Switchable Wideband Directional Coupler IC BGC100GN6

Directional Coupler for RF Front Ends in Cellular Handheld Devices

About this document

Scope and purpose

This application note describes Infineon's BGC100GN6 bi-directional coupler IC designed for 2G/3G/4G RF front end applications. The coupler is used as a part of power control and antenna tuning loops. The main focus of this document is put on:

- Design-in guidelines – recommendation for integrating BGC100GN6 into a RF front-end of a cellular handheld device
- Application circuit example with board design details and measurement results

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

1 Introduction to Tunable Antenna RF Front-Ends

Mobile phones represent the largest worldwide market in terms of both volume and number of applications on a single platform today. More than 1.5 billion phones are shipped per year worldwide. The major wireless functions in a typical mobile phone include a 2G/3G/4G (GSM/EDGE/CDMA/UMTS/WCDMA/LTE/LTE-A/TD-SCDMA/TD-LTE) cellular modem, and wireless connectivity systems such as Wireless Local Area Network (WLAN), Global Navigation Satellite System (GNSS), broadcasting receivers, and Near-Field Communication (NFC).

4G Long-Term Evolution-Advanced (LTE-A) specifies more than 50 bands to be used worldwide. The ability of 4G LTE-A to support single-carrier bandwidth up to 20 MHz and to have more spectral efficiency by using high-order modulation schemes such as Quadrature Amplitude Modulation (QAM-64) is of particular importance as the demand for higher wireless data speeds continues to grow rapidly. LTE-A can aggregate up to 5 carriers (up to 100 MHz) to increase user data rates and capacity for high-speed applications.

Increased number of bands and CA cases calls for use-case-specific antenna tuning. The benefits of antenna tuning front-ends include improved total radiated power, higher flexibility in the choice of antenna form-factor and reduced system power consumption through optimized matching.

Antenna-centric devices are the enablers for antenna tuning technology. Among the most widely-used RF devices targeting antenna tuning front-ends are:

- Antenna feed point tuners
- Antenna aperture tuners
- Switchable bi-directional couplers

Switchable directional couplers are used as sensors in the main transmitted path of the front-end and are able to sense RF power propagating in a particular direction (transmitted or reflected back from antenna). Based on the output of the coupler sensor dynamic PA control and antenna tuning is performed.

The BGC100GN6 wideband switchable coupler IC and its use in a cellular RF front-end are considered further in this document.

More information on the Mobile Phone RF Frontend and related Infineon product portfolio are available in the Application Guide Mobile Communication: www.infineon.com/appguide_rf_mobile.

1.1 Key Performance Requirements for Directional Couplers

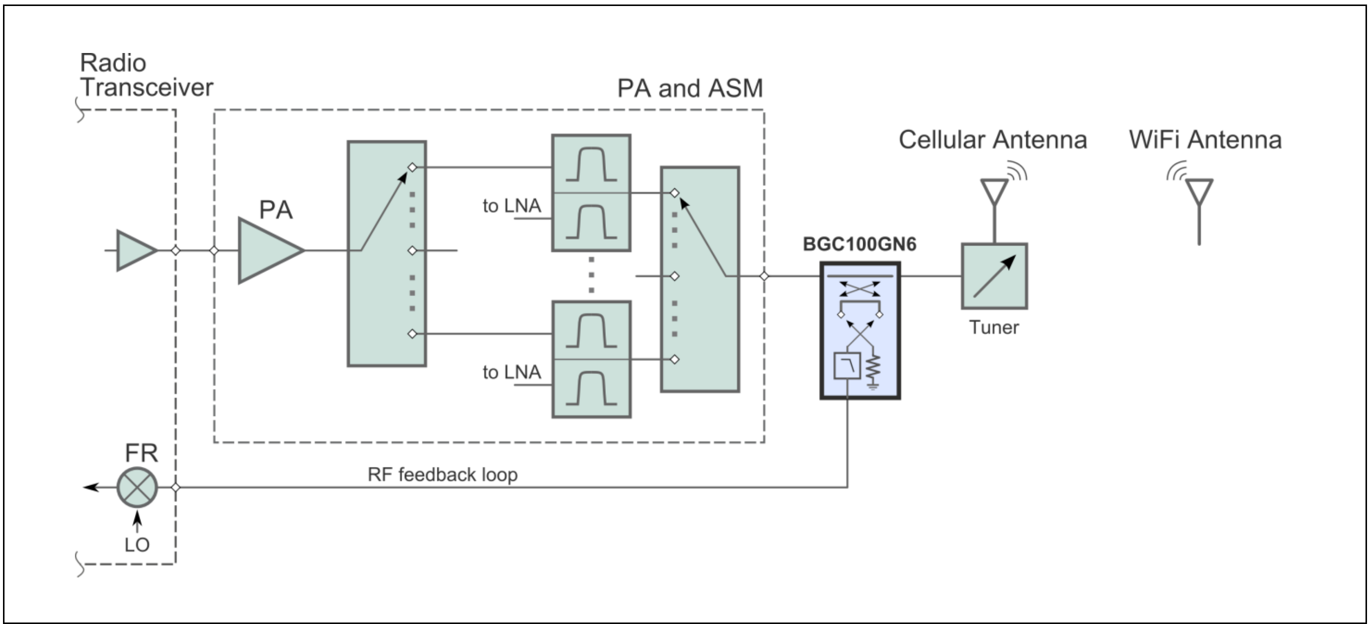

Figure 1 Block diagram of a cellular RF front-end

RF front-ends in cellular applications in general and LTE applications in particular incorporate directional couplers for performing transmitted power control and antenna tuning. A directional coupler in RF front-ends of cellular phones is located between a PA&ASM (power amplifier and antenna switch module) and an antenna tuner and is used in power control and antenna tuning loops. Figure 1 demonstrates the generic block diagram with BGC100GN6 switchable coupler IC attached to the main transmit path of the RF front-end. An RF front-end usually comprises multiple dedicated PADs for specific frequency bands and multiple directional couplers attached to PADs. Coupled outputs from all couplers are combined into to a single feedback path by means of, for example, a general purpose RF switch and are fed back to a feedback receiver (FR).

Radio transceiver specification and front-end architecture define the requirements for directional couplers in RF front-ends, these are [2]:

Frequency range: All cellular bands coverage between 698 MHz and 2.7 GHz.

Coupling factor typically between 20 and 30 dB – a range where the best trade-off between feedback receiver sensitivity, insertion loss of the coupler and directivity can be achieved;

Directivity of above 20 dB, dictated by the system's requirements on maximum coupled power variation over different phase angles at a specified VSWR in the transmitted signal path. For high-end devices such directivity has to be guaranteed over the temperature range of –40°C…+85°C. Obviously, return loss in the main signal path must exceed directivity in order to introduce less mismatch into the signal path than the coupler is able to sense.

Insertion loss of up to 2.7 GHz is expected to be below 0.25 dB in the state-of-art couplers;

Cellular-to-WiFi interference suppression: A 5.5-GHz WiFi has to be suppressed in the RF feedback path, such that feedback receiver does not downconvert the WiFi blocker and distort the target cellular content. More information on this topic is provided in [3].

2 BGC100GN6 Overview

2.1 Features

- Fully integrated coupler in RF CMOS
- Bi-directional coupler
- Fitted for feedback receivers to accomplish closed loop power control and antenna tuning
- Wide frequency range: 0.6 to 2.7 GHz
- Designed for low insertion loss and high directivity
- Supports all cellular standards: GSM /WCDMA / HSPA+ / FDD-LTE / TDLTE / TD-SCDMA / CDMA
- Integrated low-pass filter for 5GHz WiFi jammers suppression
- GPIO controlled
- Small form factor 1.1mmx 0.7mm
- RoHS and WEEE compliant package

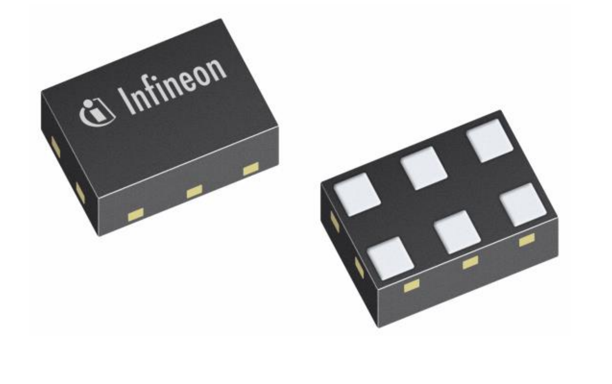

Figure 2 BGC100GN6 in TSNP-6-2

2.2 Description

The BGC100GN6 bi-directional coupler IC is designed for 2G/3G/4G RF front end applications. The device contains a bidirectional coupler operating in one or multiple bands within 0.6 GHz to 2.7 GHz frequency range. The coupled output contains a low-pass filter for 5 GHz ISM blockers suppression. The coupler offers low insertion loss and high directivity. The coupler is controlled via a GPIO pin. No external power supply blocking or RF decoupling capacitors are required. The BGC100GN6 is a fully integrated device deploying Infineon high volume RF-CMOS technology. The device has a very small size of only 1.1 x 0.7mm^2 and a maximum heigth of 0.4 mm.

