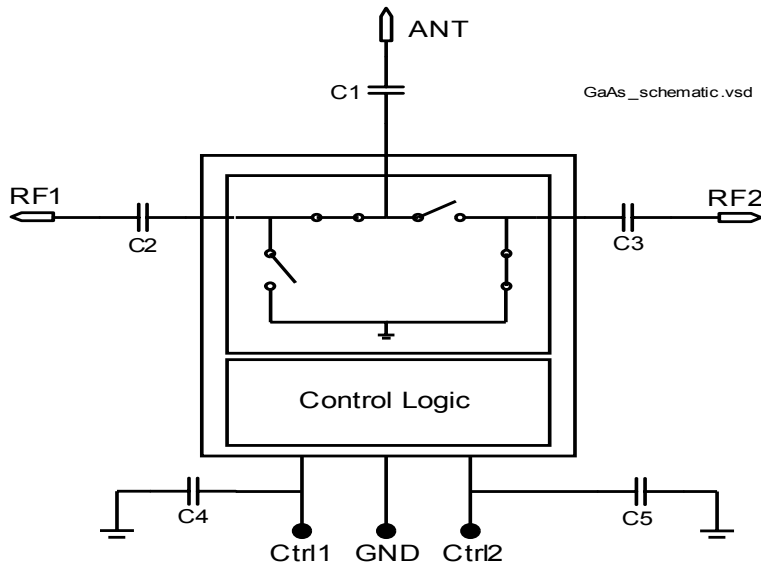
To meet the size constraints of handheld devices and still maintain ease of handling, Infineon offers a tiny variant of the SPDT in a TSLP7-6 package, which is 50 % smaller in size compared to the TSLP7-4 version. It has the dimensions of 1.4 mm x 1.26 mm with a maximum height of only 0.4 mm, which matches the trend of the modern slim mobile handheld devices.



Figure 3 BGS12AL7-6

### 3 Switch application schematic

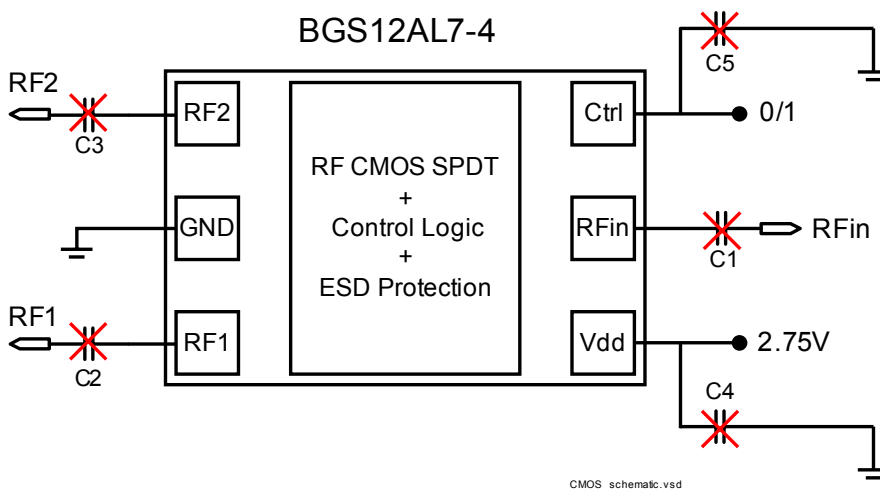
In this section, a comparison is made between the application schematic of a GaAs switch and an Infineon CMOS switch. Most GaAs switches require DC blocking capacitors at all RF ports and DC filtering capacitors at the control inputs as show in the figure below. The switch, in this case, is a multi chip (GaAs RF + CMOS logic) solution in one package.



#### GaAs SPDT Switch

- Multi-chip Package
- 5-6 External Capacitors
- Two Control Lines

Application schematic of the SPDT switch offered by Infineon is shown below. It is a one chip solution integrating RF switch and the control logic. The switch can be connected to the respective RF and DC ports in an application directly without the need for any external components. The device also integrates ESD protection devices which protect it against ESD events up to 1 kV (Human Body Model; IEC61340-3-1) on all ports



#### Infineon SPDT Switch

- Single-chip Package
- **NO** External Capacitors
- Single Control Line

## 4 Electrical Characteristics

The table below summarizes the electrical characteristics of the three devices for the following test conditions

- Port Z= 50 Ohm
- Temperature = 25 °C
- Supply Voltage = 2.8 V
- Pin = 15 dBm
- Control Voltage = 1.4 to 2.8 V

**Table 2 Electrical Characteristics**

Parameter	Symbol	Typical Value			Unit	Note
		BGS12A	BGS12AL7-4	BGS12AL7-6		
Insertion Loss	$IL$	0.3	0.4	0.35	dB	f = 1 GHz
		0.55	0.5	0.5		f = 2 GHz
Return Loss	$RL$	> 15	22	22	dB	f = 1 GHz
		> 10	22	22		f = 2 GHz
Isolation RFin- RF1	$ISO_{RFin-RF1}$	34	32	32	dB	f = 1 GHz
		27	25	25		f = 2 GHz
Isolation RFin- RF2	$ISO_{RFin-RF2}$	34	32	32	dB	f = 1 GHz
		27	25	25		f = 2 GHz
Isolation RF1- RF2	$ISO_{RF1-RF2}$	43	32	32	dB	f = 1 GHz
		34	25	25		f = 2 GHz
Isolation RFports - Vdd, Vctrl	$ISO_{RF-DC}$	35	35	35	dB	f = 1 GHz
		35	35	35		f = 2 GHz
Harmonic Generation upto 12.75 GHz	$P_{Harm}$	-75	-75	-75	dBm	f = 1 GHz
		-80	-80	-80		f = 2 GHz
ON Switching Time (10-90%) RF	$t_{on}$	< 4	< 5	< 5	µs	f = 1 GHz
OFF Switching Time (10-90%) RF	$t_{off}$	< 4	< 5	< 5	µs	f = 1 GHz
Input 0.1 dB Compression point	$P_{0.1dB}$	> 21	> 21	> 21	dBm	f = 1 GHz
I						

## 5 Applications

SPDT switches have numerous applications covering different market segments including

- Mobile
- Industrial
- Consumer
- Automotive

We shall look into some of the applications corresponding to each of the aforementioned market segments in the next sections.

### 5.1 Mobile Phone Applications

The aforementioned SPDT switches are medium power switches and can handle powers up to +21 dBm. They can thus be used in mobile phone transmit path before the power amplifier. In a multi-mode, multi-band mobile phone, SPDT switch can be used in two configurations as explained in case 1 and Case 2, based on the RF transceiver architecture.

