Application note BGSA147ML10

Measurement and Application Guide

About this document

Scope and purpose

This application note provides an overview of the features, parameters and application guidelines for the antenna tuning switch BGSA147ML10. The measurement procedures are described for determining different key parameters.

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1 Antenna tuning

Nowadays, connected devices need more and more antennas to support growing RF requirements and cover an even wider frequency range. At the same time, antenna dimensions must be minimized due to Industrial Design (ID) constraints. As a result, antenna performance can be affected with regard to radiated power and receiver sensitivity.

Antenna tuning is a solution to this challenge, helping RF engineers to optimize antenna efficiency, which translates into enhanced user experience in terms of higher data rates, longer battery life and improved signal quality. Infineon offers a comprehensive portfolio of antenna tuning switches for impedance and aperture tuning cases to address antenna design challenges and enable maximum power transfer for best antenna efficiency.

1.1 Antenna impedance tuning

Antenna impedance matching is carried out at the antenna feed point, as shown in Figure 1. Using this type of antenna tuning, forward power to the antenna can be optimized by matching the antenna input impedance to 50 Ω. In this way, impedance tuning helps to maximize signal transmission between RF Front-End (RFFE) and the antenna by compensating for frequency and environmental effects.

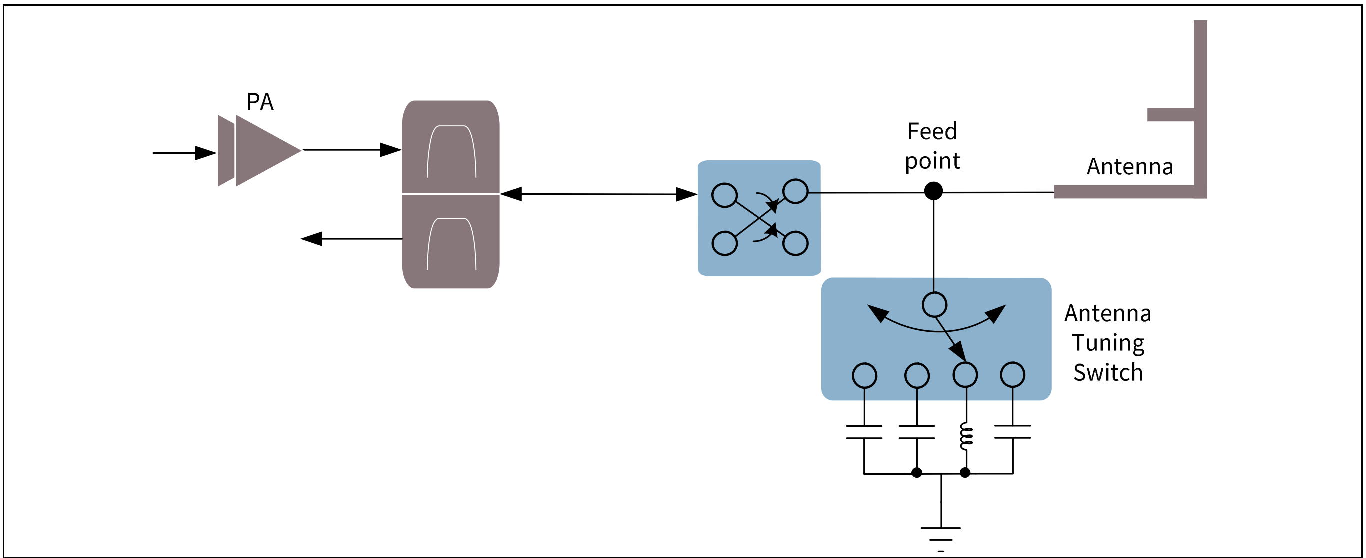

Figure 1 Antenna impedance matching

1.2 Antenna aperture tuning

A more widely used antenna tuning technique is aperture tuning, which improves antenna efficiency by shifting the natural resonance of an antenna to the required frequency band of operation. This reduces stress on the antenna-driving hardware on the transmitter side (Tx) and increases sensitivity on the receiver side (Rx). Aperture tuning also allows antennas to communicate on multiple bands simultaneously to support carrier aggregation.

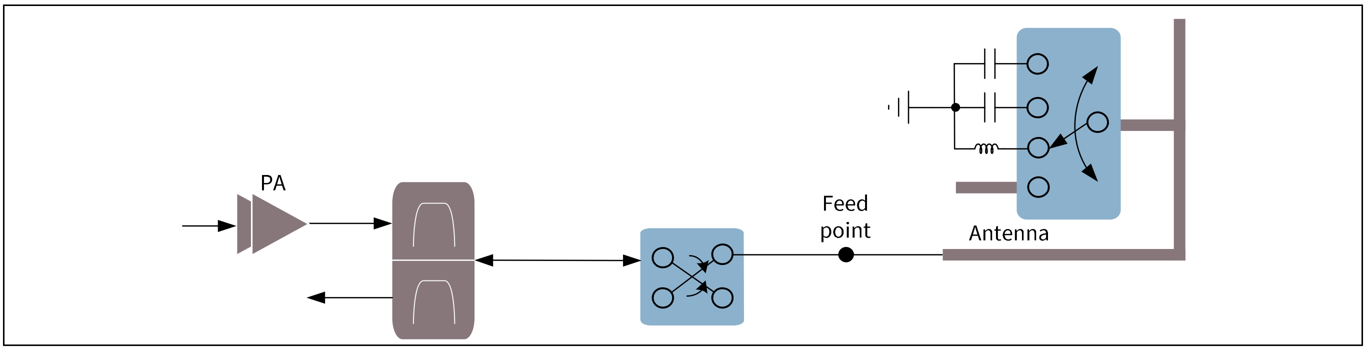

Figure 2 Antenna aperture tuning

1.3 Antenna tuner key parameters

Certain characteristics are important for antenna tuning. These are explained in the following section.

1.3.1 Voltage distribution on antenna tuning switches

Aperture tuners are implemented at the antennas with certain electromagnetic field distributions in the near field. For example, an IFA antenna is a quarter-wavelength resonating structure consisting of one open circuit at one end and one short-circuit at the other end. Its electromagnetic field distribution can be analyzed through the voltage and current distribution on the conducting parts. As shown in the figure below, the highest RF voltage (V_{RF}) is observed at the open-circuit side, while the highest RF current is located at the short-circuit side. Voltages across the tuner that exceed its limit can damage the device and can lead to antenna efficiency degradation. Therefore, the antenna tuner should be placed in the appropriate position at the antenna.

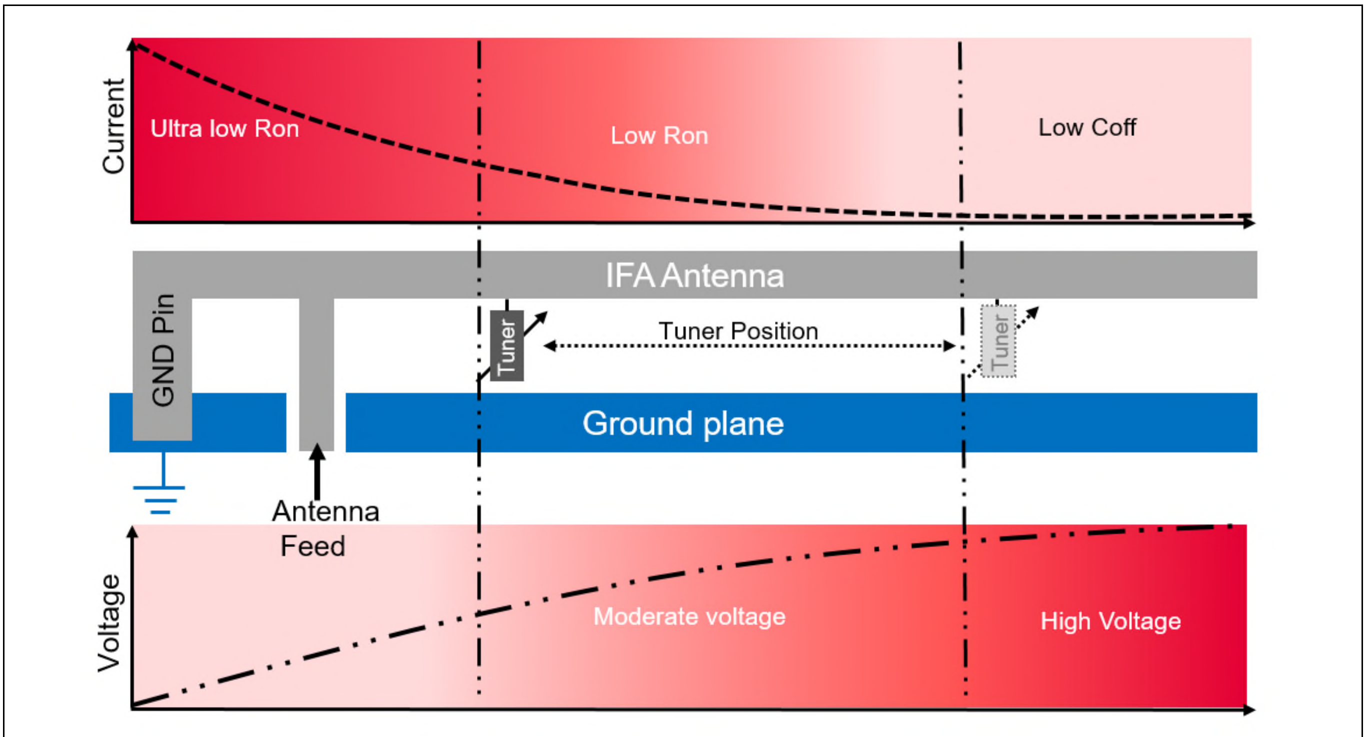

Figure 3 Impact of antenna tuner placement at the antenna on V_{RF}, R_{ON} and C_{OFF}

1.3.2 ON resistance (R_{ON})

The R_{ON} of antenna tuning switches is a key differentiating feature. The lower the R_{ON}, the lower the ON path loss. Because an antenna tuning switch is directly connected to the antenna, higher R_{ON} means higher ON path loss and consequently lower quality factor (Q-factor). The effect of R_{ON} varies depending on different types of antenna tuning. For antenna tuning at a higher RF voltage point of the antenna, where lower RF current is flowing through the ON path of the switch, R_{ON} has a negligible effect. However, for low-voltage tuning cases, R_{ON} has a significant effect. This phenomenon is explained in the figure below. The RF voltage level depends on the power fed to the antenna as well as the placement of the tuner at the antenna.