Product Name	Marking	Package
BGC100GN6	2	TSNP-6-2

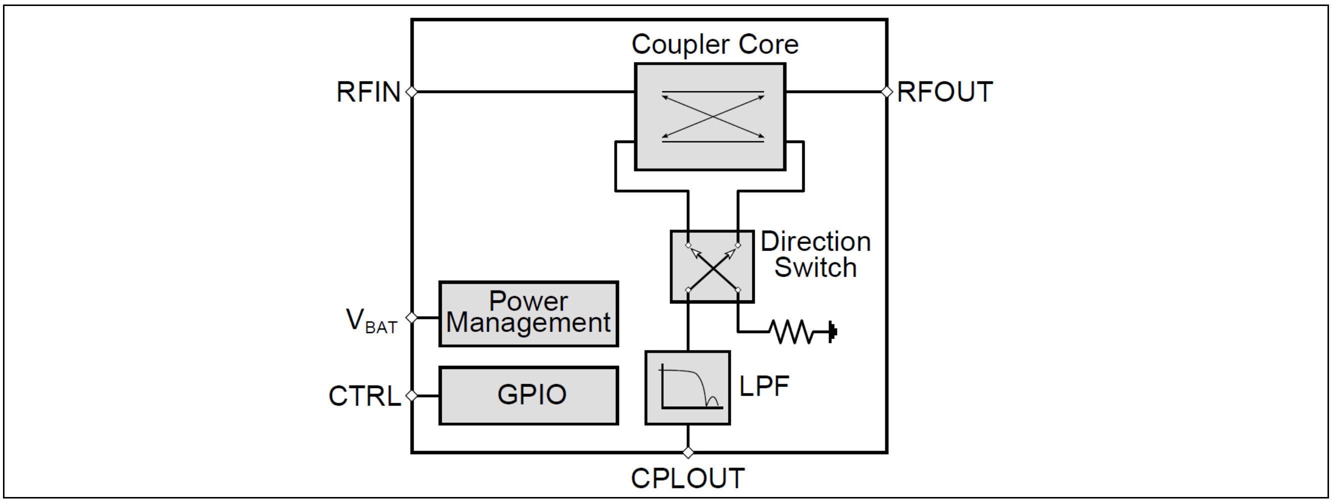

Figure 3 Functional block diagram of BGC100GN6

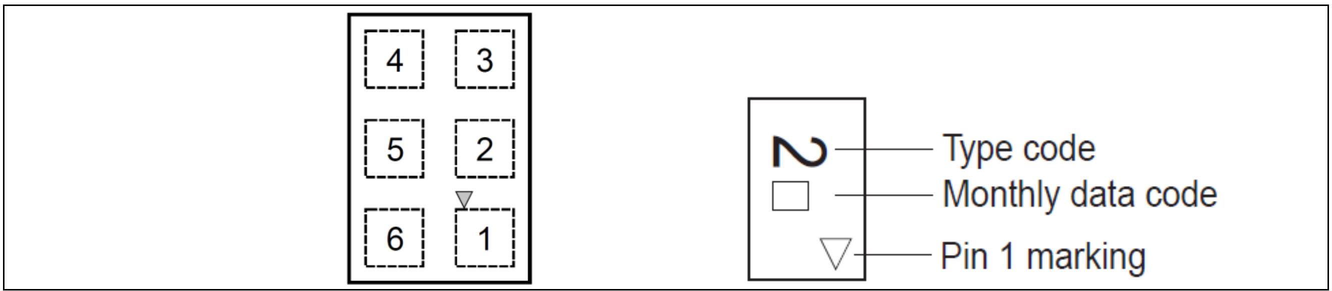

Figure 4 Package and pin connections of BGC100GN6

Table 1 Control Table

State	Mode	CTRL
1	RF power propagating from RFOUT to RFIN is coupled into CPLOUT	Low
2	RF power propagating from RFIN to RFOUT is coupled into CPLOUT	High

Table 2 Pin Assignment of BGC100GN6

Pin No.	Symbol	Function
1	RFOUT	Main path output port
2	VBAT	Supply voltage
3	CTRL	Control pin
4	CPLOUT	Coupler output
5	GND	Ground
6	RFIN	Main path input port

3 Design-In Guidelines

In this section recommendations for integrating the BGC100GN6 directional coupler IC into the application (cellular handheld device) are given. The recommendations include information about

- preferred arrangement of RF pins of the BGC100GN6 IC in the main transmitted path of a RF front-end;
- layout recommendations for an application board to achieve best system-level RF performance.

3.1 Integration into RF Front-End

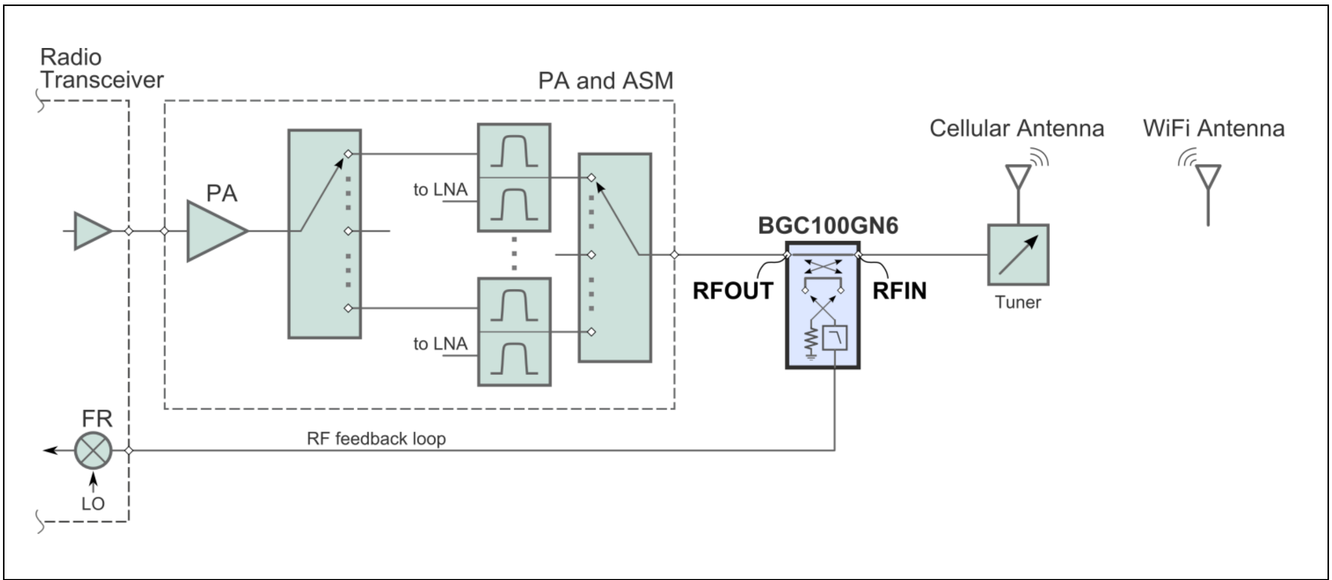

Figure 5 RF front-end block diagram with BGC100GN6 switchable coupler IC

The BGC100GN6 switchable coupler IC is optimized for RF front-end applications, where it is a part of power control and antenna tuning loops. The BGC100GN6 IC exhibits 3 to 6 dB higher directivity and 3 to 5 dB higher WiFi jammer suppression when it is configured to operate in reverse mode, i.e. when incident RF signal is propagating from RFOUT towards RFIN pins of the IC and reflected signal is propagating from RFIN towards RFOUT pins of the IC. Figure 5 demonstrates an example of BGC100GN6 IC connected in reverse mode in a generic RF front-end of cellular handheld device. The **RFOUT pin is coupled to the PA&ASM module, while RFIN pin is coupled to antenna side**. The benefits of such configuration (as opposed to configuration in which RFOUT and RFIN pins are swept in the main RF path) for the application are:

- higher accuracy of power control loop due to lower peak-to-peak forward coupled power variation over the angle for a given antenna VSWR;
- 30...35 dB WiFi signal suppression parasitically coupled into LTE antenna. Such suppression prevents feedback receiver from downconverting the WiFi blockers at frequencies which are the integer multiples of target LTE signal. For more information on cellular-to-WiFi signal integrity improvements provided by BGC100GN6 IC the reader is referred to [3].

Check the truth table for GPIO control pin to ensure that forward and reverse directions are correctly configured.

3.2 Board Layout Recommendation

Switchable coupler IC is a compact, high dynamic range (over 60 dB) device. Care must be taken during design-in phase to preserve RF performance of the device and achieve specified values for directivity and WiFi suppression on the system level.

The recommendations for board design are provided below (please refer to Figure 6 for details):

1. All RF lines (RFIN, RFOUT and CPLOUT) shall be implemented in a **form of grounded co-planar waveguide**, namely as a RF signal line and a pair of ground planes in the same metal layer. The gap between the signal line and ground planes shall be kept small, for example 100…200 um. Ground planes shall be grounded with vias to a common ground plane. These measures are aimed at minimizing RF coupling between the RF lines. As an example, see the RFOUT line surrounded by ground planes GND1 and GND2 and a set of vias V2 running along the RFOUT line in Figure 6.

2. **Coupled RF output CPLOUT must be well isolated from the main RF path** (RFIN and RFOUT lines). The isolation between main and coupled paths must be
   - at least 60 dB for 690 MHz – 960 MHz
   - at least 55 dB for 1400 MHz – 2000 MHz
   - at least 50 dB for 2200 MHz – 2700 MHz
   - at least 45 dB for 4900 MHz – 5900 MHz

   It is recommended to implement a CPLOUT line in a bottom metal layer, using top metal as a common RF ground. Such configuration may help improving isolation between main path implemented on top and a coupled path. CPLOUT line must be surrounded by ground planes in a similar way as described above. A via (V3) connecting CPLOUT pad on top with the CPLOUT RF line must be located underneath the IC pad. V3 via, thus, shall be a plugged via coated with metal on the top. If plugged coated vias are not available, CPLOUT can be routed in top metal, in the same way as RFIN and RFOUT lines. Ensure that CPLOUT is isolated from the main RF path **over the complete phone board** (not only at the interface to BGC100GN6 IC). **If required isolation levels are not provided by proper board design, the directivity of the coupler as well as suppression at WiFi frequencies may degrade**.

3. Place a ground via (V1) in the vicinity (100 µm away) of GND pad of IC, as pictured in Figure 6.

4. Ensure that there is **no RF coupling** from the main path (RFIN and RFOUT) into the coupled path CPLOUT **via supply (VBAT) and control (CTRL) lines**. Directivity of the coupler may drop and WiFi suppression may degrade if VBAT and CTRL are not properly blocked. VBAT and CTRL lines shall be surrounded by ground blocks (GND1 and GND3) in the vicinity of IC.

5. Minimize the return loss in the main RF path. Return loss in the RFOUT and RFIN path shall preferably reach 25 dB or higher up to 2700 MHz. This can be achieved by optimizing the characteristic impedance of RFIN and RFOUT to 50 Ohm.