#### Case 1

Case 1 considers a 2G/3G transceiver which features Quad band GSM/Edge and single band UMTS. For GSM operation, the Power Amplifiers or PAs used are broadband covering two GSM/EDGE bands each and thus a switch can be used as shown in [Figure 4](#).

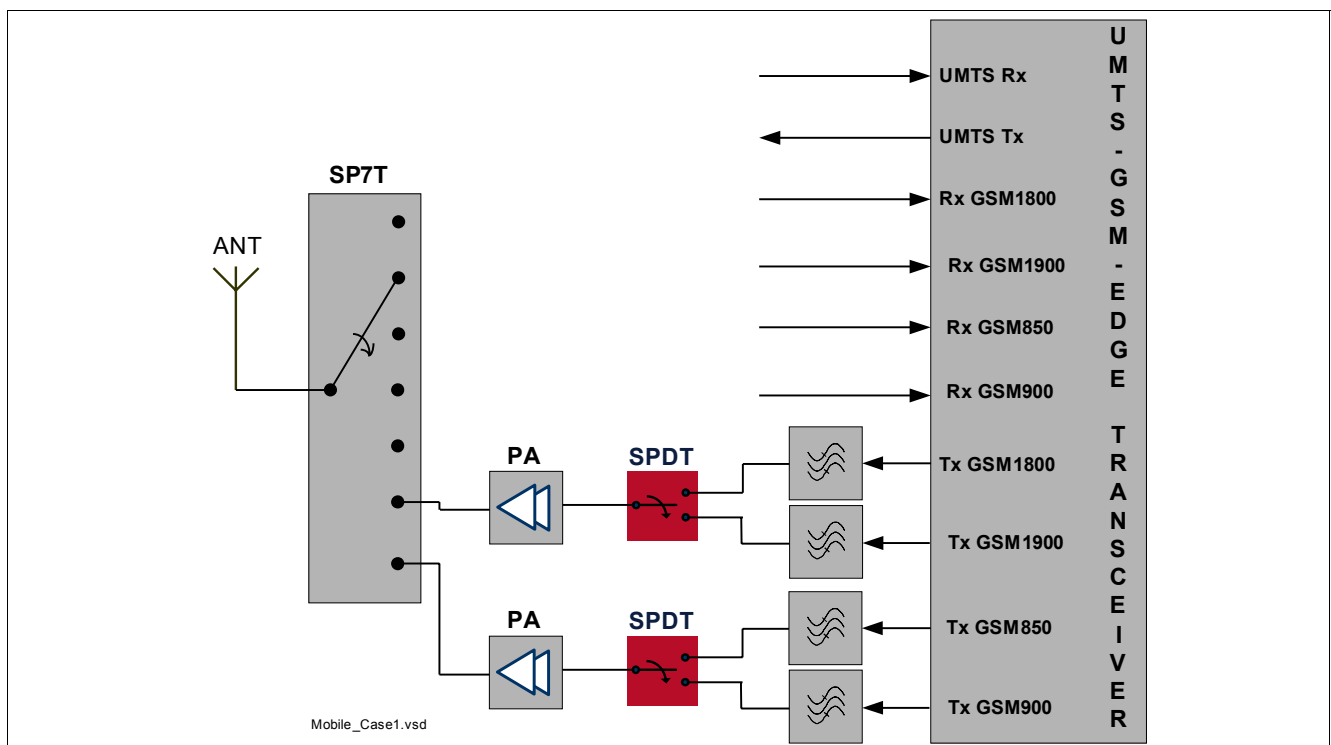
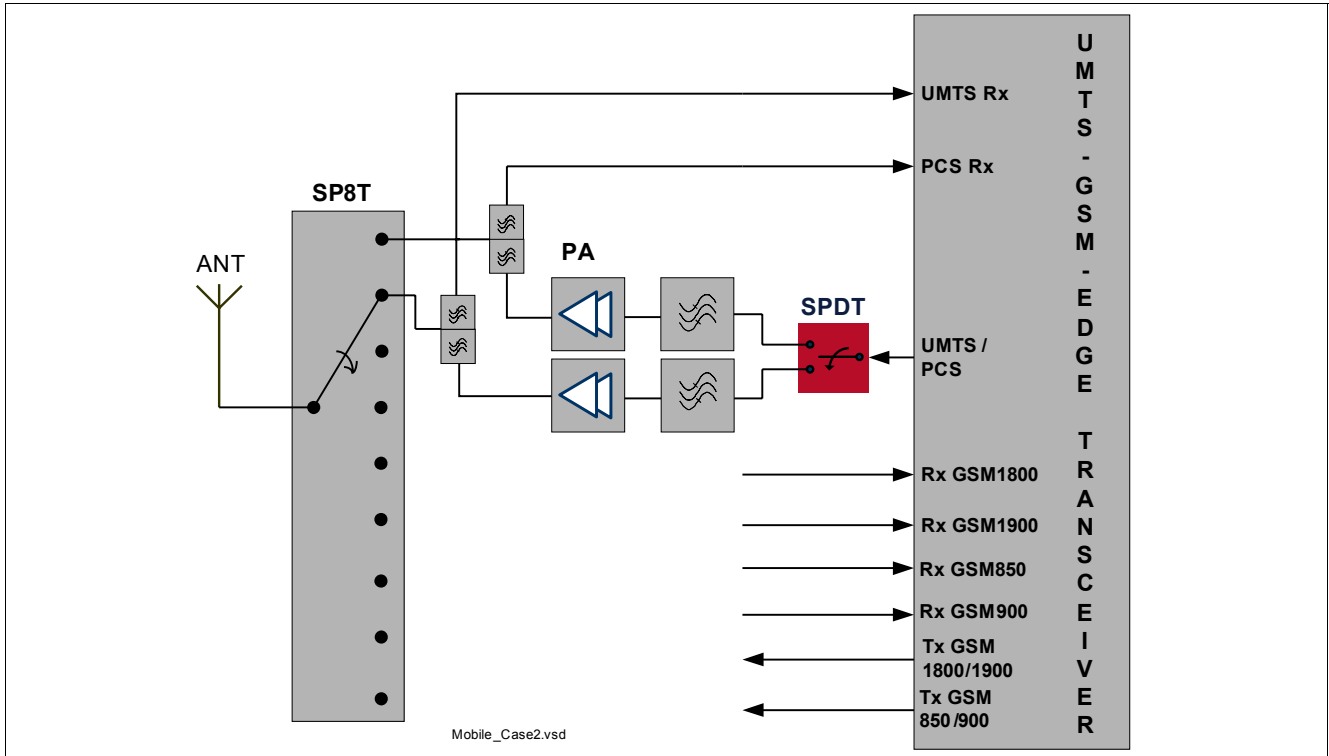


Figure 4 Case 1



**Case 2**

In this case, the PAs are narrowband, supporting one band each. In this case the transmitter output can be connected to either of the PAs using a SPDT switch as shown in [Figure 5](#).