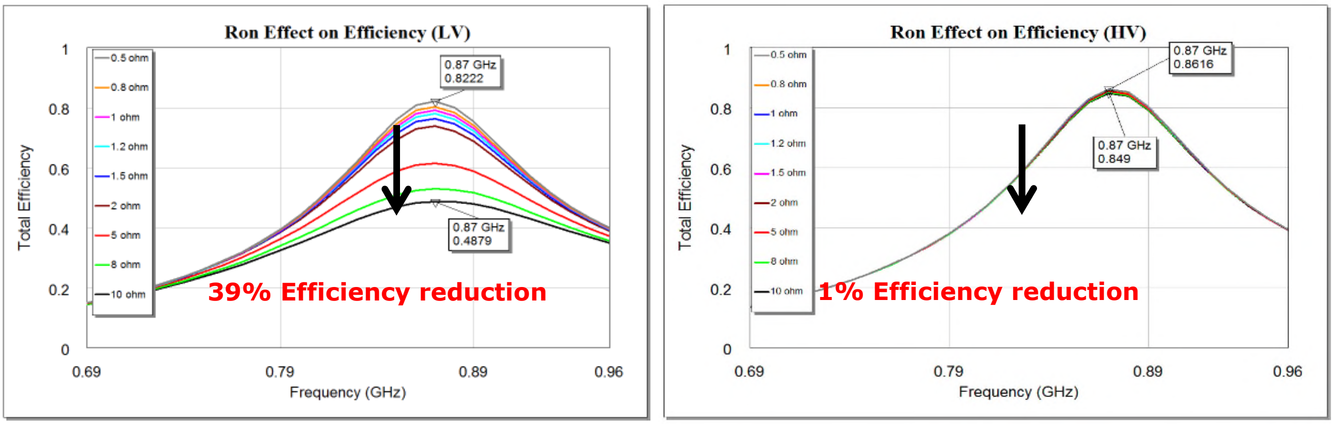

Figure 4 Low-voltage versus high-voltage tuning case

1.3.3 OFF capacitance (C_{OFF})

C_{OFF} is also one of the key features of antenna tuning switches. A higher C_{OFF} results in a large high-frequency band loss and causes self-resonances. Thus, for better performance, a lower C_{OFF} is important for an antenna tuning switch. The impact of C_{OFF} varies depending on different types of antenna tuning. For high-voltage aperture tuning, C_{OFF} has a significant de-tuning effect on the antenna. For low-voltage aperture tuning, this effect is quite small. This behavior is shown in Figure 5.

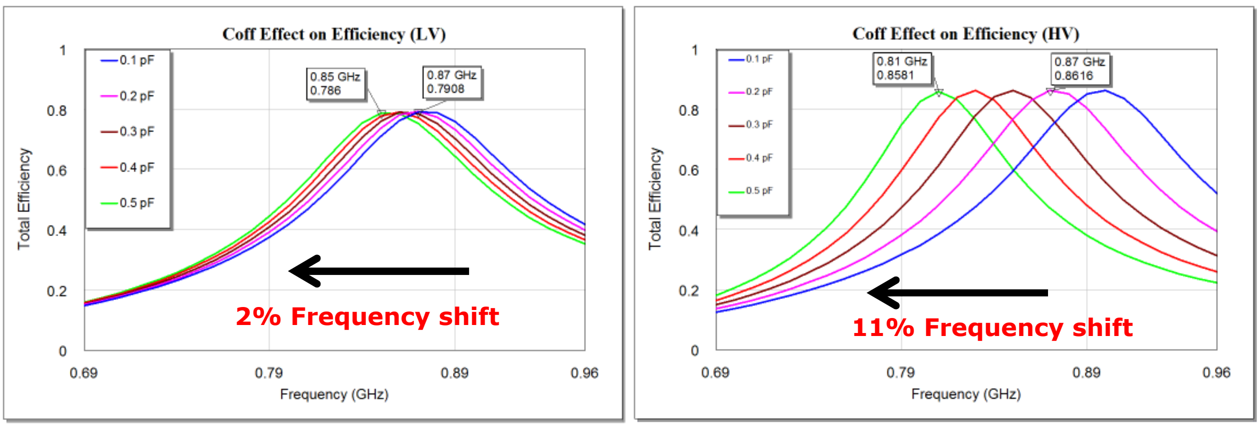

Figure 5 Low-voltage versus high-voltage tuning case

1.3.4 Maximum RF voltage (V_{RF})

Antenna tuning switches only work under certain RF voltage regulations, e.g. below breakdown voltage. When the antenna is analyzed by using a transmission line model, the characteristic impedance of the antenna model varies with antenna structure. High impedance of the antenna results in high V_{RF} across the antenna tuning switch (see VRF measurement). Generally, the voltage generated is much higher than the specified V_{RF} for a standard switch.

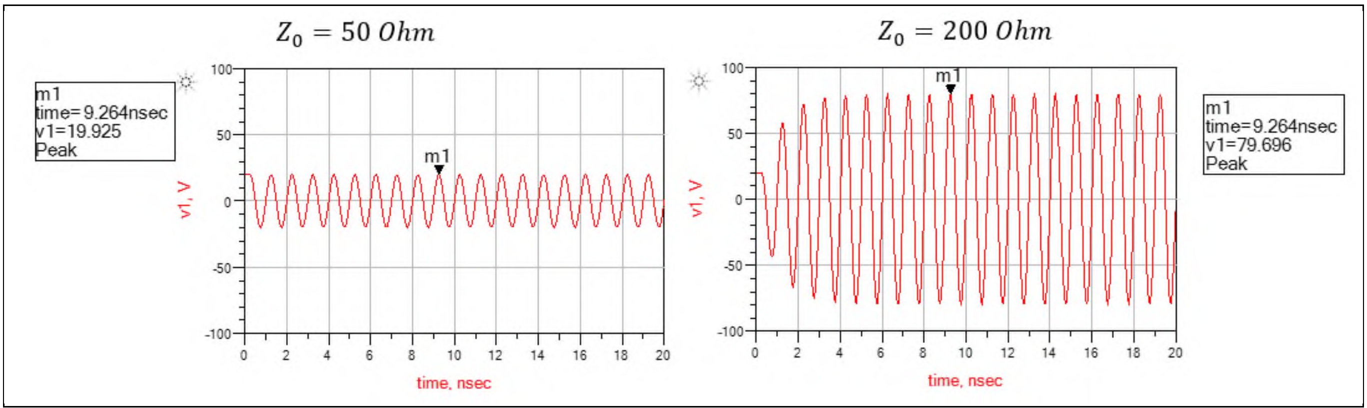

Figure 6 Maximum RF voltage with different impedances

The figure above shows how the characteristic impedance Z0 directly impacts the RF voltage across a transmission line. When Z0 is ideal (50 Ω), the RF voltage is moderate, but when the characteristic impedance increases, the RF voltage reacts accordingly. To calculate the RF voltage across a transmission line, the formula below can be used.

$$|V|_{RF} = \sqrt{2P\boldsymbol{Z_0}}$$

In the formula, V_{RF} is the RF voltage, $\boldsymbol{Z_0}$ is the characteristic impedance and P is power at a lossless transmission line.

2 BGSA147ML10

The BGSA147ML10 is a single-pole four throws (SP4T) antenna tuning switch optimized for RF applications up to 7.125 GHz. Its MIPI RFFE digital control interface allows easy implementation and best flexibility when operated in cellular mobile RFFE designs.

The BGSA147ML10 is made of four ultra-low ON resistance/low OFF capacitance series switches and four shunt-to-ground switches enabling on-demand open-reflective or short-reflective OFF ports behavior. This last feature is valuable to reduce antenna engineer development time in case of unwanted antenna resonance or to improve antenna efficiency with less component tuning effort. Unlike GaAs RF switches, highly linear RF performance is reached at all signal levels within the operating conditions. High RF voltage ruggedness and individually programmable shunt-to-ground switches on each RF throw make BGSA147ML10 particularly efficient for switching inductors and capacitors in RF matching and antenna tuning circuits.