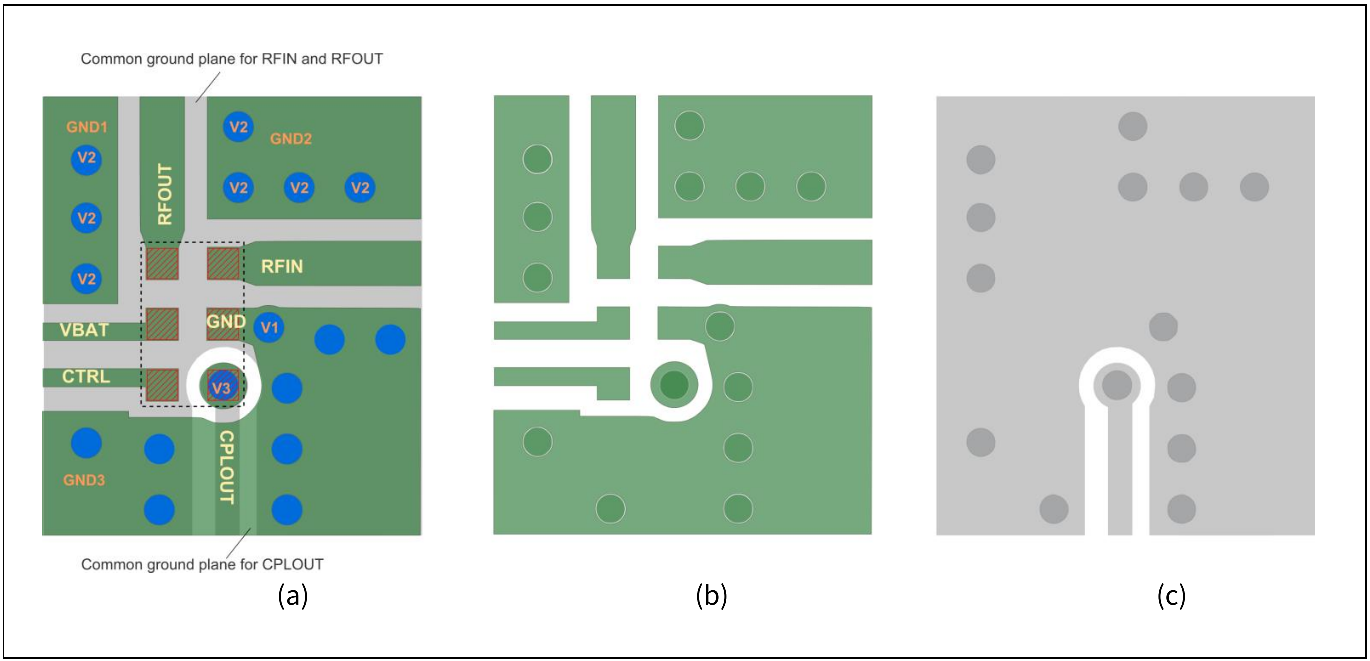

Figure 6 **Recommended board layout for design-in of BGC100GN6 coupler IC: (a) – layout overly, (b) – top metal layer, (c) – bottom metal layer**

4 Application Circuit and Performance Overview

In this section an application circuit including bill-of-materials is presented, measurement results on the application board are demonstrated.

Device:	BGC100GN6
Application:	Directional Coupler for RF Front Ends in Cellular Handheld Devices
PCB Marking:	BGC100GN6-A1
EVB Order No.:	AN521

4.1 Summary of Measurement Results on Application Board

The performance of BGC100GN6 coupler IC is summarized in the following tables.

Table 3 Small Signal Electrical Characteristics of the BGC100GN6 (at room temperature)

Parameter	Symbol	Value	Unit	Comment/Test Condition	
DC Voltage	V_{BAT}	2.8	V		
DC Current	I_{BAT}	55	µA		
Main Path Insertion Loss (RFIN to RFOUT)	IL	0.07	dB	Low-Band: 824 MHz	
		0.14	dB	Mid-Band: 1800 MHz	
		0.2	dB	High-Band: 2500 MHz	
Main Path Return Loss (RFIN and RFOUT)	RL_{TX}	36	dB	Low-Band: 824 MHz	
		27	dB	Mid-Band: 1800 MHz	
		23	dB	High-Band: 2500 MHz	
Coupled Path Return Loss (at CPLOUT port)	RL_{CPL}	26	dB	Low-Band: 824 MHz	
		25	dB	Mid-Band: 1800 MHz	
		25	dB	High-Band: 2500 MHz	
Cellular Coupling Factor (RFIN and RFOUT to CPLOUT Ports)	CPL_{LTE}	28	dB	Low-Band: 824 MHz	
		22.5	dB	Mid-Band: 1800 MHz	
		21.8	dB	High-Band: 2500 MHz	
Coupling / Isolation at WiFi Frequencies	CPL_{WIFI}	33	dB	5400 MHz, CTRL = 0	
		29	dB	5400 MHz, CTRL = 1	
Reverse Directivity (CPLOUT to RFOUT versus RFIN)	DIR_{REV}	27	dB	Low-Band: 824 MHz	CTRL = 0
		33	dB	Mid-Band: 1800 MHz	
		31	dB	High-Band: 2500 MHz	
Forward Directivity (CPLOUT to RFIN versus RFOUT)	DIR_{FWD}	21.5	dB	Low-Band: 824 MHz	CTRL = 1
		23	dB	Mid-Band: 1800 MHz	
		23	dB	High-Band: 2500 MHz	

Table 4 Large Signal Electrical Characteristics of the BGC100GN6 (at room temperature)

Parameter	Symbol	Value	Unit	Comment/Test Condition
Low-Band Second Harmonic RFIN-to-RFOUT Path	$P_{H2.824.24}$	-87	dBm	P_{in} = 24 dBm, 50 Ω, F_{in} = 824 MHz
	$P_{H2.824.33}$	-72	dBm	P_{in} = 33 dBm, 50 Ω, F_{in} = 824 MHz
Low-Band Third Harmonic RFIN-to-RFOUT Path	$P_{H3.824.24}$	-92	dBm	P_{in} = 24 dBm, 50 Ω, F_{in} = 824 MHz
	$P_{H3.824.33}$	-62	dBm	P_{in} = 33 dBm, 50 Ω, F_{in} = 824 MHz
Mid-Band Second Harmonic RFIN-to-RFOUT Path	$P_{H2.1800.30}$	-78	dBm	P_{in} = 30 dBm, 50 Ω, F_{in} = 1800 MHz
Mid-Band Third Harmonic RFIN-to-RFOUT Path	$P_{H3.1800.30}$	-73	dBm	P_{in} = 30 dBm, 50 Ω, F_{in} = 1800 MHz
IMD2, B39+B41, F_2–F_1, RFIN-to-RFOUT Path	IMD_2	-87	dBm	P_1 = P_2 = 24 dBm, F_1 = 1.9 GHz, F_2 = 2.6 GHz, F_{IMD2} = 700 MHz
IMD3, B39+B41, $2F_2$–F_1, RFIN-to-RFOUT Path	IMD_2	-75	dBm	P_1 = P_2 = 24 dBm, F_1 = 1.9 GHz, F_2 = 2.6 GHz, F_{IMD3} = 3300 MHz
IMD4, B39+B41, $2F_2$–$2F_1$, RFIN-to-RFOUT Path	$IMD_{4,1}$	-100	dBm	P_1 = P_2 = 24 dBm, F_1 = 1.9 GHz, F_2 = 2.6 GHz, $F_{IMD4,1}$ = 1400 MHz
IMD4, B39+B41, $3F_2$–F_1, RFIN-to-RFOUT Path	$IMD_{4,2}$	-98	dBm	P_1 = P_2 = 24 dBm, F_1 = 1.9 GHz, F_2 = 2.6 GHz, $F_{IMD4,2}$ = 5900 MHz

4.2 Schematic and Bill-of-Materials

Ther schematic of BGC100GN6-A1 application circuit is presented in Figure 7 and its bill-of-materials is shown in Table 5.

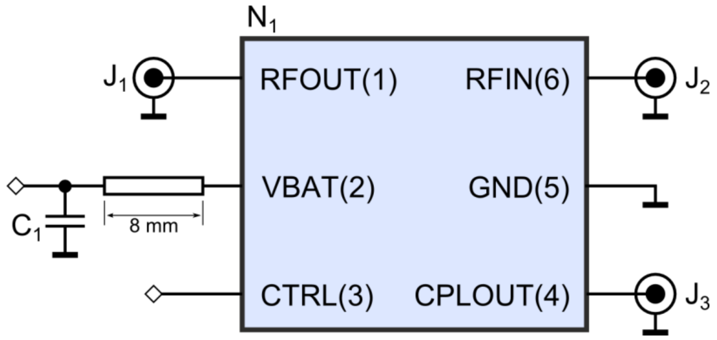

Figure 7 Schematic of BGC100GN6-A1 application circuit with BGC100GN6 coupler IC

Table 5 Bill-of-Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
N_1	BGC100GN6		TSNP-6-2	Infineon Technologies	Switchable coupler IC
C_1	82	pF	0603	Mira	Blocking capacitor
J_1, J_2, J_3	PAF-S05-002 1 mm board thickness			GigaLane	SMA connector

The blocking capacitor C_1 is used to suppress parasitic RF coupling from the main path (RFIN and RFOUT) into the coupled path (CPLOUT) via supply line VBAT. The capacitor C_1 is not required for proper coupler operation and can be omitted if proper isolation between main and coupled path is ensured on the application board. If capacitor C_1 is used, then it must be placed at least 8 mm away from to BGC100GN6 IC.

4.3 Layout of Application Board

The RF performance of BGC100GN6 IC can be evaluated using the board described below. Nominal measurements provided in this document are performed on the presented evaluation board.

The BGC100GN6 IC is mounted on a 3-layer PCB with 200-µm thick Rogers 4003C dielectric material between the top and middle metal layers and 700-µm thick FR4 carrier between the middle and bottom metal layers. Figure 8 shows the photograph of the application board and a THRU de-embedding structure.

All 50-Ω RF lines connecting the chip with SMA connectors have identical length. The outer ground conductor of the SMA connector is soldered both at top and bottom sides of the board. The standard 0.1"-spaced connector is used for power supply and GPIO control. The supply pin is blocked by a 82 pF capacitor soldered at supply connector side, bottom side of the board (it is approximately 8 mm away from the IC).

The marking of RF and DC lines on the application board is consistent with pins definition and function specified in the datasheet.