**Figure 5 Case 2**

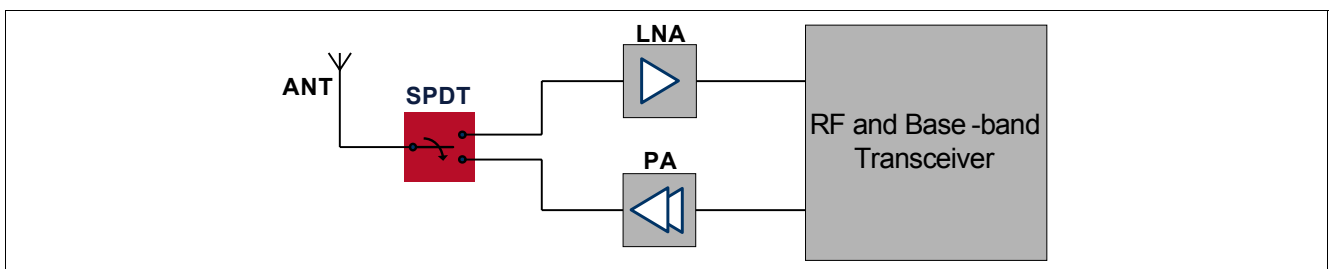
**5.2 Industrial Applications**

The BGS12xx switches can be used for all frequencies below 3 GHz, which cover the most popular ISM bands of 450 MHz, 900 MHz and 2.4 GHz. The switch can be used for the following purposes in industrial applications:

**TX/Rx Switching**

- Transmit/Receive Switch
- Bypass Switch
- Band Select Switch

Most of the industrial applications include a master and a slave device, wherein, both are bi-directional RF systems or only the master is bi-directional with a passive slave or vice-versa. In a bi-directional system, the architecture is mainly divided into transmit and receive blocks and the transmit and receive modes are switched using SPDT switch as shown in [Figure 6](#).

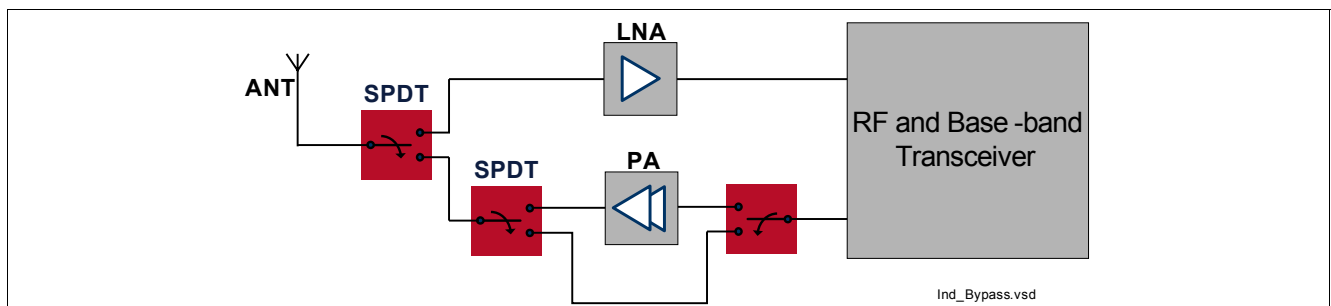


**Figure 6 Tx/Rx Switch**

The switch in the above configuration can be used in the following applications:

- Automated Meter Reading
- Bluetooth
- Zigbee
- Home Comfort, Control and Security

Yet another application of the SPDT switch in the industrial systems is for bypass functionality. One such case is to bypass the Power Amplifier in Automated Meter Reading or AMR devices, to optimize power consumption as shown in **Figure 7**. The same can be used also to bypass the LNA.



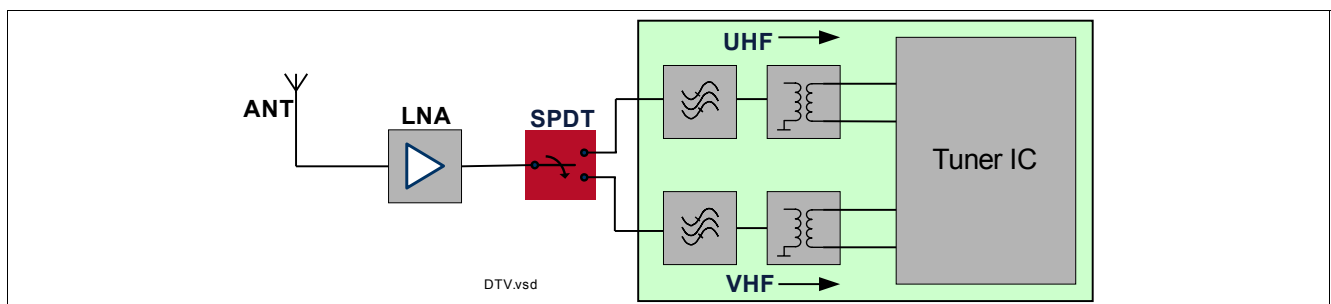
**Figure 7** Bypass switch

### 5.3 Consumer applications

When we talk about consumer applications, the two things that come first to our mind are TV and Radio. Digital/Analog TV and FM Radio have become an integral part of our day to day life. In both segments, enormous advancements have taken place since their invention and today they are integrated into mobile devices which follow us everywhere.

#### Digital Television

Digital TV is known with different names based on the geographical location. In Europe as DVB, in North America as ATSC, ISDB in Japan and DMB in Korea and India. The frequency spectrum for DTV is spread across the VHF and UHF bands. In today's front end systems, a single antenna and a single broadband LNA is used to cover the whole spectrum and thus an SPDT switch is used to select the respective band as shown in **Figure 8**. An additional SPDT can be used to further split the relatively wide VHF band into VHF low and VHF high bands.