Block diagram and key features

- Designed for high-linearity antenna tuning switching and RF tuning applications
- Ultra-low R_{ON} resistance of 0.8 Ω at each RF port in ON state
- Individually controlled reflective open or short-to-ground OFF ports to eliminate unwanted antenna resonances
- Low C_{OFF} capacitance of 155 fF at each port in OFF state
- High RF operating voltage handling above 45 V in OFF state
- MIPI RFFE 2.1 compliant control interface
- External USID_sel pin enabling three default USID addresses
- No RF parameter change within supply voltage range
- No power supply decoupling required
- Small form factor 1.1 mm x 1.5 mm (MSL1, 260_C per JEDEC J-STD-020)

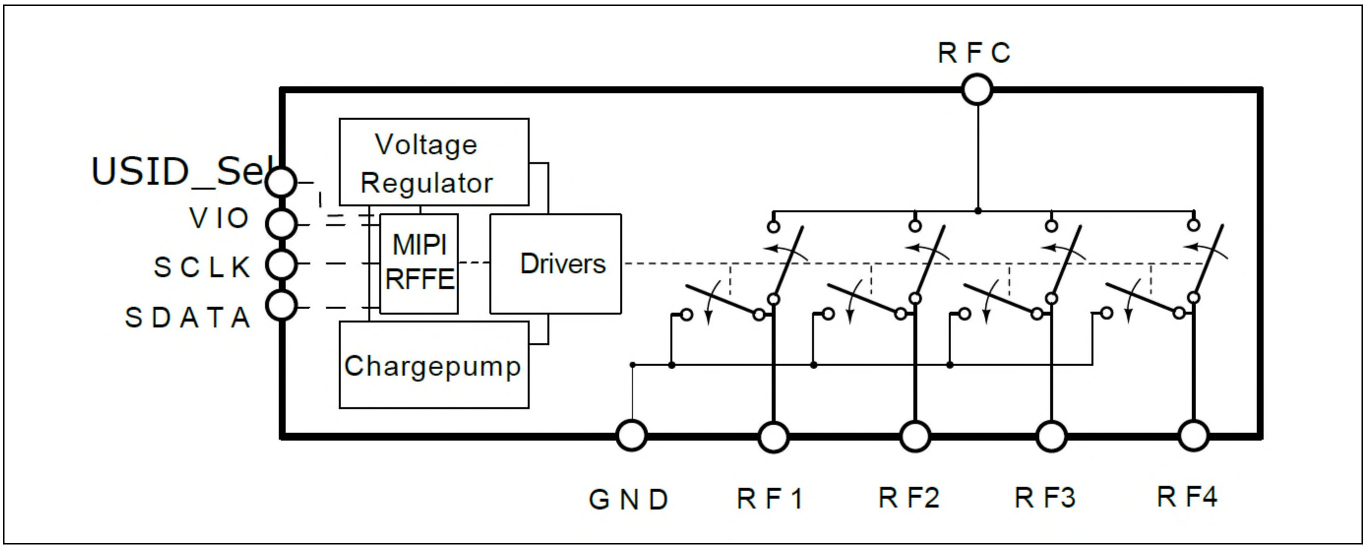

Figure 7 Block diagram BGSA147ML10

3 Measurement setups

3.1 Application boards

The evaluation boards (EVBs) for S-parameters, harmonics and V_{RF} measurements are shown below. The measurement setups and measurement procedures are explained in the following chapters. Each EVB has a 10-pin connector to control the device via the MIPI RFFE interface (see MIPI RFFE control interface). The pin configuration is printed on the EVB.

3.1.1 S-parameter evaluation board

The S-parameter EVB is used for S-parameter measurements (see S-parameter measurement) as well as ON mode harmonics measurements (see Harmonics measurement). A separate de-embedding board set is used to compensate for the effects of the PCB on the test results.

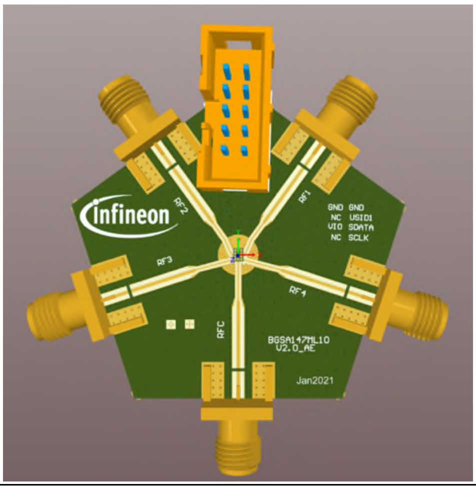

Figure 8 S-parameter evaluation board of BGSA147ML10

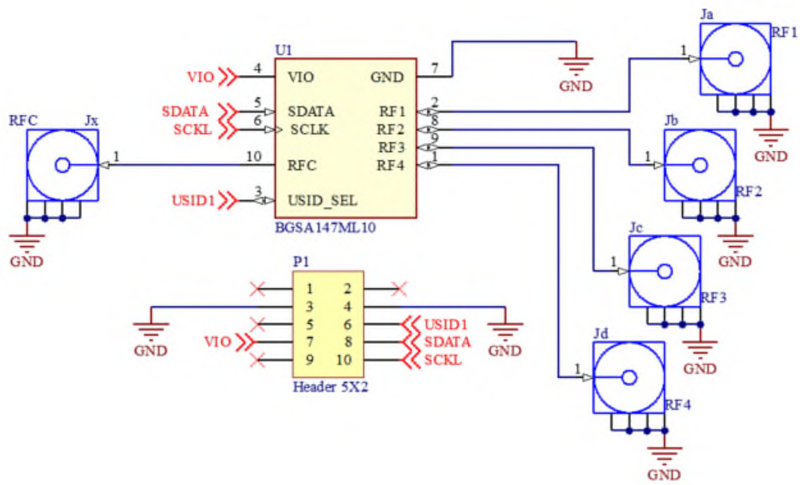

Figure 9 Schematic of the BGSA147ML10 S-parameter evaluation board

The layers of the S-parameter EVB are shown below.

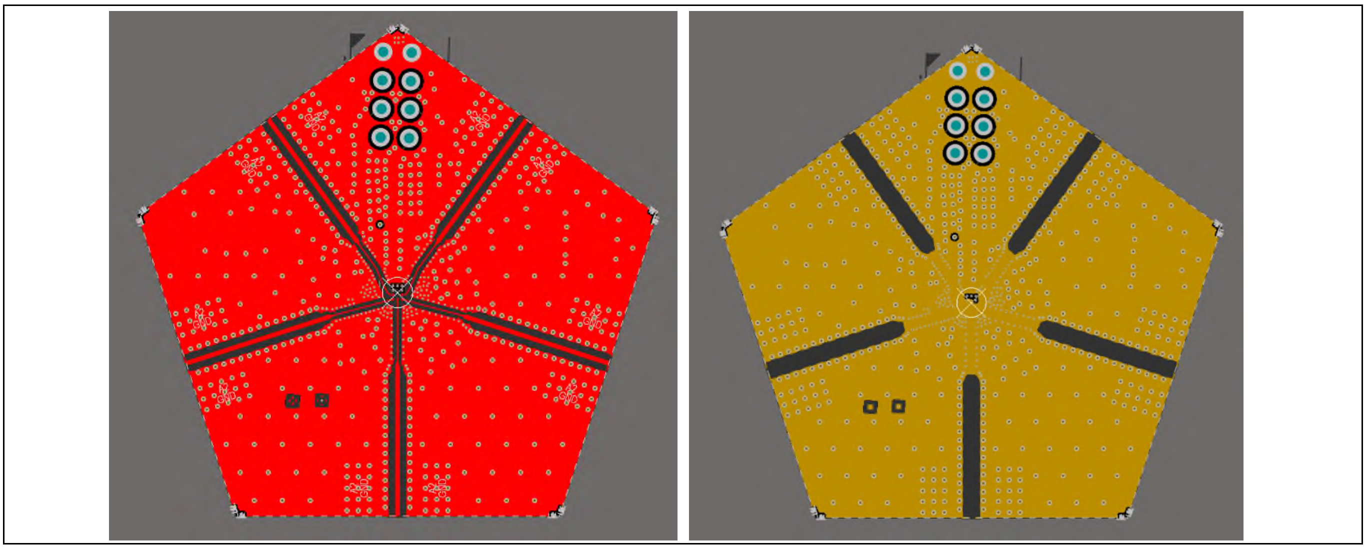

Figure 10 S-parameter EVB first and second layer

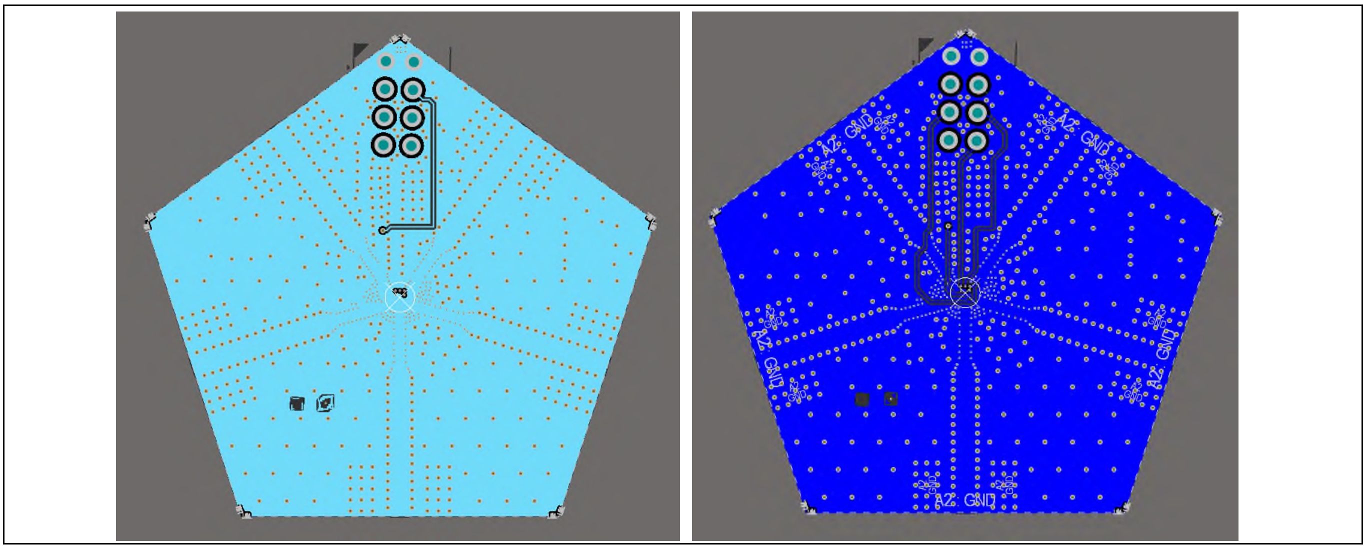

Figure 11 S-parameter EVB third and fourth layer

3.1.2 V_{RF} evaluation board

The V_{RF} EVB is used for V_{RF} measurements (see VRF and harmonics measurement setup). Each individual port can be stressed using this EVB.