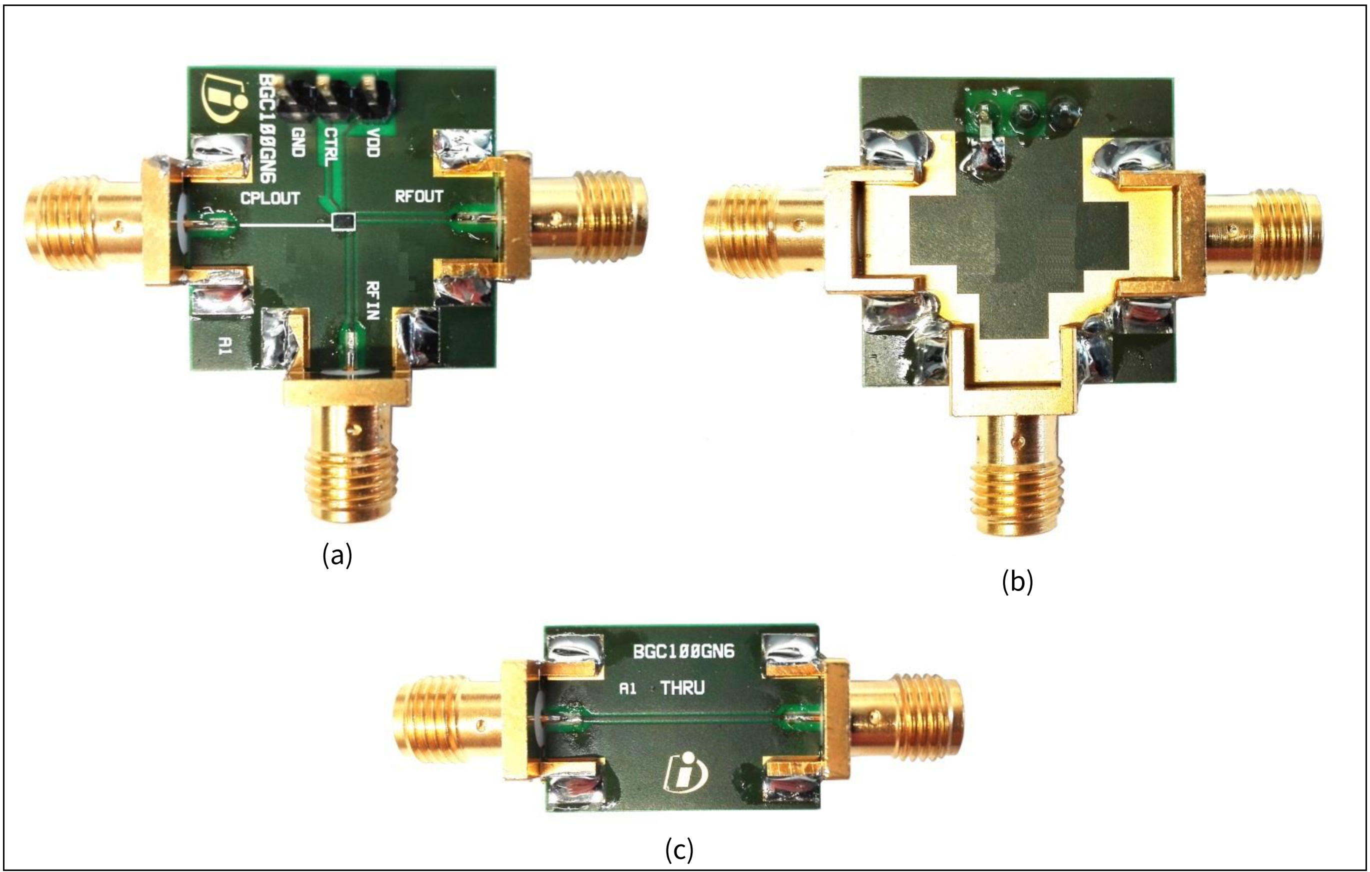

Figure 8 Assembled application board photograph, (a) – top side, (b) – bottom side, (c) – calibration THRU structure

Evaluation board layout (all layers) is demonstrated below. The layout is designed according to board layout recommendation provided in Section 3.2.

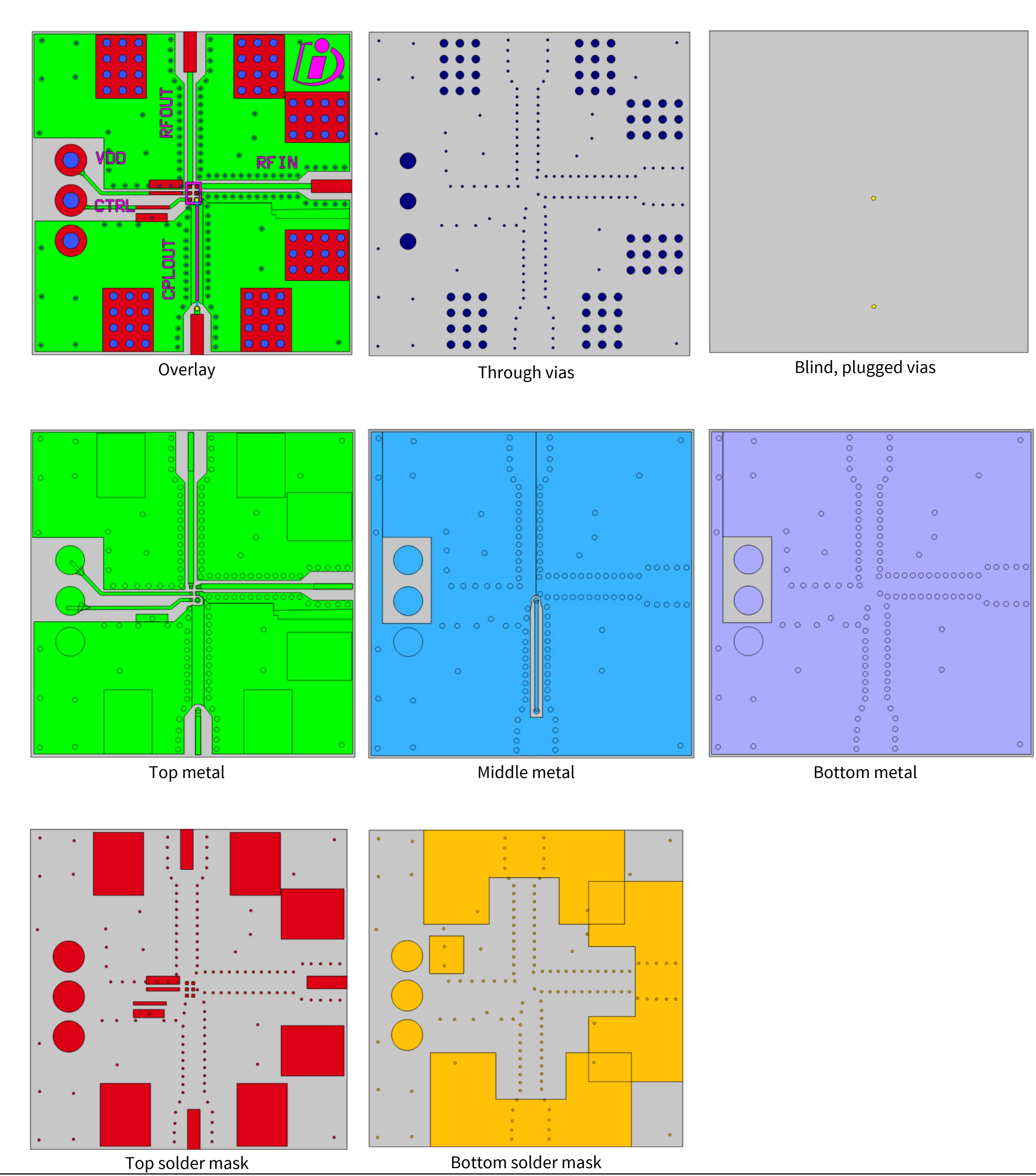

Figure 9 Application board layout

Figure 10 demonstrates the measured geometry of the cross-section of grounded coplanar RF line of actually fabricated application board according to the layout shown above. Etched metal structures have trapezoidal shapes with wider bottom side and a narrower top side. The dimensions provided in Figure 10 (b) are measured on a fabricated sample. Such boards were used for BGC100GN6 parts evaluation, with measured curves presented in the following section.

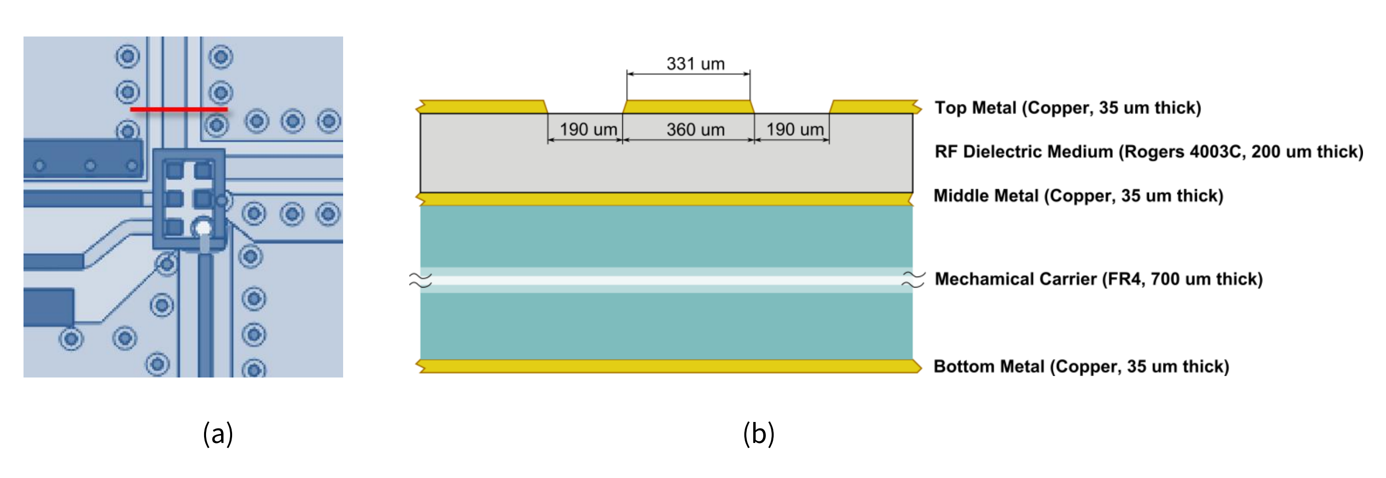

Figure 10 Measured cross-section of grounded coplanar waveguide of fabricated board: (a) – cross-section location, (b) – dimensions and material properties

Figure 11 shows the cross-section of a blind via used for routing out the coupled RF signal CPLOUT. The via shorts top and middle metal layers (so-called "blind" via). It is filled up with a dielectric material inside and is "plugged" with metal and polished on the top, such that IC pad can be soldered right on the top of the via.