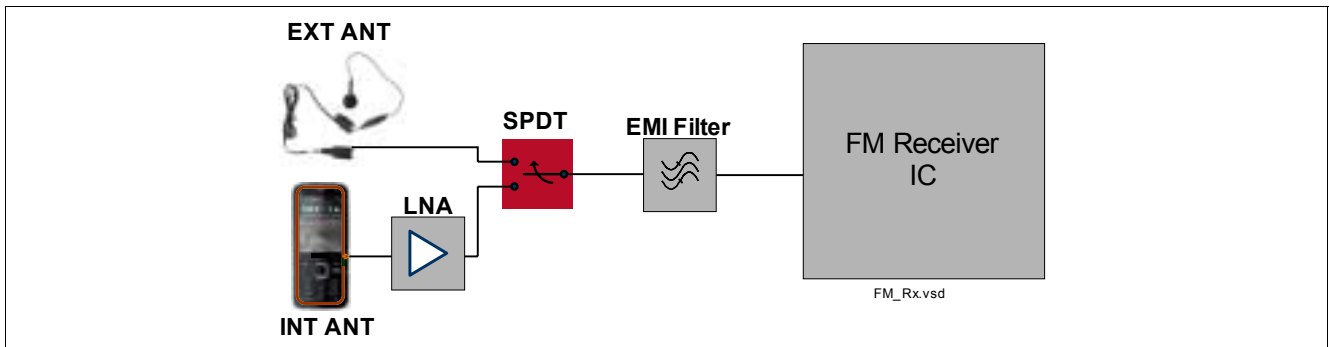
**Figure 8** Digital TV

#### FM Radio

FM Radio has a long history to its credit starting from its development in 1933. Although FM broadcast was introduced quite early, it became popular among the top radio stations only in the early 80's. Today, FM radio is an integral part of almost all mobile phones. In a common mobile phone, the hands-free cable serves as the antenna for FM reception, and hence the antenna has reasonable gain. To be able to use FM radio also without

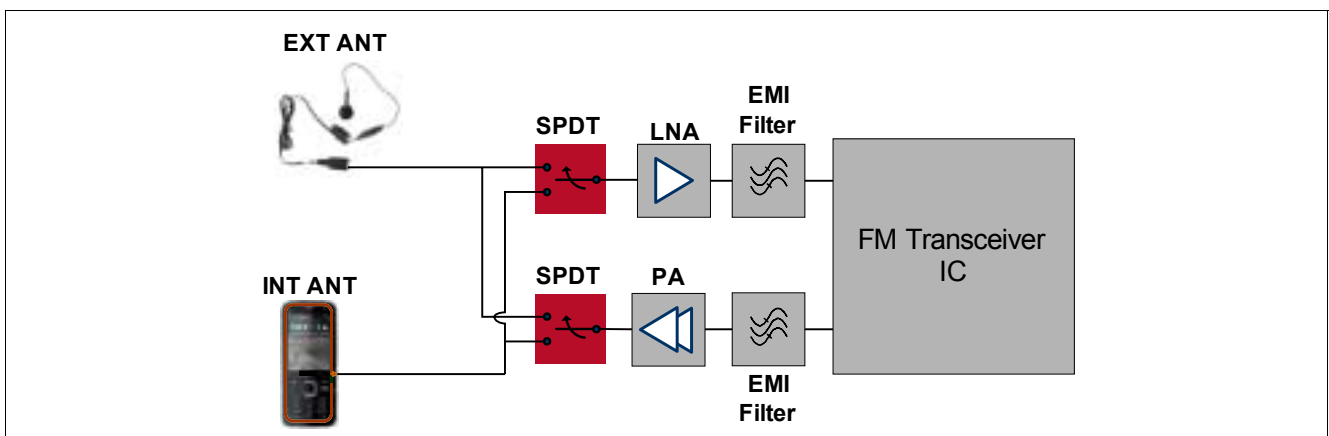
the headset, the antenna is integrated inside the phone. The internal antenna, due to its small size contributes to losses in the system, thus making it essential to include a Low Noise Amplifier before the receiver IC.

In a simple FM receiver, SPDT switch can be used to switch between the internal and external antenna as shown in [Figure 9](#).



**Figure 9 FM Receiver**

Recently, FM transmitters are gaining popularity for various purposes like transmitting MP3 files to the car radio, transferring mobile phone calls to the car radio for hands-free operation, transmitting MP3 songs to home Hi-Fi systems etc. Thus, a large percentage of future mobile phones will be equipped with FM transmitters in addition to the standard reception. In this case two SPDT switches are required, one switch each for transmit and receive section, to toggle between external and internal antennae as shown in [Figure 10](#).