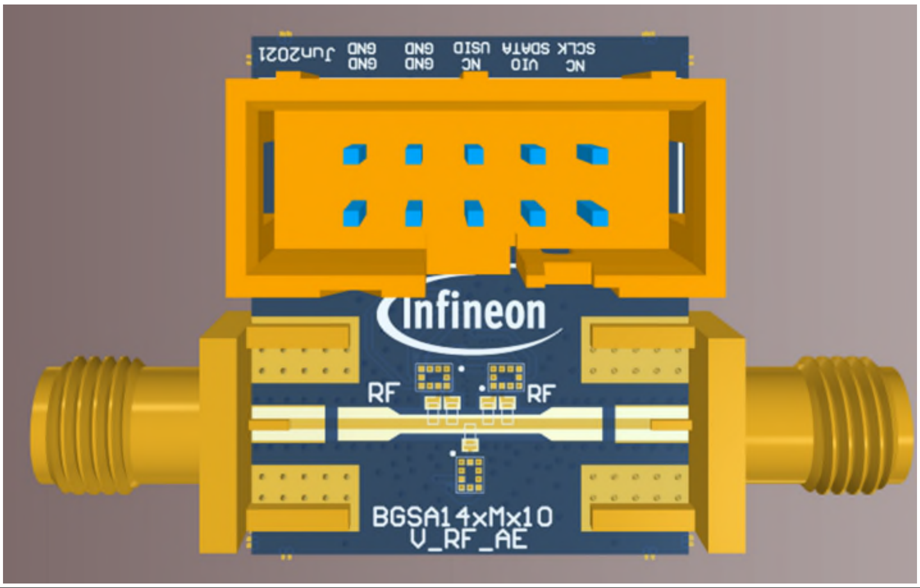

Figure 12 V_{RF} EVB for BGSA147ML10

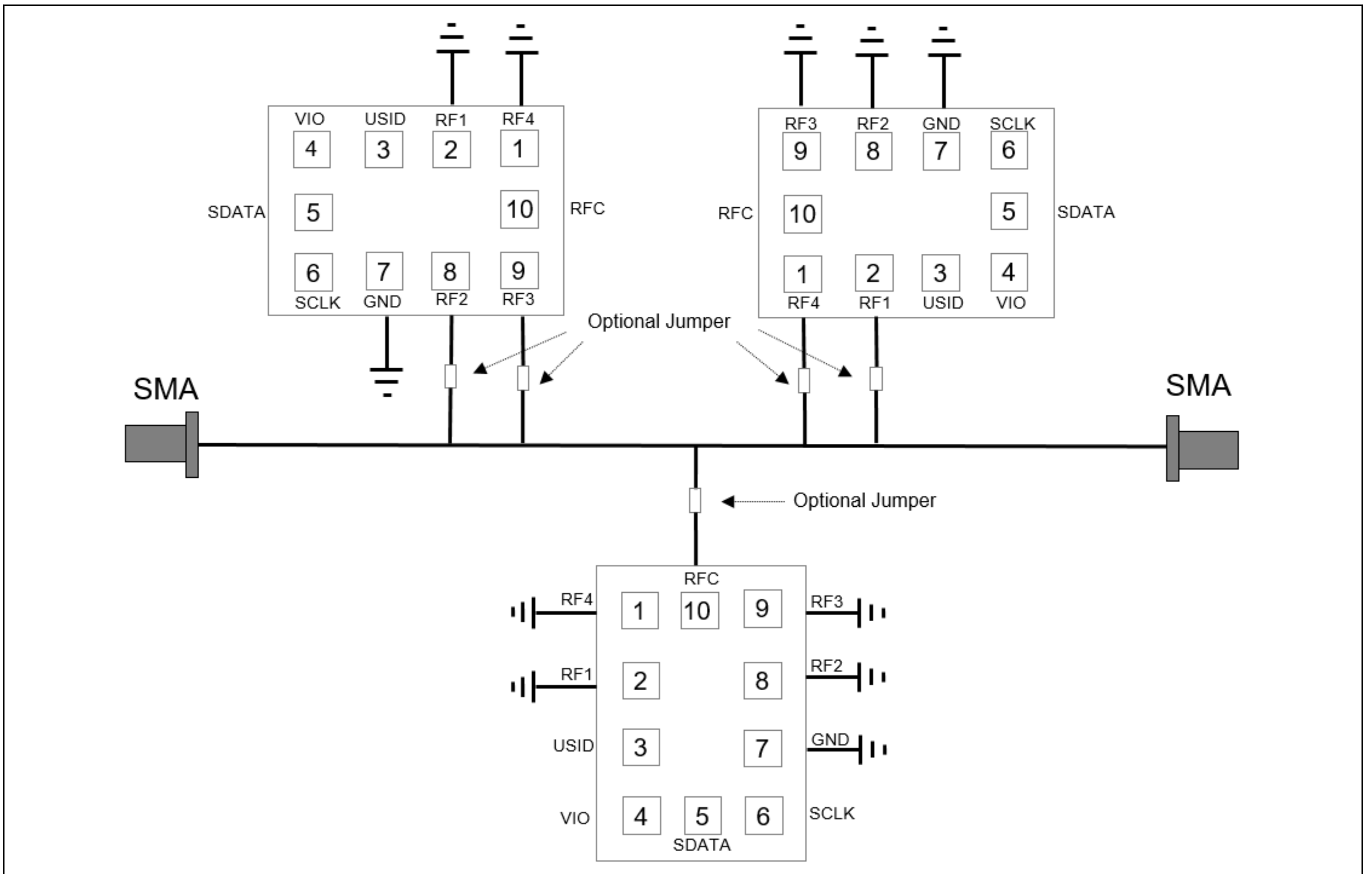

Figure 13 Schematic of the V_{RF} EVB for BGSA147ML10

The layers of the V_{RF} EVB are shown below.