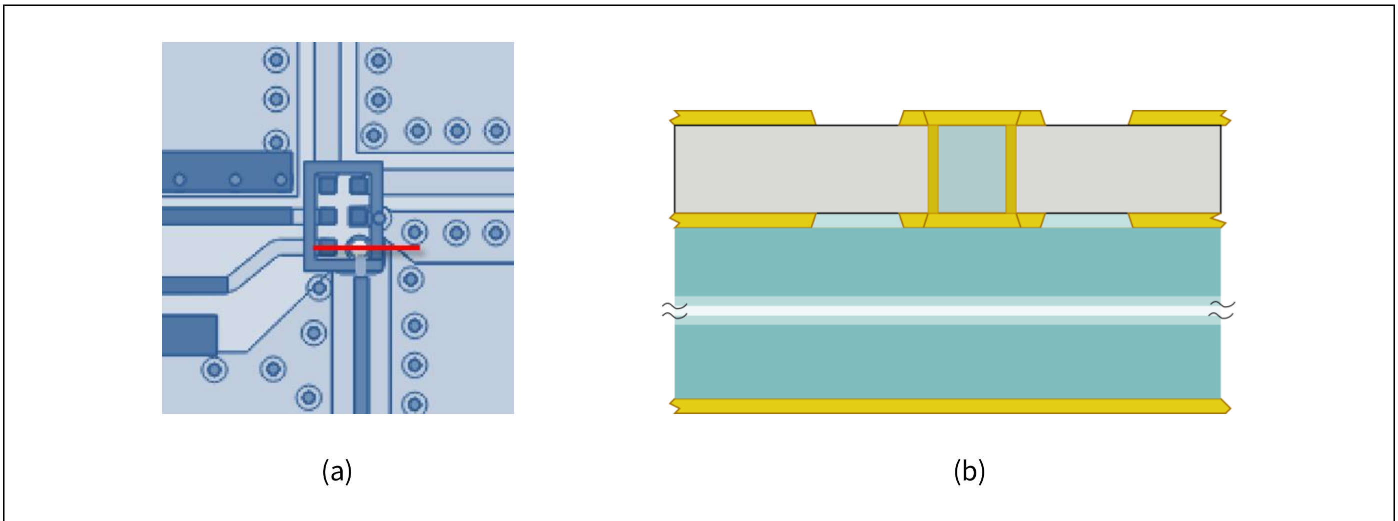

Figure 11 Example of blind plugged via used in coupled path RF line: (a) – cross-section location, (b) – cross-section

4.4 Detailed Measurement Results on Application Board

Test Fixture De-Embedding

For the ease of de-embedding and minimization of de-embedding errors it is proposed to calibrate losses of the main RF path only.
The calibration/de-embedding and measurements are performed as follows:

1. A VNA is calibrated using any conventional method up to the SMA coaxial interface;
2. The s-parameters of the application board are measured;
3. The s-parameters of the THRU structure are measured;
4. Insertion loss (in dB) of the THRU structure is subtracted from the insertion loss (in dB) of the main RF path of the application board. Such simple subtraction is mathematically correct because return loss of the THRU structure is well above 30 dB (almost no mismatch loss, only power loss).

Advantages of the proposed de-embedding procedure:

1. Ease of de-embedding, low probability of errors;
2. No distortion in the impedance of main RF path caused by de-embedding errors;
3. No distortion in the isolation/directivity caused by de-embedding errors.

Drawbacks of the proposed de-embedding procedure:

1. Phase shift caused by the PCB lines is not calibrated out;
2. Minor error in the coupling factor (up to 0.07 dB) – this very small error can be tolerated.

Small-Signal Measurement Results

Measured data for a typical sample of BGC100GN6 IC on the evaluation board at room temperature are presented below. All measurements were performed at the supply voltage of 2.8 V at room temperature
The ports are mapped as follows:

- Port 1 → RFIN port of application board
- Port 2 → RFOUT port of application board
- Port 3 → CPLOUT port of application board

The THRU calibration structure is represented by Port 4 and Port 5.