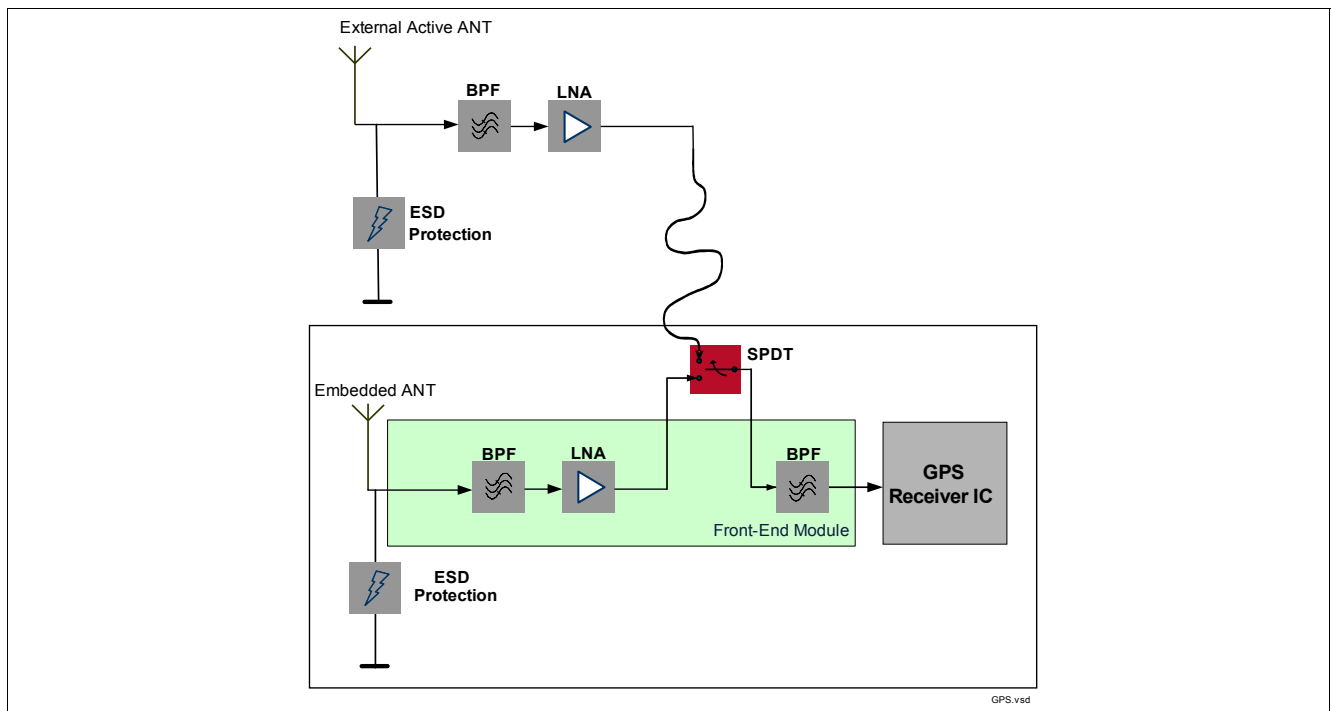
**Figure 10 FM Transceiver**

### 5.4 Automotive applications

The ever advancing telematic and security systems in car demand more and more RF components, of which, RF switches play a vital role. The two major application fields of SPDTs in Automotive segment are: GPS and Key fob.

#### GPS

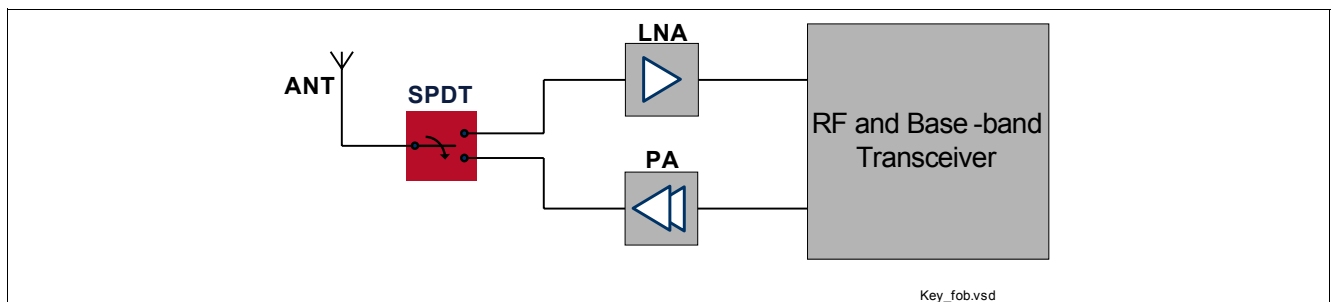
Navigation devices are generally equipped with integrated antenna, but at times when the reception is very weak, an external active antenna is necessary to operate satisfactorily. Thus a SPDT switch is needed to switch between the two antennae as shown in **Figure 11**.



**Figure 11** GPS receiver with external antenna

#### Car security

Of late, key fobs for automobiles are bidirectional systems, wherein the key fob can receive and also send control signals from/to the car. For example, the car owner is informed with a beep or vibration if there is an event at the car and then an appropriate control signal can be sent back. Such systems including transmission and reception demand again SPDT switch as shown below.



**Figure 12** Key fob

## 6 PCB Layout

This section deals with some tips and recommendations for the PCB design. Standard FR4 can be used as the PCB substrate material, but in order to keep the losses as low as possible, Rogers 4003 is used for the application boards provided by Infineon for switch evaluation. In addition, to attain mechanical strength, a layer of FR4 can be used in a multilayer configuration as shown in [Figure 13](#). Signal grounding is a prime concern for RF circuits and thus it is recommended to have via holes under the chip for an optimum RF grounding. The vias under the chip also act as a good heat sink. For the given PCB structure, the microstrip line width is 0.45 mm, with a spacing of 1.2 mm to the coplanar ground plane.

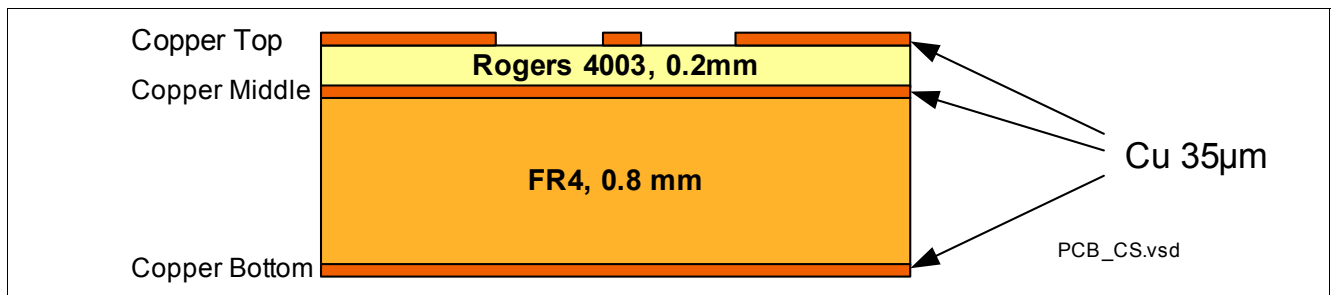
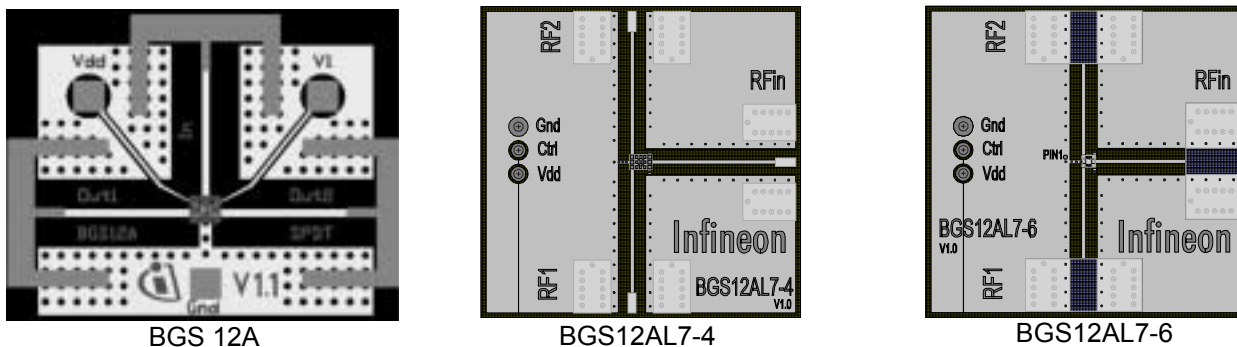


Figure 13 PCB cross-section

### 6.1 Application Board

Application boards are available for all three variants of the SPDTs offered by Infineon. They can be used to have a quick stand alone evaluation of the switch performance. A top view of the application boards is depicted below.