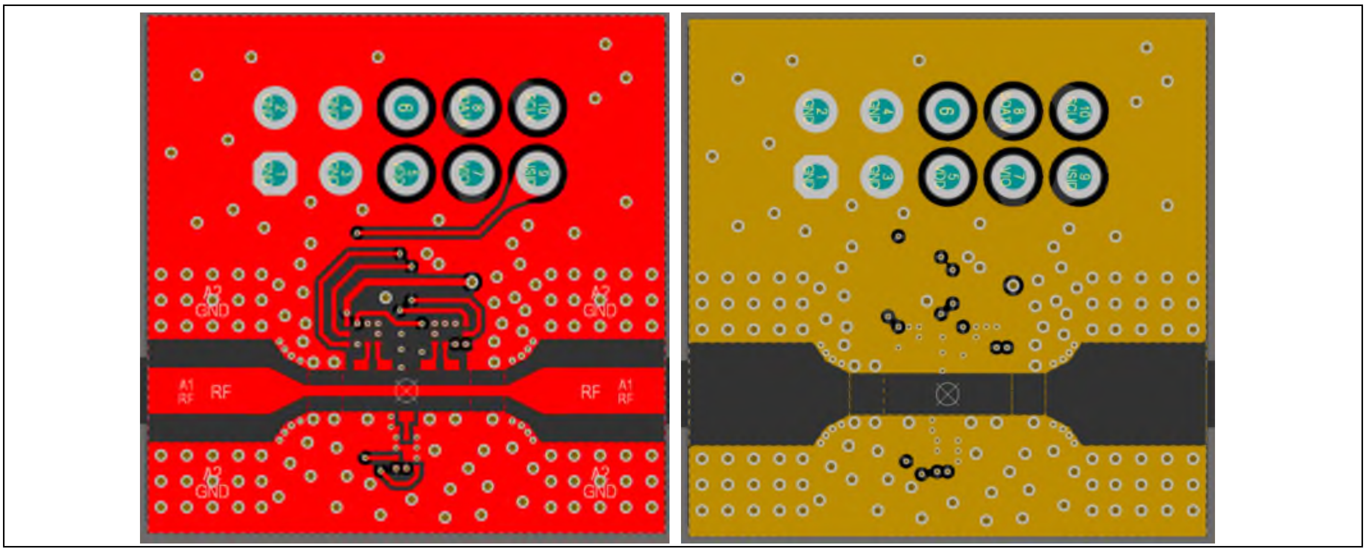

Figure 14 V_{RF} EVB first and second layer

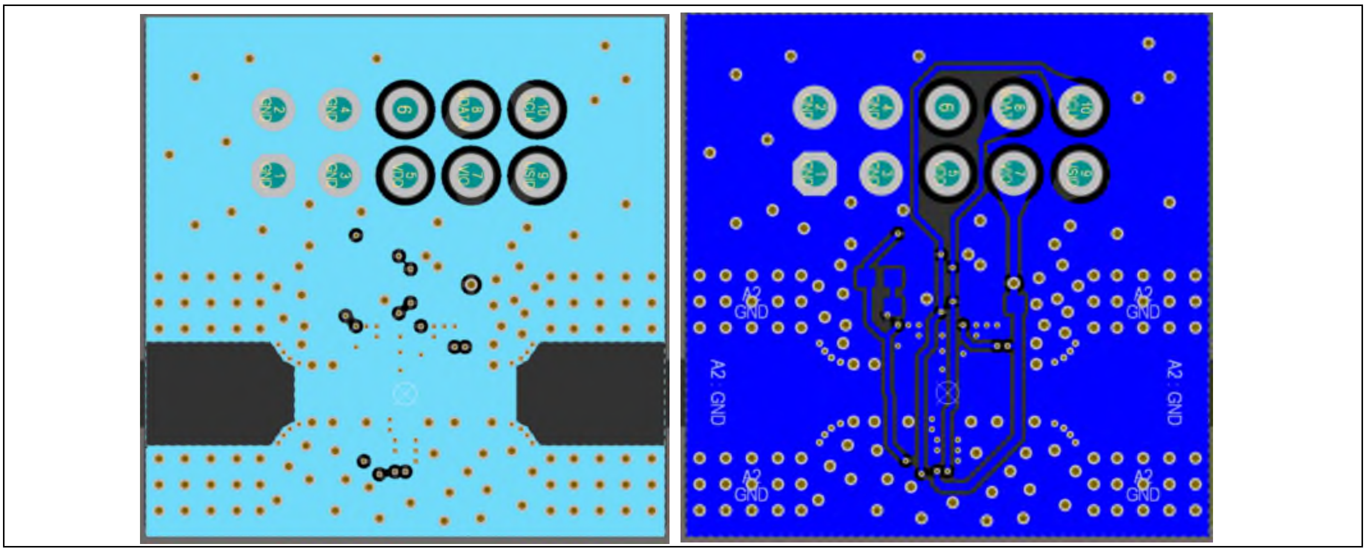

Figure 15 V_{RF} EVB third and fourth layer

3.2 Measurement setup preparation

3.2.1 De-embedding

The RF device under test (DUT) is soldered on to a PCB for evaluation. A de-embedding procedure is necessary to compensate for the effects of the PCB (in terms of mismatch, losses, phase delay and parasitics).

For BGSA147ML10 the TL calibration method is used.

3.2.1.1 TL calibration

TL calibration requires two lines with a fixed length (through-line (T) and through-line +ΔL (L)), hence two separate measurements are needed. The through-line is equal to two times the length of the EVB's RF-line. The through +ΔL line is 7 mm longer than the through-line.

With the information of the S-parameters from these two calibration lines, the loss and delay of the EVB's RF lines can be calculated and subtracted from the EVB's measurement.

Figure 16 Through-line, and through-line plus ΔL

Because the de-embedding file is generated using internal Infineon software, only the through-line is provided with the EVBs. The RF-line de-embedding file is delivered on request. The de-embedding file can be verified using the through-line.

The figure below shows an example of the method, where the through-line and the through-line +ΔL are measured and compared to the generated half-line de-embedding file.

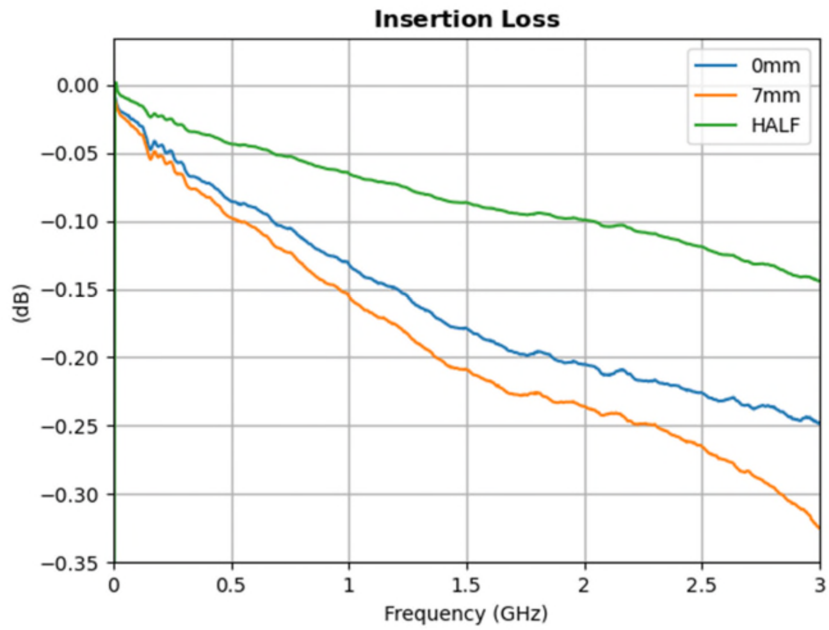

Figure 17 Example measurement of the through-line, through-line plus ΔL and half-line

3.3 MIPI RFFE control interface

A MIPI stick is needed to control the device via a computer. In the picture below, all the connections of the MIPI stick are shown that can be used to activate and control the device.

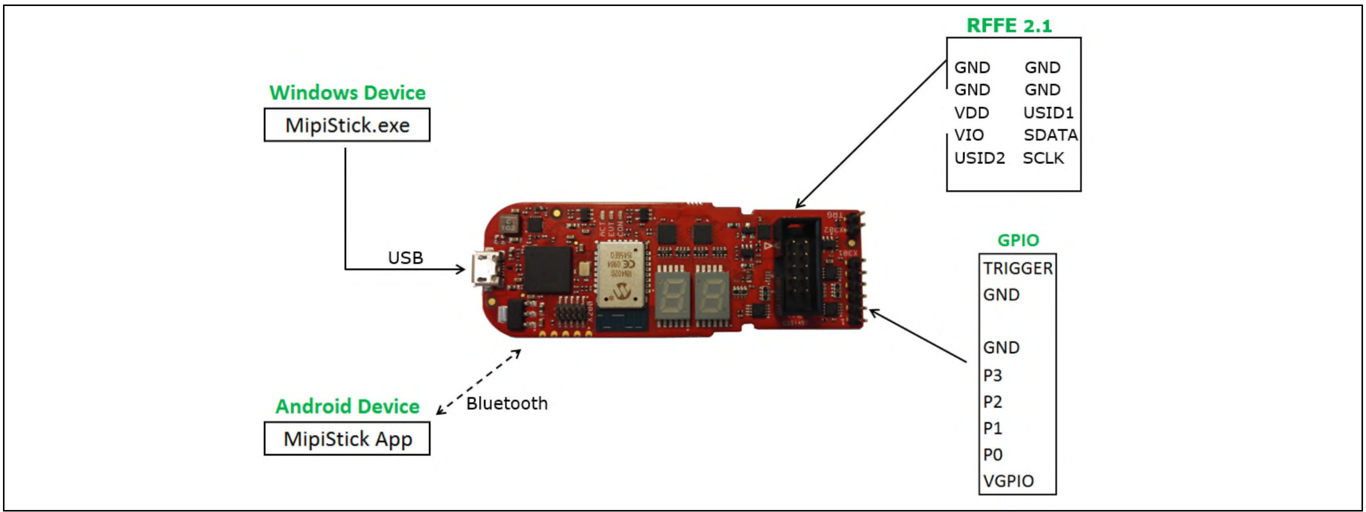

Figure 18 MIPI stick

Once the connection (VIO, SCLK, SDATA, GND) between the MIPI stick and the EVB is set up, it can be connected to a PC via USB. After starting the GUI and activating the device, the following control interface appears.

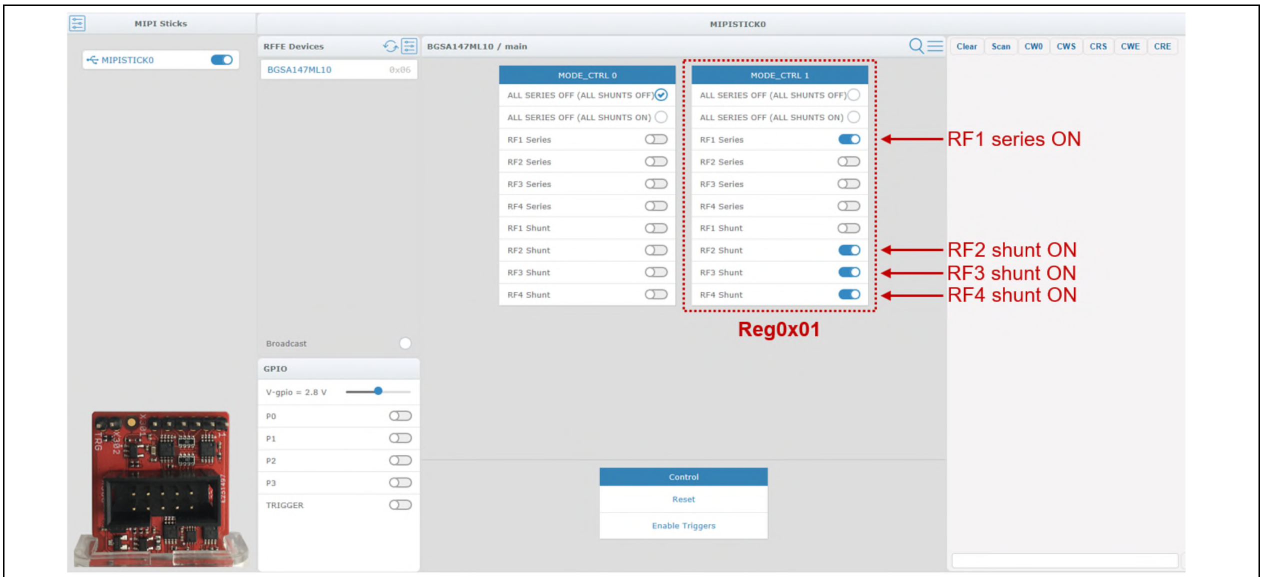

Figure 19 The MIPI GUI (control interface to control MIPI devices via a computer)

Here also the desired device states can be set. Register_0 and Register_1 RF switch control bits are identical. Writing both Registers (Register_0 and Register_1) simultaneously will lead to undefined behavior. The unused Register (Register_0 or Register_1) must remain 0x00 (all series OFF and all shunt OFF).

3.3.1 Truth table

With the help of the truth table, the desired state can be chosen. The BGSA147ML10 truth table enables connection of any combination of the bits below in one single write to register_0 (respectively register_1) command. As an example, RF1 series ON can be set, while RF1 shunt is set to OFF. At the same time, RF2, RF3 and RF4 series OFF and shunt ON can be set by using this single write to register_0 command “0b:11100001”.