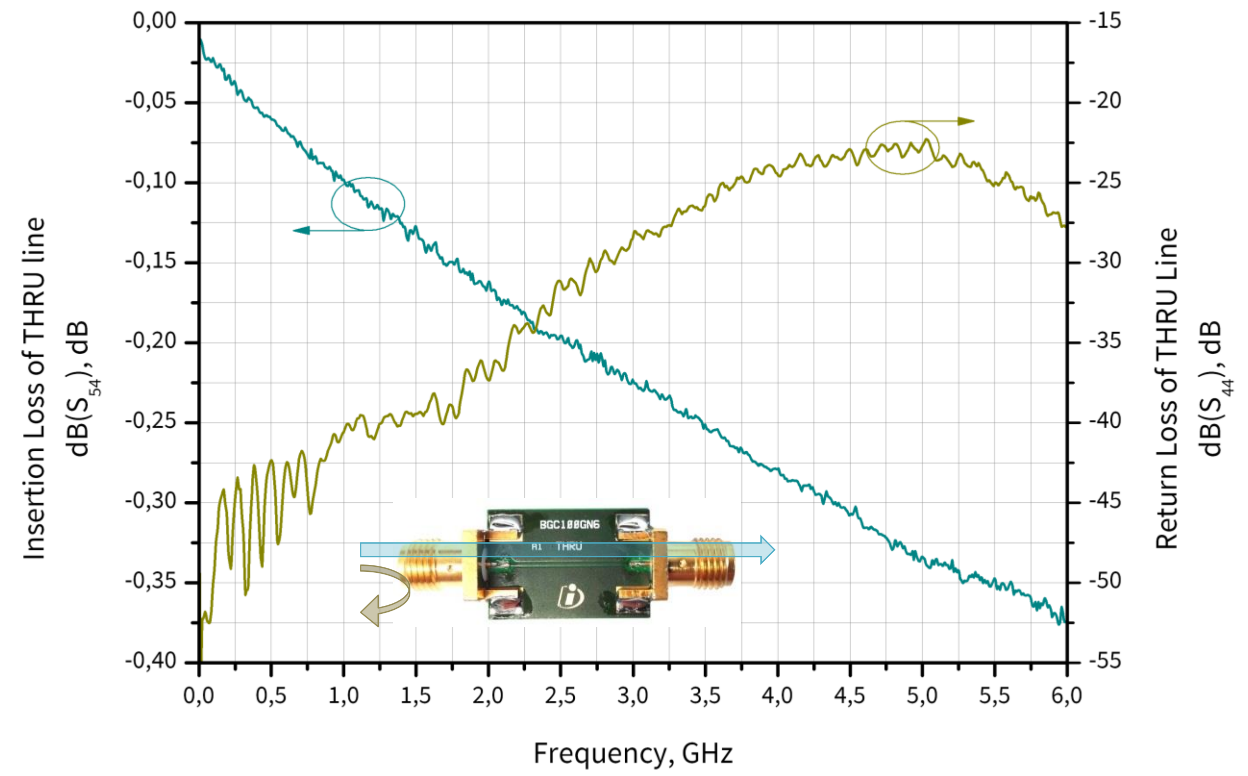

Figure 12 Insertion loss and return loss of the THRU calibration structure

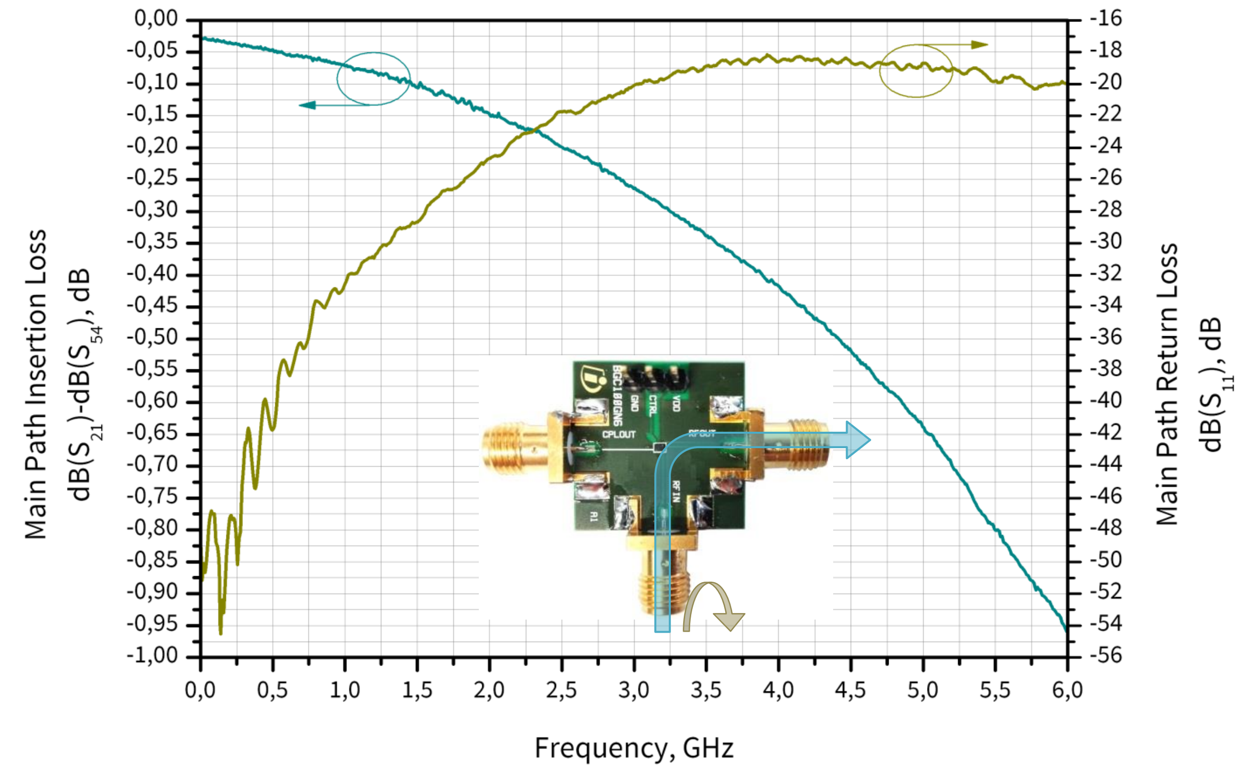

Figure 13 Insertion loss and return loss of the BGC100GN6 main path

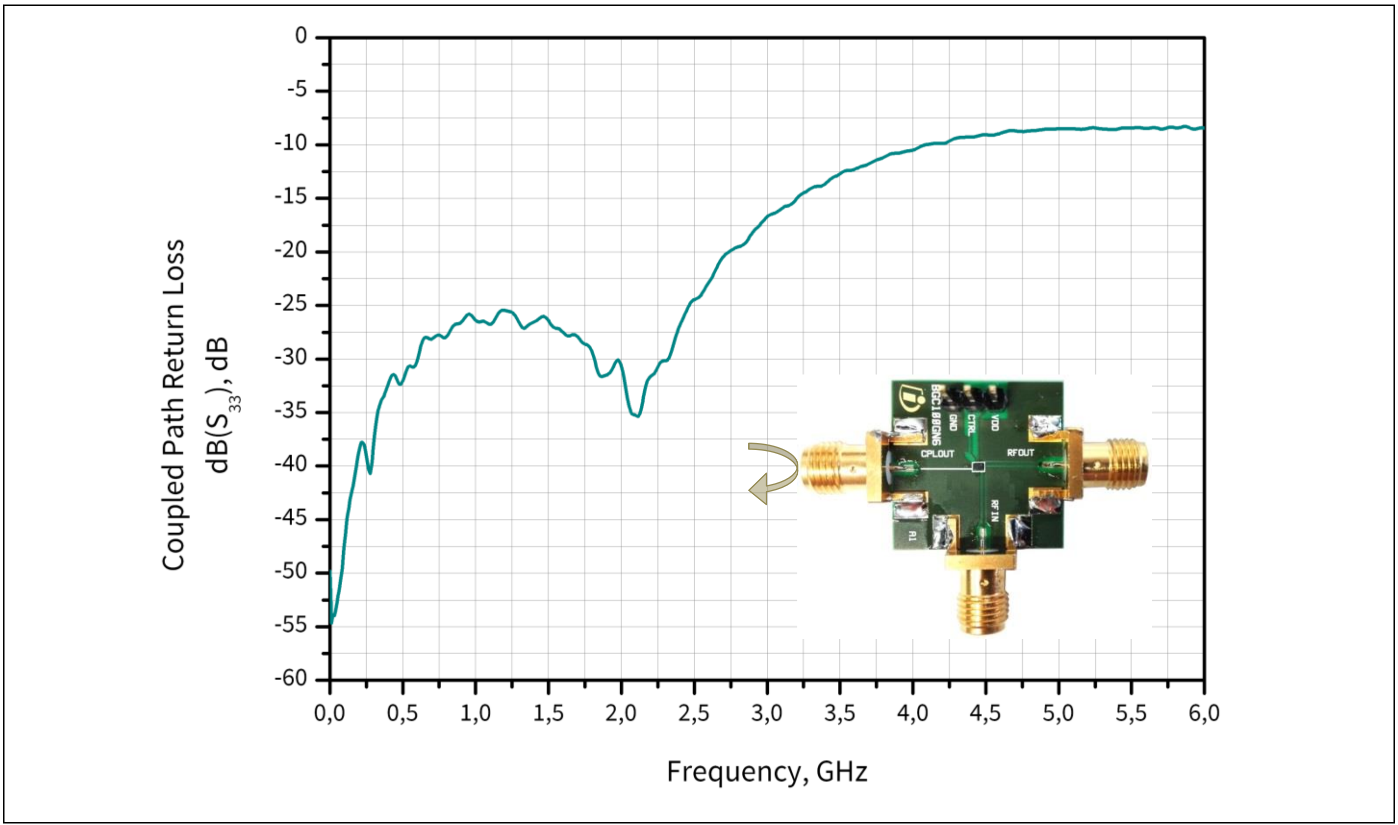

Figure 14 Return loss of the BGC100GN6 coupled path

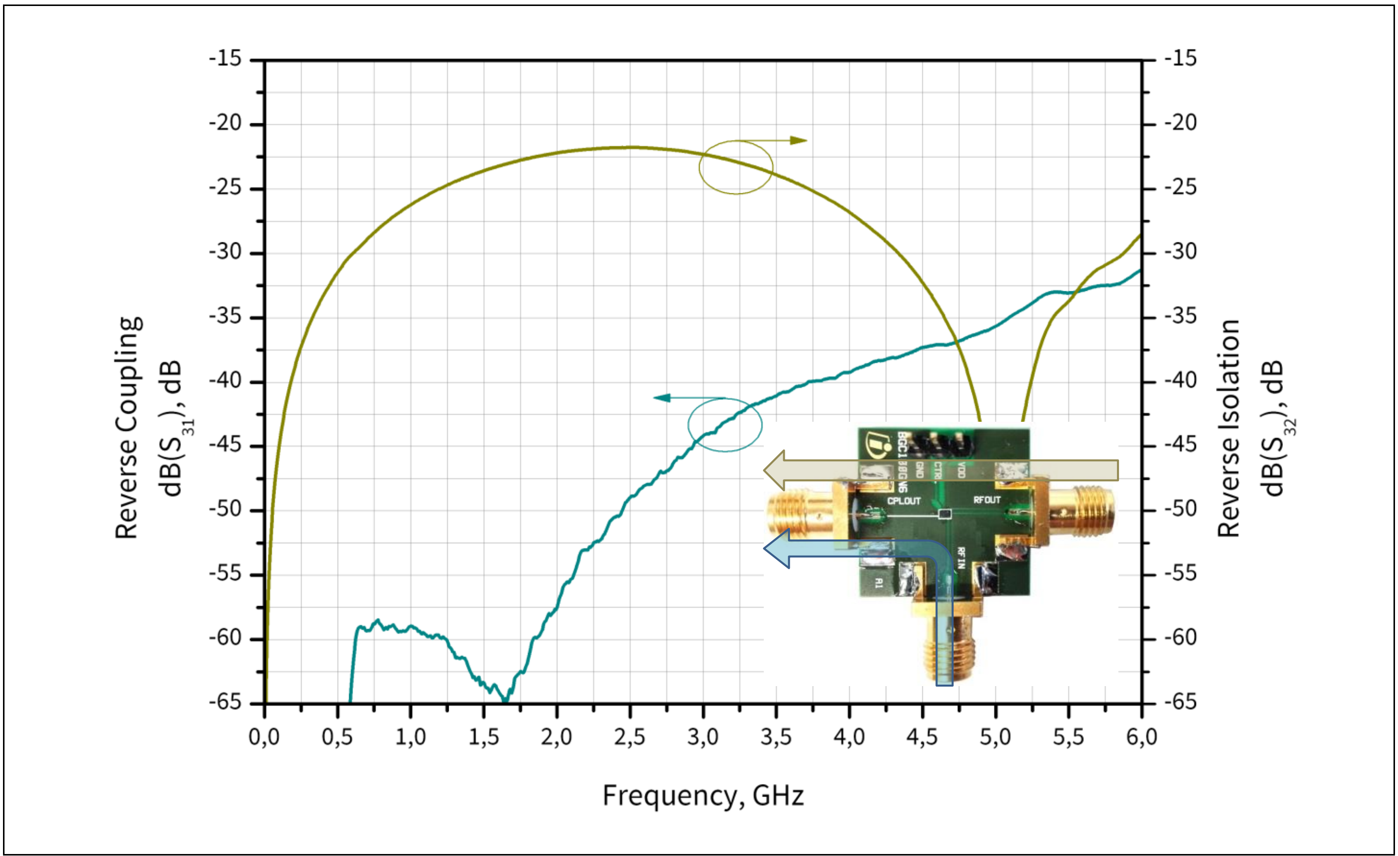

Figure 15 Reverse coupling and isolation of BGC100GN6 coupler (CTRL = 0)