### 6.2 De-embedding board

When talking about RF CMOS switches for front-end systems, we are looking at very low values for insertion loss which are of the order of sub dB. Thus it is very important to calibrate the measurement setup to compensate for the PCB, SMA connector and other losses for precise measurements. For this purpose, Infineon offers de-embedding boards for all its RF switches which can be used to calibrate the measurement setup.

## 7 Measurement setup

A few important points to the measurement setup are covered in this section. For medium power RF switches which are discussed in this AN, the RF measurements can be classified into Small and Large signal measurements.

### 7.1 Small Signal Measurements

Small signal measurements characterize the switch in terms of Insertion Loss (IL), Return Loss (RL) and Isolation. These values can be arrived at by measuring S-parameters of the device. The insertion loss of the switch in this case is only a fraction of dB and thus the measurement setup should be calibrated to eliminate all other losses. Thus, to measure the S-parameters of the switch with a Network Analyzer, the NA should be first calibrated with the de-embedding board to account for the PCB and SMA connector losses. The de-embedding function in the NA should be turned on and then the actual application board with the DUT can be measured. The unused ports shall be terminated by 50 Ohm load. A multi-port NA will be helpful to measure the isolation between the various ports of the switch.

### 7.2 Large Signal Measurements

Large signal measurements include Harmonic generation and Compression point measurement of the switch.

#### Harmonic distortion measurement

Harmonic distortion measurement of a device should be carried out with great care. It is very sensitive to the measurement equipment and many other factors. Thus, utmost care must be taken to avoid harmonic generation from the equipment itself and avoid the interference of any external signals. In [Figure 14](#), a block diagram of the measurement setup is shown.

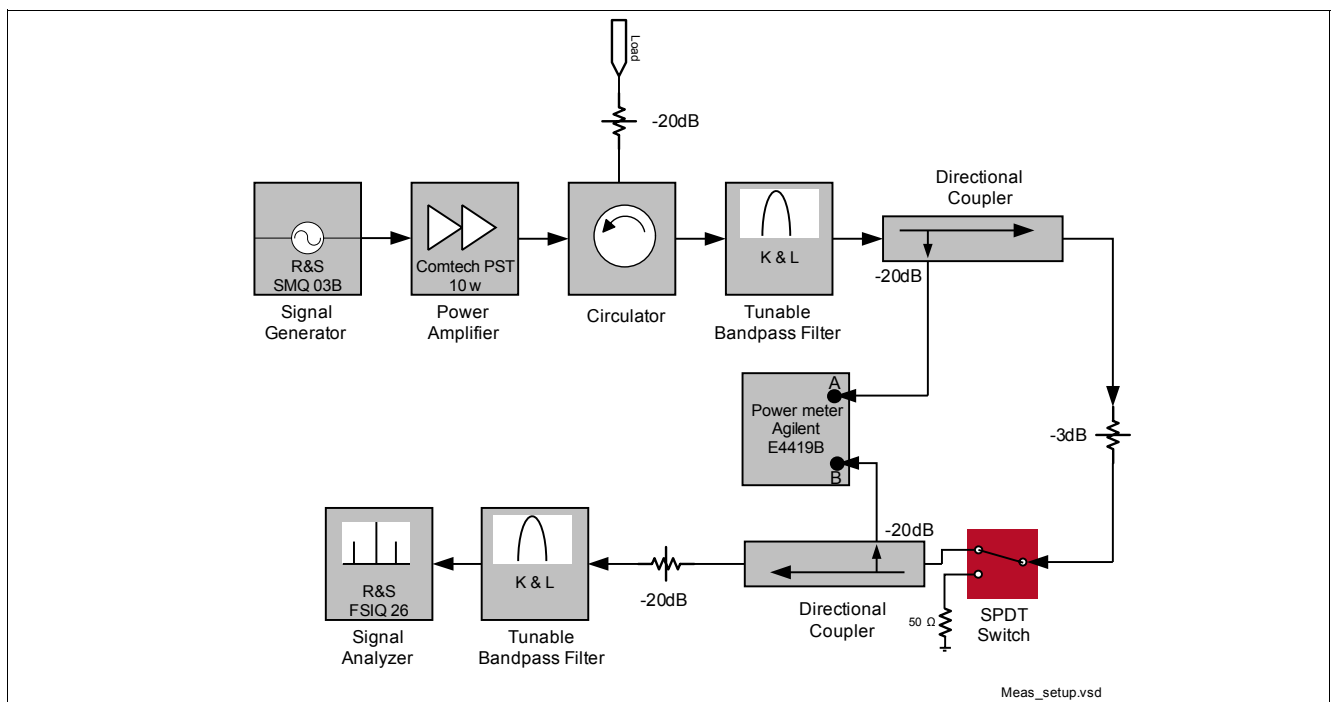


Figure 14 Measurement Setup

For harmonic measurements, higher power levels are involved, which cannot be delivered by common signal generators. Thus, a power amplifier is used to get the desired power levels. One has to consider that the power amplifier is not a linear source and therefore will generate harmonics itself. Hence, a tunable band pass filter is used to obtain a clean single tone signal free of harmonics to be delivered to the device under test. It is clear that

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**Measurement setup**

considerable amount of power will be reflected back by the bandpass filter input for the unmatched frequencies which could damage the PA. To avoid this, a circulator is used to absorb the reflected power with an attenuator and load connected at the third port of the circulator. Directional couplers are used at the input and output of the switch, by which a part of the power is coupled to the power meters in order to monitor the power at the two ports. To have a good matching between the coupler and the switch input, a 3 dB attenuator is used. The output of the switch is fed to a tunable bandpass filter through a 20 dB attenuator to protect the measurement equipment against high power levels. The bandpass filter helps to deliver only the harmonic product of interest to the signal analyzer while suppressing all other unwanted products and thus the level of the harmonic distortion generated by the switch can be measured on the analyzer.

It is important to choose the right values for the attenuator in front of the signal analyzer. High power levels can increase distortion at the input mixer of the analyzer there by generating internal harmonics, which will give false values for the harmonic generation by the switch. So, the attenuator should be large enough to avoid harmonic generation at the input mixer. At the same time there is a limit on the amount of attenuation as introducing attenuator increases the noise floor in the system. This decrease in the dynamic range of the analyzer can make it difficult to measure the original signal. The dynamic range can be increased by lowering the resolution bandwidth, which has a limit too, as it increases the measurement time.