State	Mode	D7	D6	D5	D4	D3	D2	D1	D0
0	ALL Series OFF (All Shunts OFF)	0	0	0	0	0	0	0	0
1	ALL Saries OFF (All Shunts ON)	1	1	1	1	0	0	0	0
2	RF1 Series	0	0	0	0	0	0	0	1
3	RF2 Series	0	0	0	0	0	0	1	0
4	RF3 Series	0	0	0	0	0	1	0	0
5	RF4 Series	0	0	0	0	1	0	0	0
6	RF1 Shunt	0	0	0	1	0	0	0	0
7	RF2 Shunt	0	0	1	0	0	0	0	0
8	RF3 Shunt	0	1	0	0	0	0	0	0
9	RF4 Shunt	1	0	0	0	0	0	0	0

Figure 20 Truth table BGSA147ML10

3.3.2 USID setting

The external USID_sel pin enables three default USID addresses: to VIO, Ground and Floating.

Address	Symbol	External Conditon at USID Port
USID=0110	Addr6	to VIO
USID=0111	Addr7	Ground
USID=1001	Addr9	Floating[1]

[1] Total capacitance on the USID_SEL pin must be <5 pF.

Figure 21 Default MIPI USID states

By using different USID addresses, up to three devices in one MIPI bus can be individually controlled. The pin configuration below shows how the USID selection pin needs to be connected to configure various addresses.

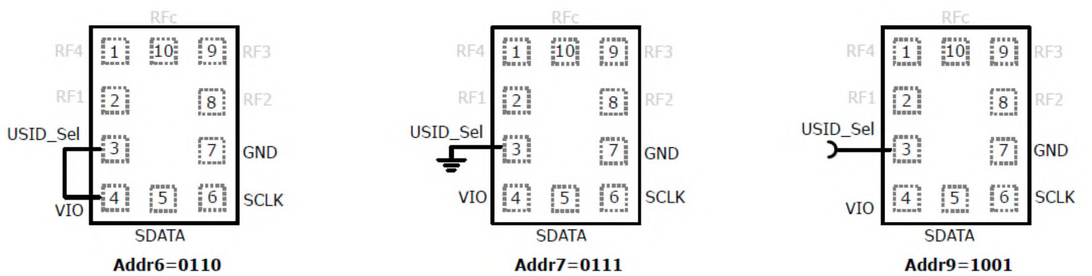

Figure 22 BGSA147ML10 USID_Sel pin configuration

3.4 Measurements

3.4.1 S-parameter measurement

With the help of a Vector Network Analyzer, the S-parameters (Isolation, Return Loss and Insertion Loss) of the device are measured. In the figure below, the connection of the RF ports as well as the DC pins with the DUT are shown. After activating the DUT in the desired state, all S-parameters for the specific RF ports with de-embedding are measured.

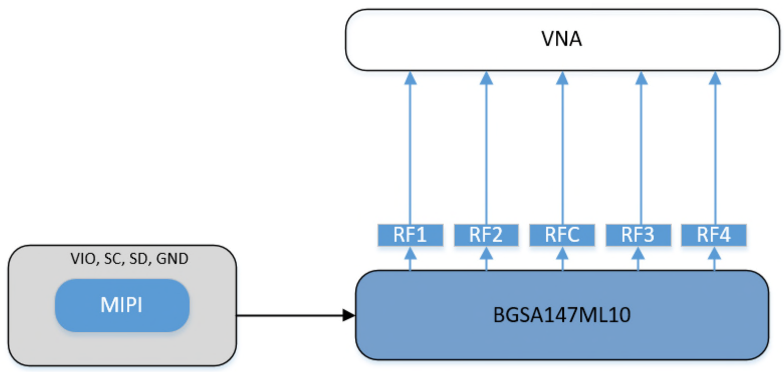

Figure 23 S-parameter measurement setup

3.4.2 C_{OFF} measurement process

One of the main parameters of antenna tuning switches is the OFF state capacitance. C_{OFF} significantly affects the antenna resonant frequency.

The capacitance value is checked using the Y21 from Y-parameters, while the device is set to isolation state. By using the following formula, the C_{OFF} can be extracted. Usually, this is done in post-processing, using for example ADS or microwave office. Usually, the OFF capacitance is specified in femto farad (fF).

$$Coff_{RFx} = \frac{-(imag\big(Y(x+1,1)\big) * 10^{15}}{(2\pi * freq)}$$

Figure 24 Formula to calculate the OFF capacitance (C_{OFF})

3.4.3 R_{ON} measurement process

To measure the ON resistance of the switch (R_{ON}), a power source is used. The force and sense lines are connected with two banana cables to the desired power source ports of the EVB using an adapter. The figure below shows the flow of measuring R_{ON} using the S-parameter board.

To negate the cable resistance, the four-wire method is used. The resistance of the through-line is measured and subtracted to compensate for the resistance of the PCB.

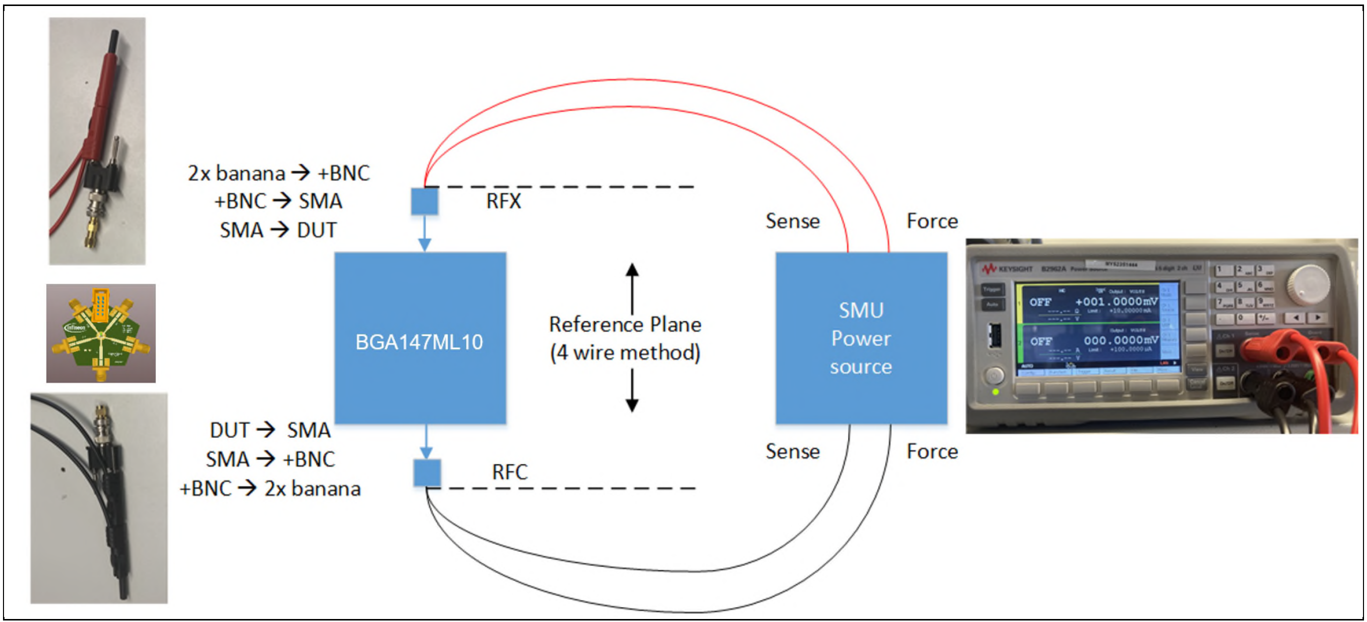

Figure 25 R_{ON} measurement setup

3.4.4 V_{RF} and harmonics measurement setup

To measure the harmonic behavior and the maximum V_{RF} capability, the same basic setup is used.

In both cases, an input signal at the DUT with a known power level and frequency is needed. The harmonic behavior of the DUT at the specified input power is monitored. The setup used to perform these measurements is illustrated and explained below.

The input signal (f = 900 MHz for the low band (LB) or f = 1800 MHz for the high band (HB)) with a duty cycle of 25 percent is generated by the signal generator. The Power Amplifier (PA) amplifies the signal by roughly 50 dB to reach an input power level that is close to the required system power level. A circulator protects the output of the PA by terminating the reflected signal. Diplexers are used as a band pass filter (LB signals below 1 GHz can pass while harmonics generated by the PA will be terminated to ground). A directional coupler is connected before the DUT to measure the available input power with the help of a power meter. This calibrated input signal is then fed to the DUT. The output signal of the DUT is fed to a Diplexer, to filter out the low band part of the post-DUT signal including the fundamental frequency, and then to the spectrum analyzer. If the low band signal is not filtered out properly, the spectrum analyzer could generate H2/H3 from the LB signal and distort the H2/H3 signals coming from the DUT.