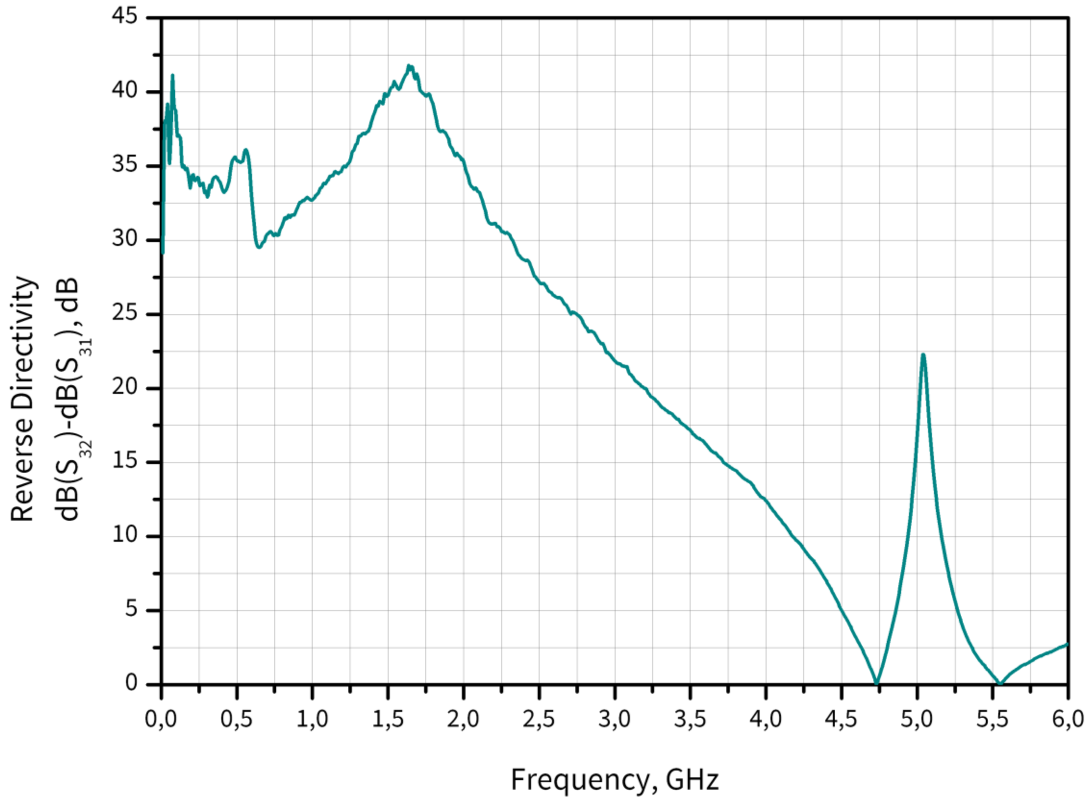

Figure 16 **Reverse directivity of BGC100GN6 coupler (CTRL = 0)**

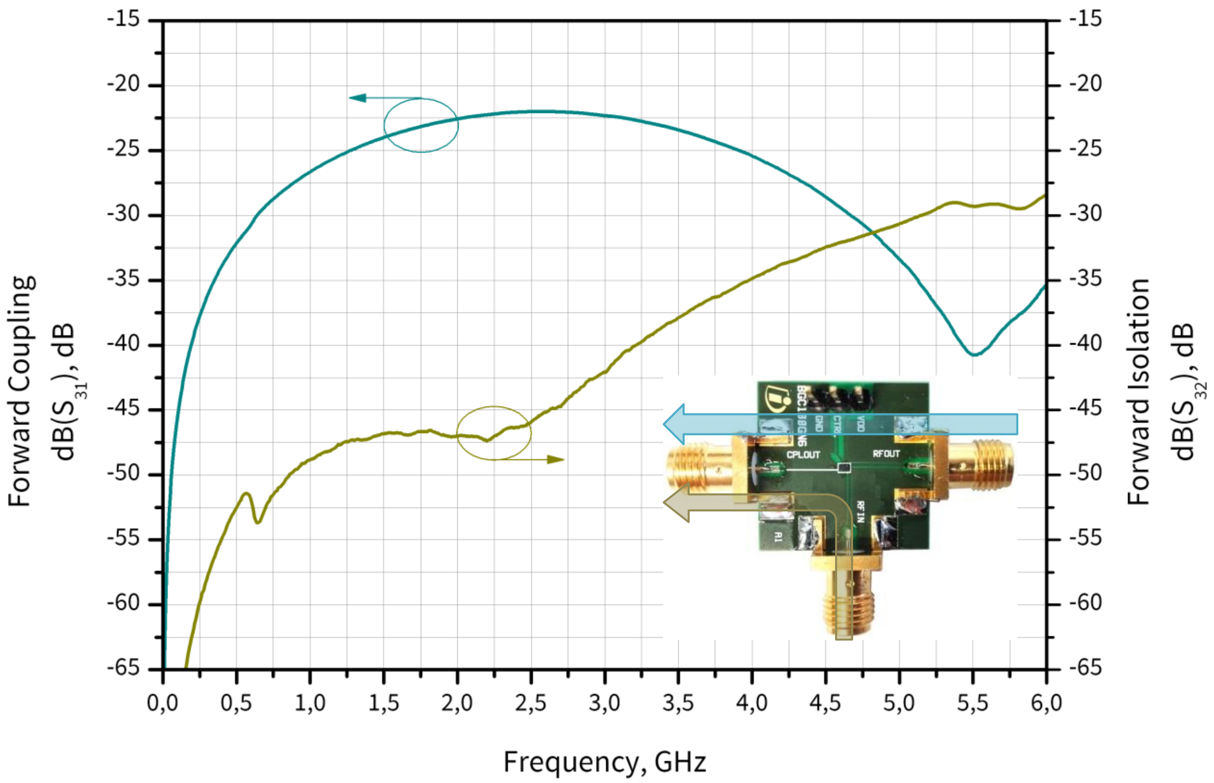

Figure 17 **Forward coupling and isolation of BGC100GN6 coupler (CTRL = 1)**

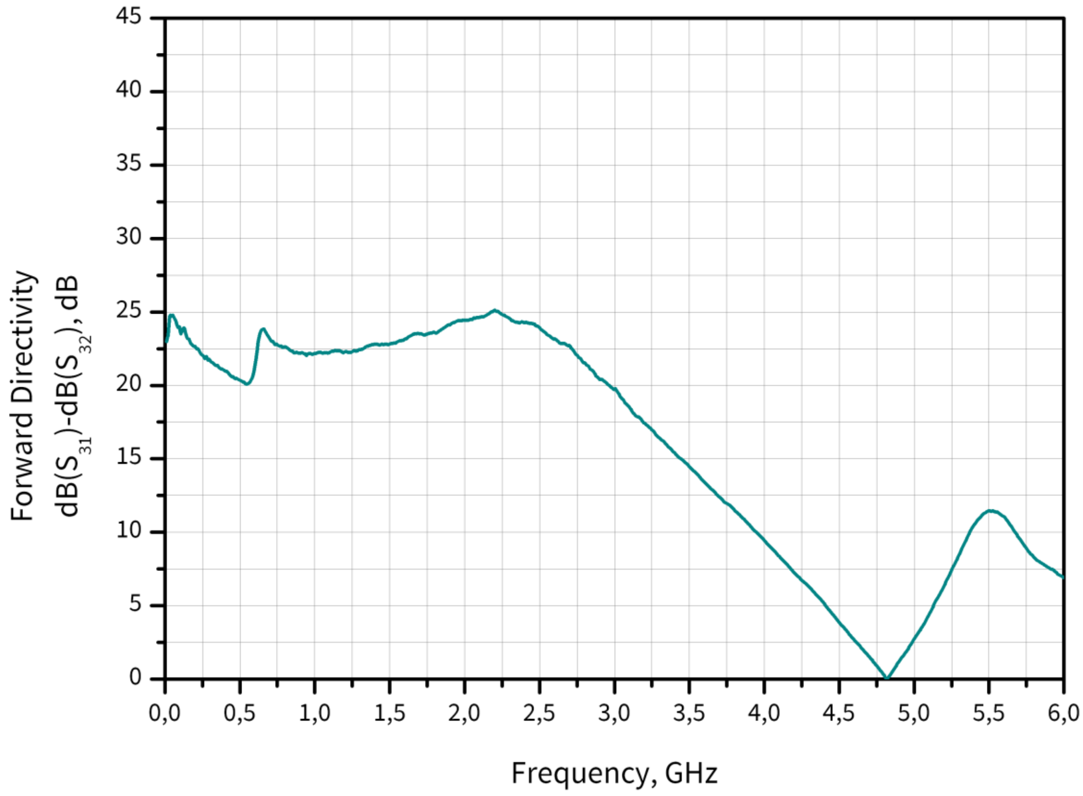

Figure 18 Forward directivity of BGC100GN6 coupler (CTRL = 1)

Large-Signal Measurement Results

Large-signal performance includes harmonics and intermodulation distortion in the main path. Figure 19 pictures the simplified measurement setup in which harmonics where measured. Measurement results at room temperature for low-band and mid-band main tone are shown in Figure 20 and Figure 21.