Care should be taken to choose the appropriate power sensors for power detection due to the high power levels involved.

**Compression point measurement**

For RF front-end switches, another measure for non-linearity is specified by  $P_{0.1\text{ dB}}$  or 0.1 dB compression point, unlike the most commonly used 1 dB compression point. The  $P_{0.1\text{ dB}}$  specifies the input power at the switch in dBm, at which, the insertion loss of the switch increases by 0.1 dB than the typical value. This value confirms the power handling capability of the switch. Infineon SPDT switches were measured up to an input power of 28 dBm and no deterioration in the insertion loss was observed as can be seen in [Figure 19](#).

## 8 Measurement curves: BGS12AL7-4

Small Signal measurements:

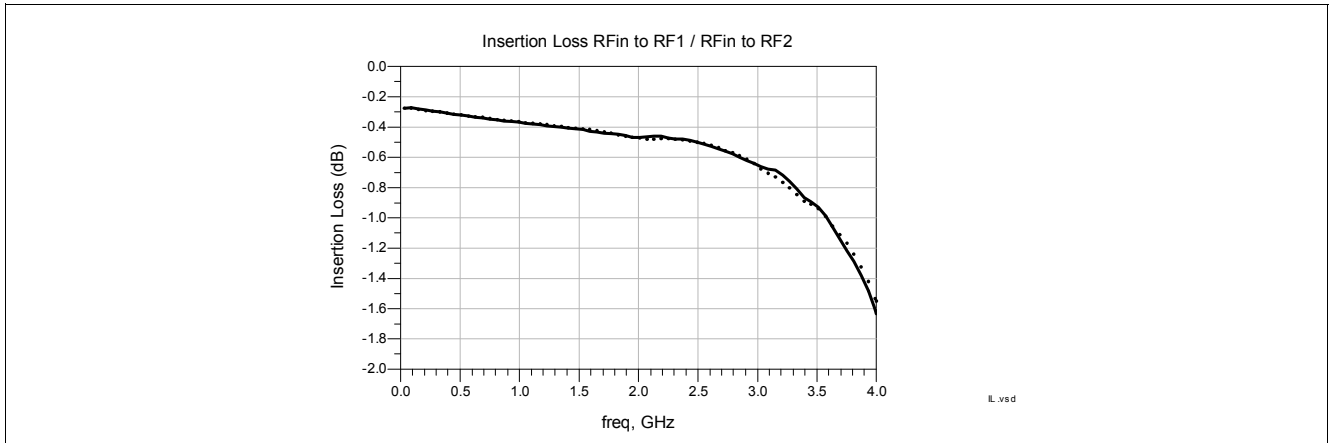


Figure 15 Insertion Loss

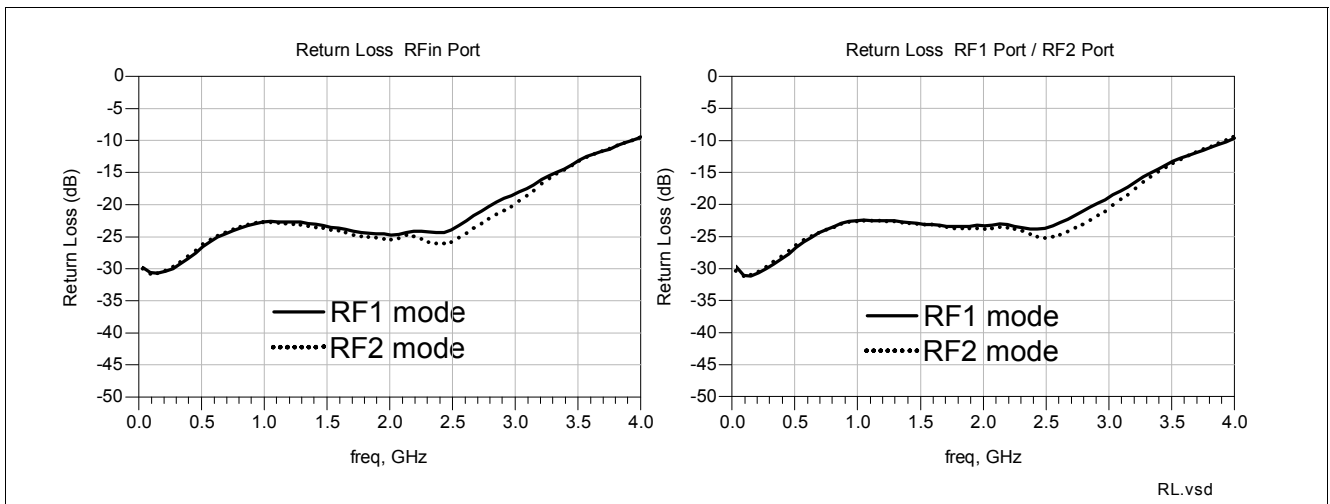


Figure 16 Return Loss

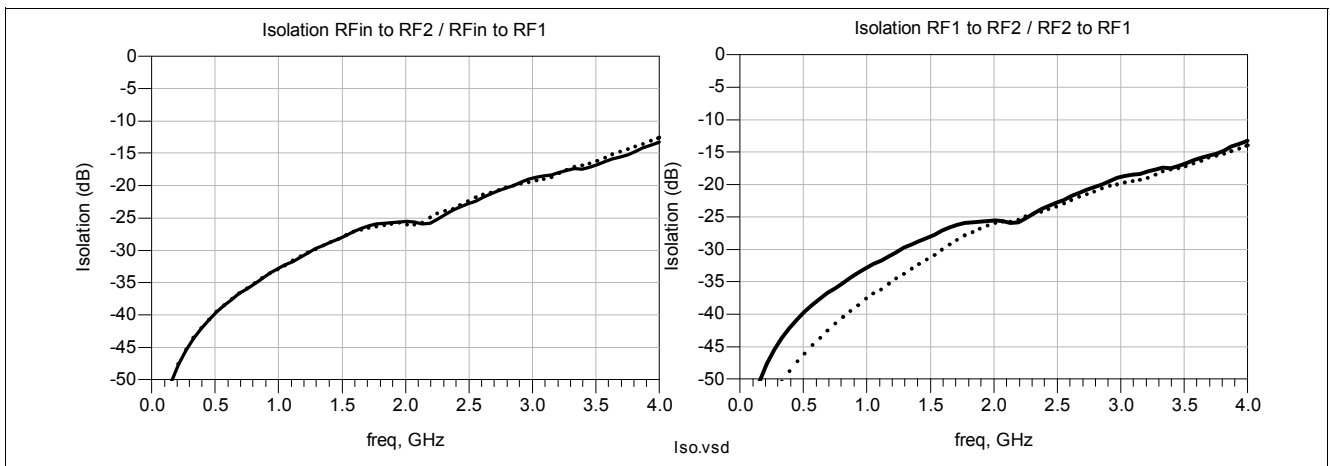


Figure 17 Isolation



Large Signal measurements:

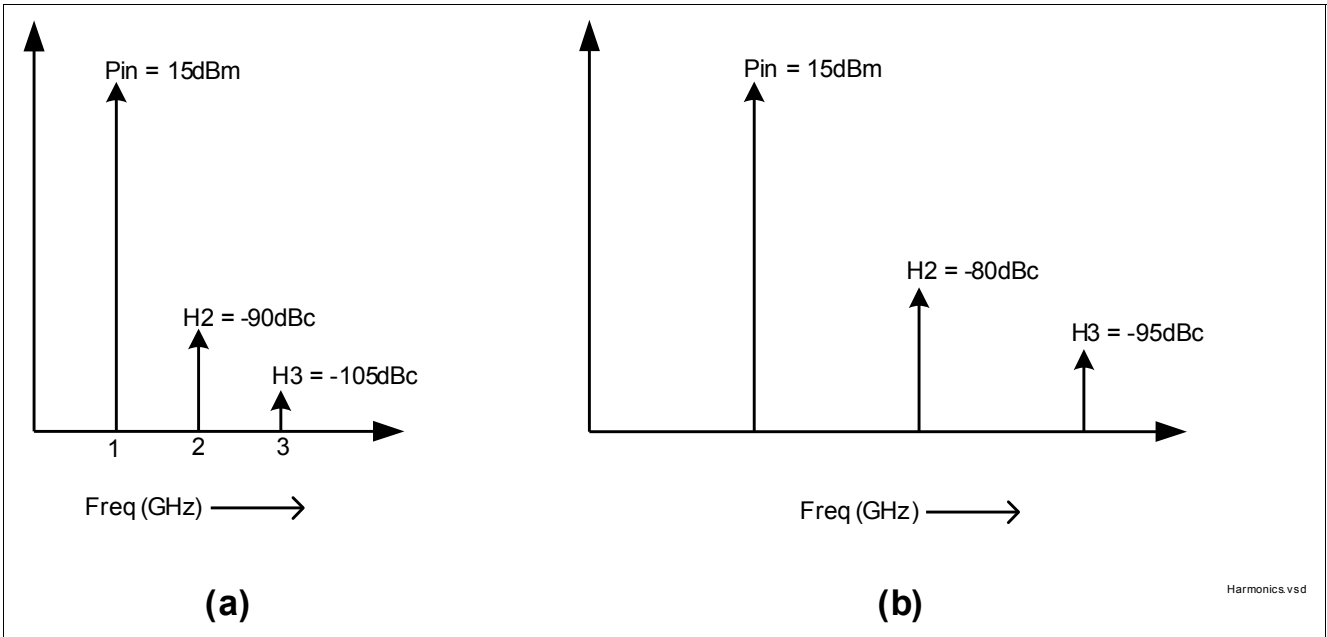


Figure 18 Harmonics: (a)  $P_{in}=15\text{ dBm @ 1 GHz}$ , (b)  $P_{in}=15\text{ dBm @ 2 GHz}$

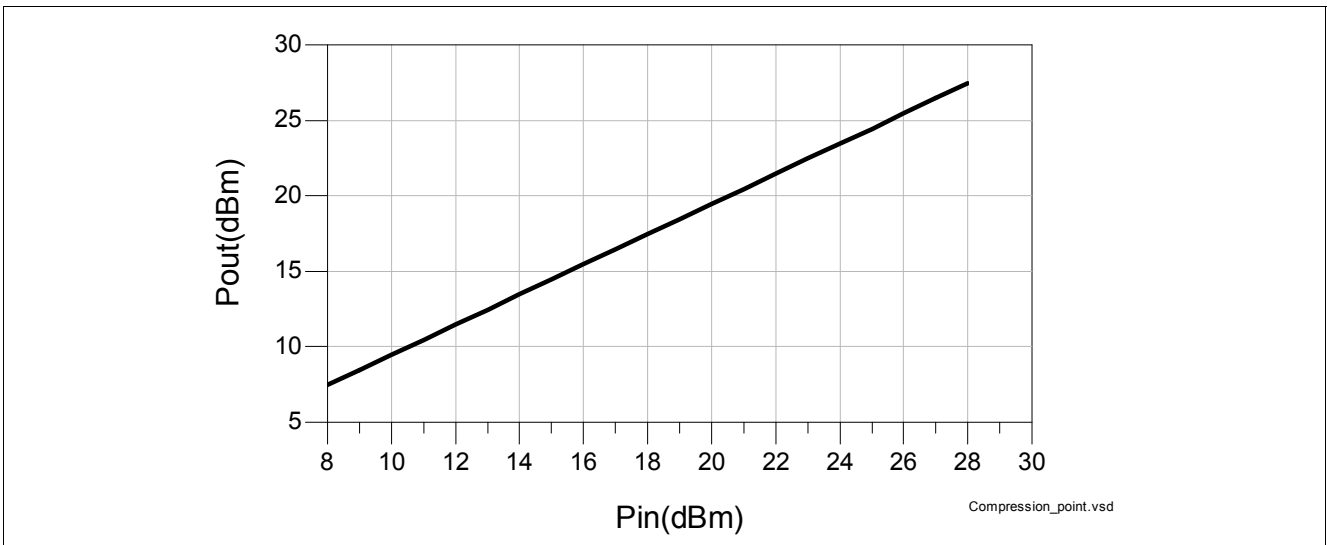


Figure 19 BGS12AL7-4:  $P_{0.1\text{dB}}$  Compression point

## 9 Summary

In this Application Note, three variants of the Infineon RF CMOS SPDT switch are presented. It is seen that with their high performance concerning insertion loss, linearity and isolation, they are applicable in almost all market segments covering a huge range of applications. A brief description of some of the applications is presented with the aid of block diagrams. In order to evaluate the switches, Infineon offers application boards and de-embedding boards for calibration. Some important notes on the switch measurements are also covered in the AN, including small signal and large signal measurements.