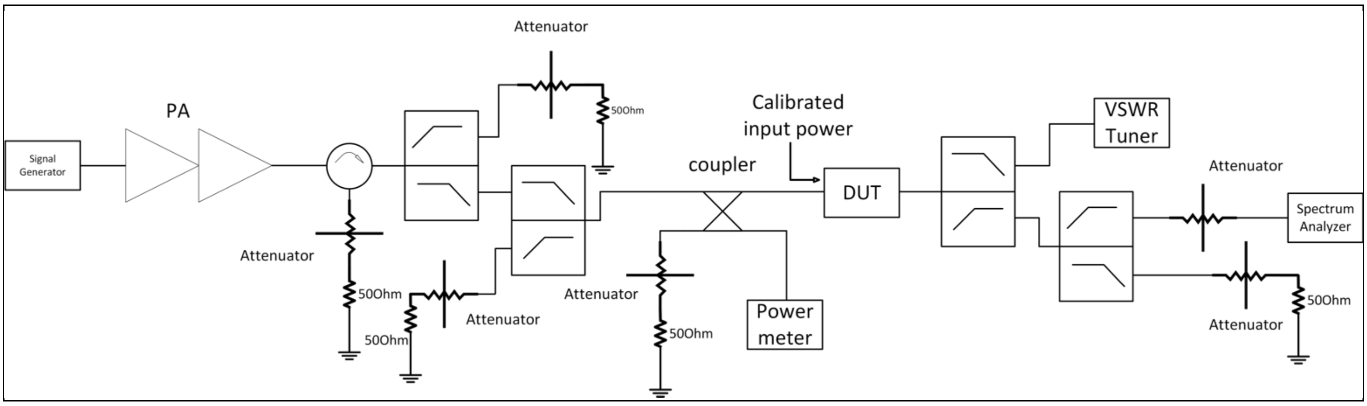

Figure 26 V_{RF} and harmonics measurement setup

3.4.4.1 V_{RF} measurement

For the V_{RF} measurements, the V_{RF} EVB is used, which allows the user to stress each channel individually. The maximum V_{RF} point is defined as the point where the harmonic level starts to increase exponentially. To perform this measurement, the device is set to isolation mode and placed in the setup shown below.

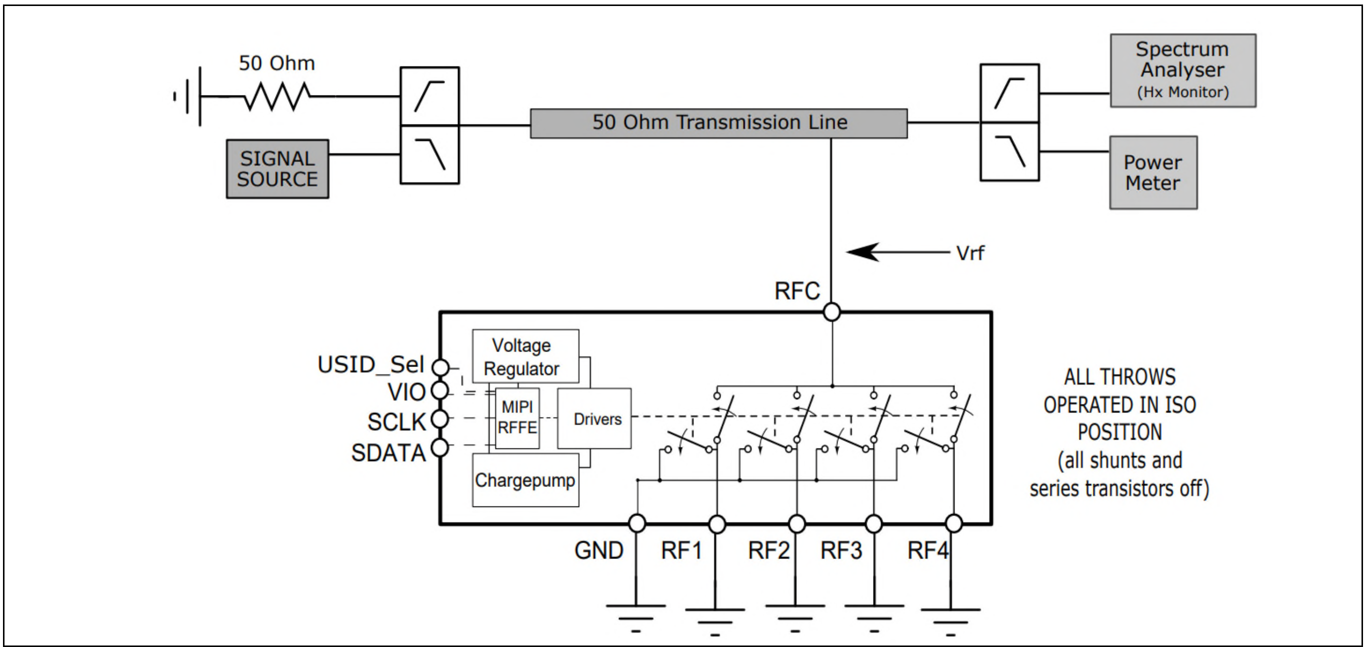

Figure 27 RF operating voltage measurement configuration in OFF mode

The input power must be increased steadily, while monitoring the harmonic behavior. At the maximum V_{RF} point of the DUT, the harmonics will start to increase drastically. This behavior is shown below.

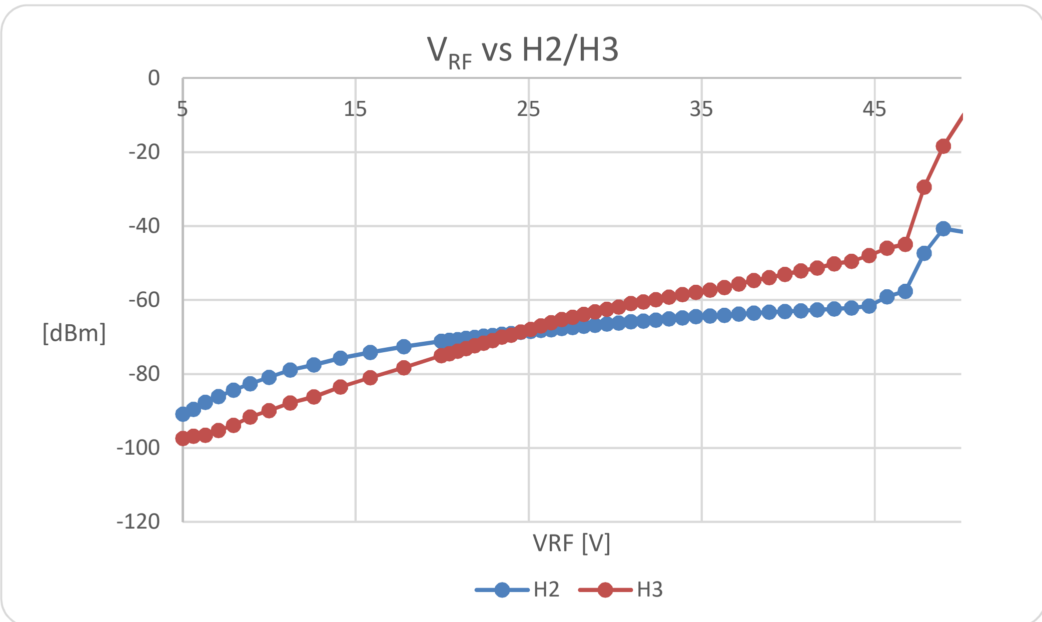

Figure 28 V_{RF} behavior of BGSA147ML10 in relation to the harmonics

3.4.4.2 Harmonics measurement

To measure the harmonic behavior, the S-parameter board is required to be able to feed the signal "through" the device in ON mode as shown below (for example from RFC to RF4).

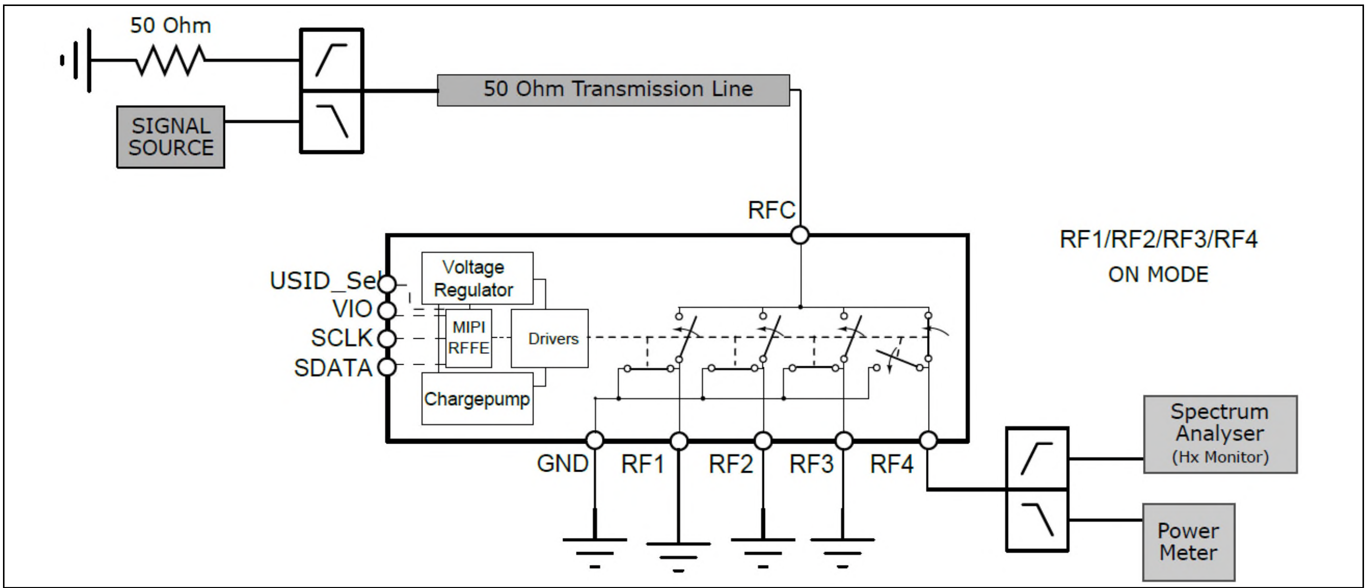

Figure 29 Harmonics measurement configuration – RFx in ON mode (RF4 as an example)

The calibrated input signal with a specific frequency and power level is fed through the device and the harmonic behavior is recorded for the desired power range. Below an example measurement of the harmonic behavior of BGSA147ML10 is shown.