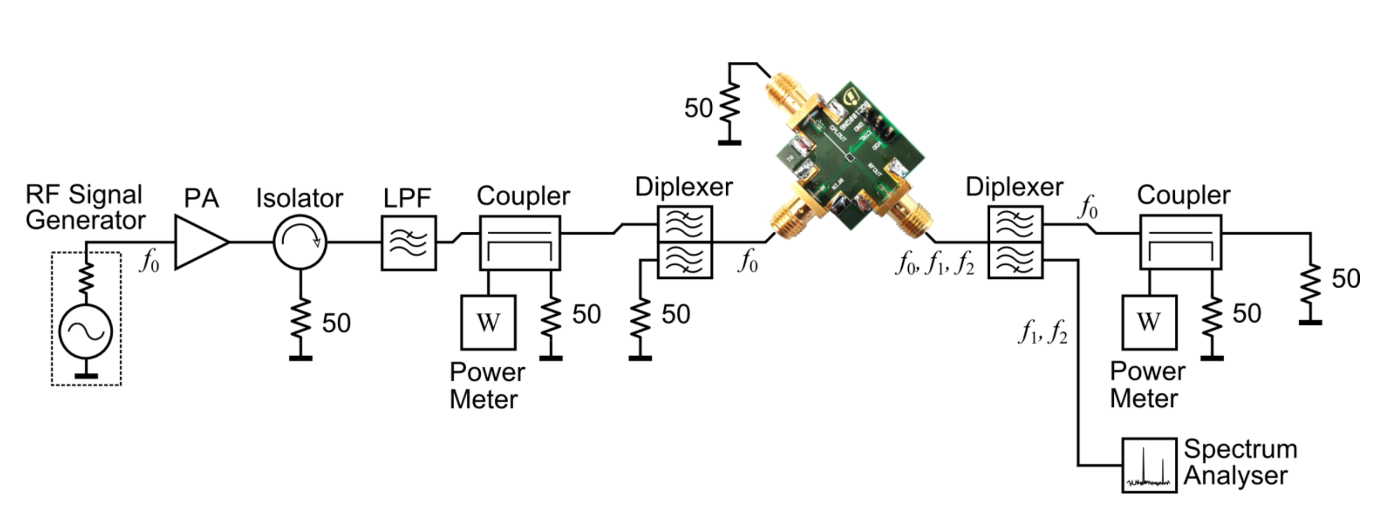

Figure 19 Harmonics measurement setup

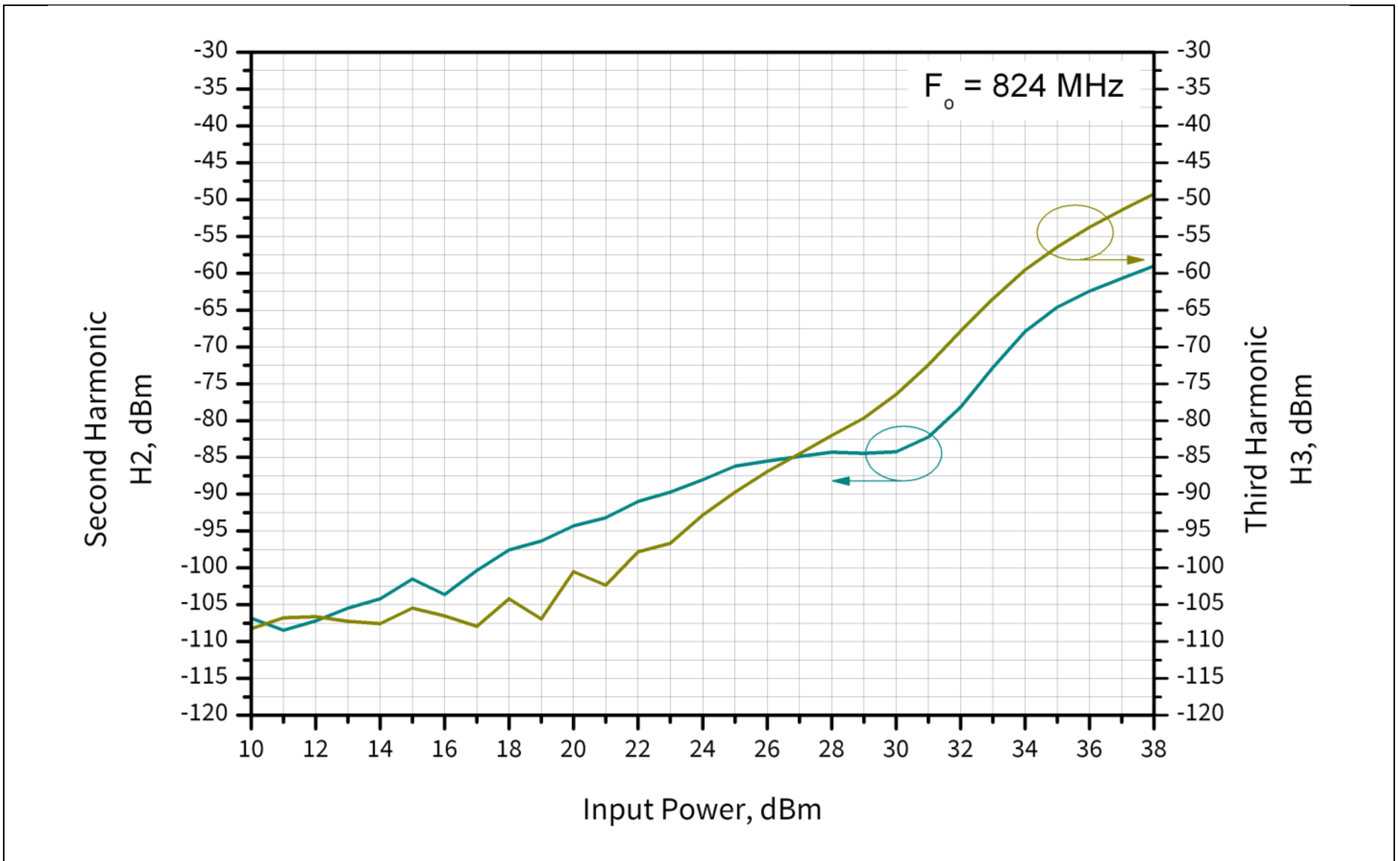

Figure 20 Harmonics of the main path at low-band (824 MHz) at room temperature

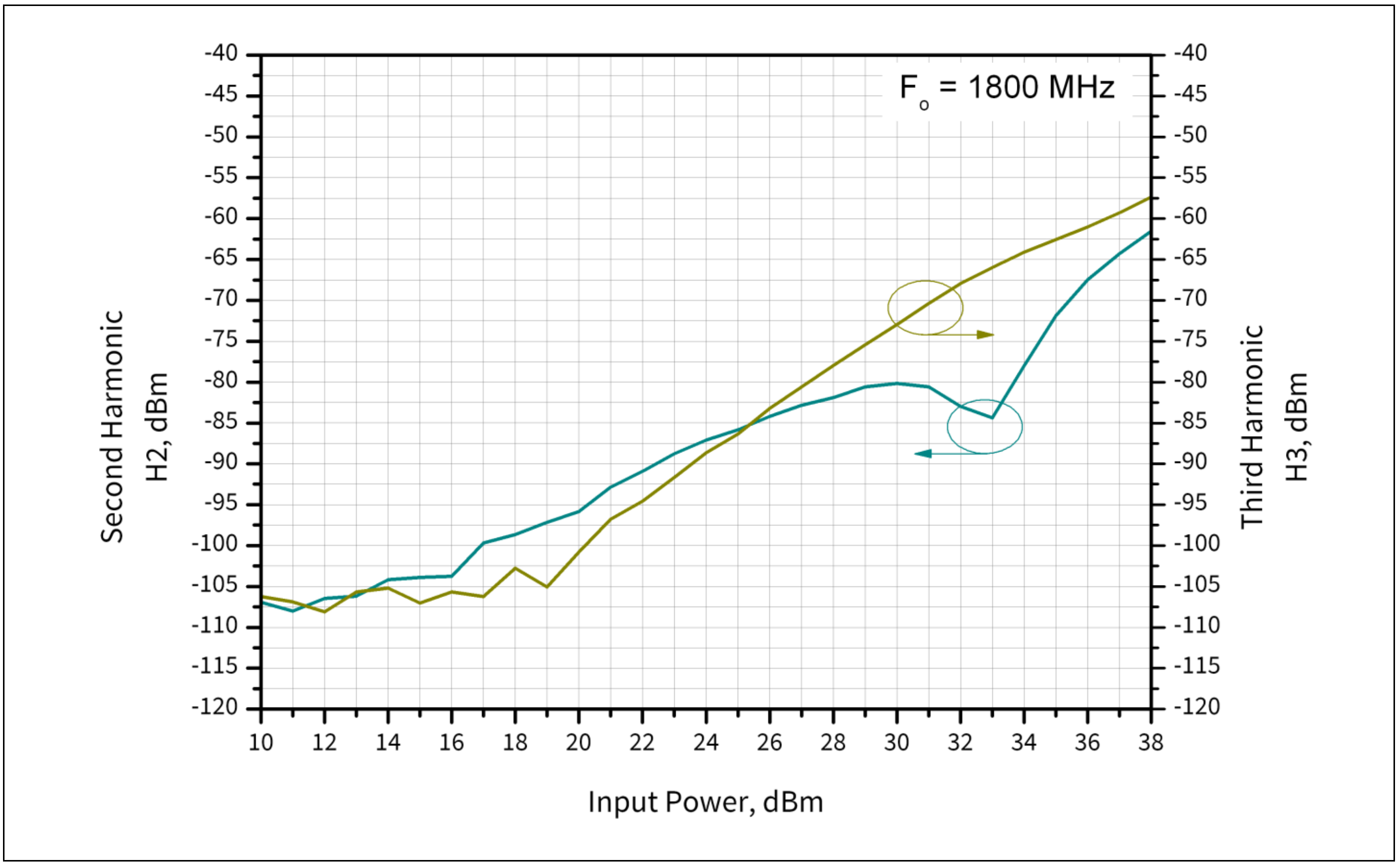

Figure 21 Harmonics of the main path at mid-band (1800 MHz) at room temperature

Since BGC100GN6 directional coupler IC can operate in TX carrier aggregation RF front-ends, an example of intermodulation product measurement is given in this document. Specifically, the case of uplink CA with band 39 and band 41 is presented. The measurement setup is demonstrated in Figure 22, measurement results are provided in Table 4 – the four application-relevant intermodulation products which may interfere with receive bands (like bands 12, 42, 46 and GPS) are listed.

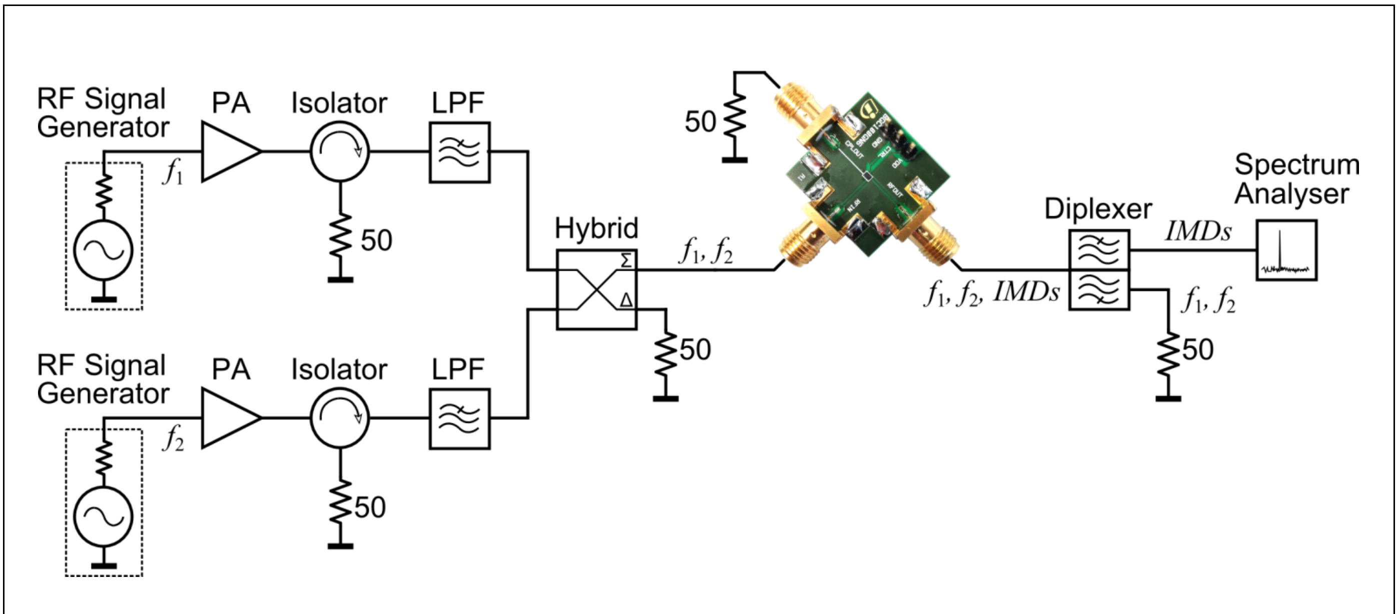

Figure 22 IMD measurement setup

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André Kindler, RF Application Engineer of Business Unit “Radio Frequency and Sensors”

6 Reference

[1] Application Guide for Mobile Communication 2015, Infineon Technologies, PMM RFS

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Revision History

Major changes since the last revision

Page or Reference	Description of change
Revision 1.0	Initial version
Revision 1.1	EVB assembly recommendations (blocking cap)

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