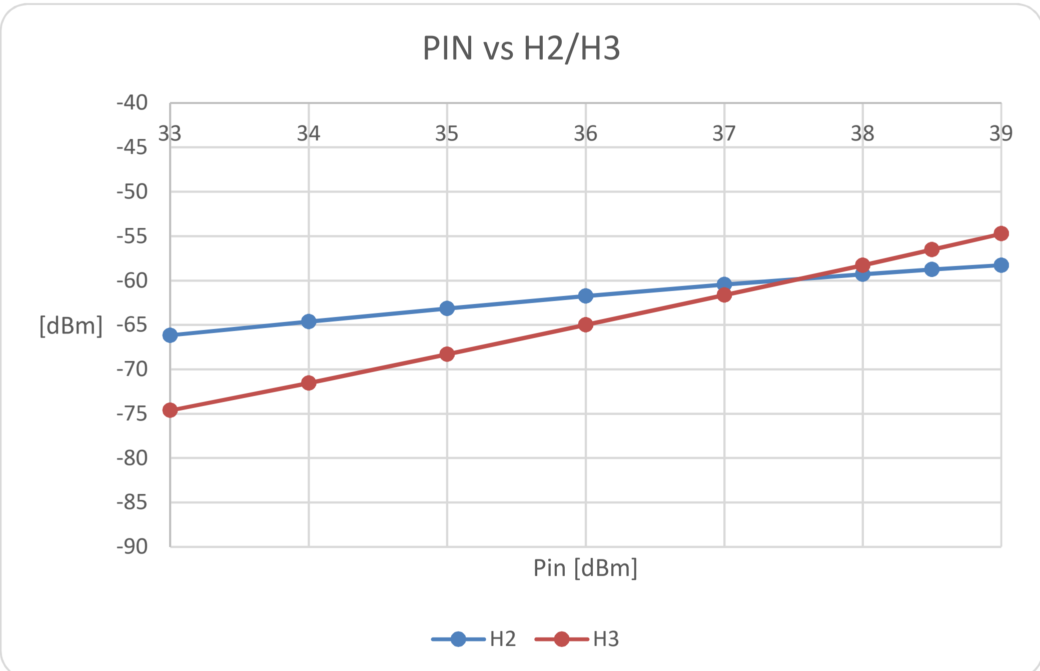

Figure 30 LB (900 MHz) harmonic behavior of BGSA147ML10 at 25°C

4 Layout guidelines

In this chapter, some design guidelines for BGSA147ML10 are discussed.

There are a few recommendations of how the RF parasitics caused by the device during the PCB layout can be minimized, so that good antenna performance can be maintained. It is recommended that no ground plane is implemented under the RF transistor area. Also the ground under the RF traces between BGSA147ML10 and the SMD tuning elements should be removed (see figure below). This layout design guide can also be applied to other similar Infineon antenna tuning devices.

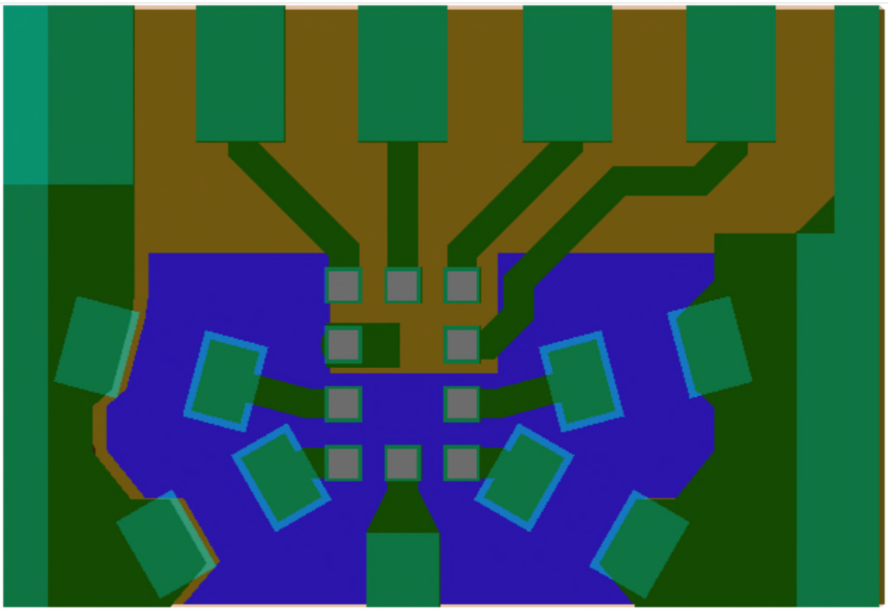

Figure 31 Top view of recommended PCB layout in device area

4.1 Trace impact on equivalent C_{OFF}

The trace length should be as short as possible. The longer trace will shift the C_{OFF} to a higher equivalent C value at the tuning elements as shown in the figure below. An example of how the traces could look in the application is shown in the 3D view of the recommended PCB layout shown above.

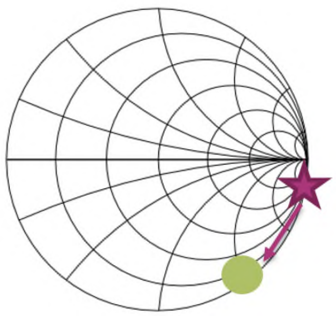

Figure 32 Impact of traces on the PCB on the C_{OFF}

The picture below shows the layout of an Infineon mini EVB that can be used to test the BGSA147ML10 in an application. By using flying cables, the mini EVB can be used to replace other components in the customer's system.

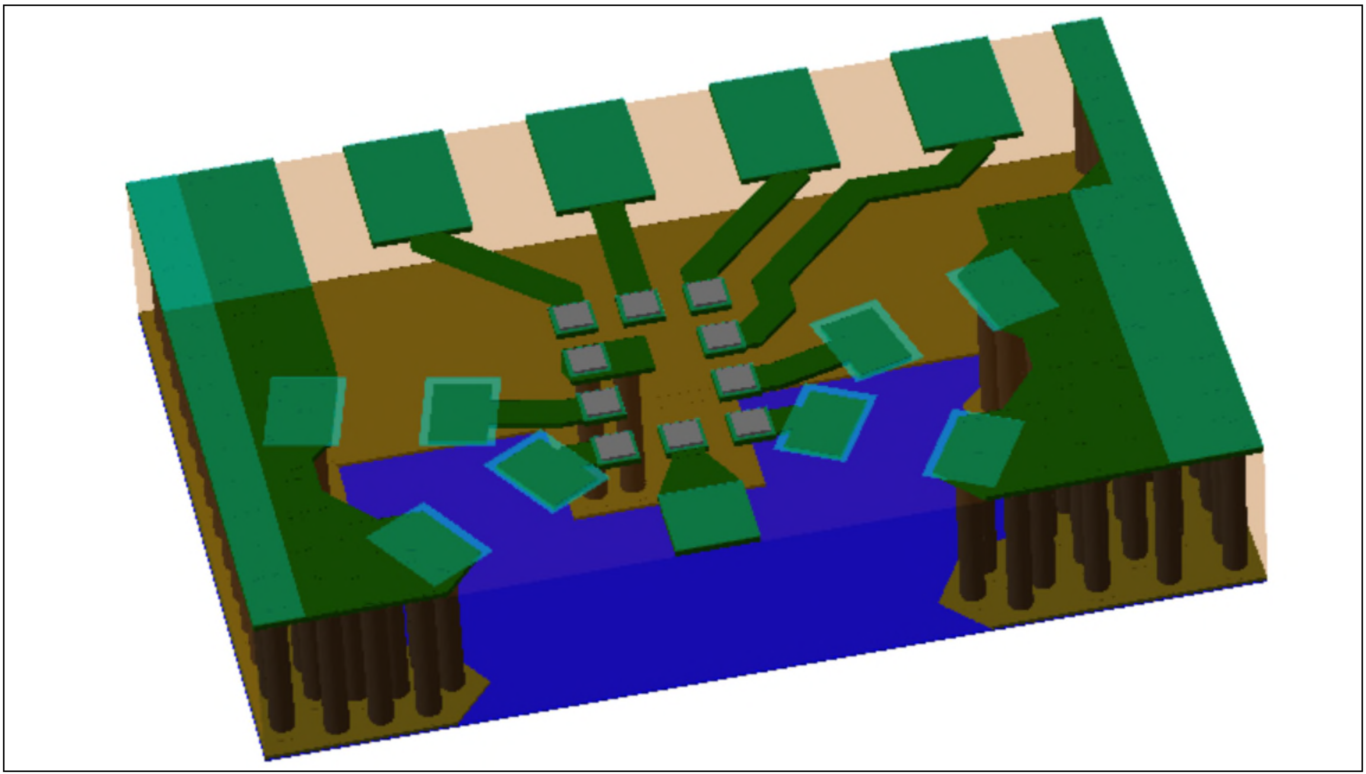

Figure 33 **Mini EVB layout of BGSA147ML10**

4.2 ESD recommendation

The device is designed to withstand 2 kV ESD human body model (HBM) performance in the worst case. To achieve higher SLT ESD levels it is recommended to use shunt inductors. The best compromise is the use of a 27 nH shunt inductor to achieve SLT ESD robustness of up to 8 kV. The ESD shunt inductor should be placed as close as possible to the place where the ESD pulse enters the PCB (in this case, this will most likely be the connection to the antenna). If there is another device in the system which already has this 27 nH for ESD purposes included, then the inductor value can be increased to 56 nH while still maintaining good ESD protection.

Table 1 **Abbreviation table**

EVB	Evaluation board
PCB	Printed circuit board
V_{RF}	RF voltage
C_{OFF}	OFF capacitance
R_{ON}	ON resistance
ESD	Electrostatic discharge
HBM	Human-body model
SLT	System level test
RF	Radio frequency
RFFE	RF Front-End

Revision history

Document version	Date of release	Description of changes
Revision 1.0	2022-02-14	Initial version

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