Schottky diode mixer for 5.8 GHz radar sensor

About this document

Scope and purpose

This application note shows a single balanced mixer for 5.8 GHz Doppler radar applications with Infineon low-barrier Schottky diodes. The mixer design is based on a rat-race coupler with an Infineon BAT15-04W series double Schottky diode.

Intended audience

This document is intended for engineers who need to design radio frequency (RF) Schottky diode mixer circuits.

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1 Introduction

1.1 Doppler radar

A simplified model of continuous wave (CW) radar is shown in Figure 1. It transmits a continuous wave at one chosen frequency through time. The wave that hits an object with a relative velocity accelerates or decelerates according to the direction of the movement. If the target is approaching the radar it accelerates the wave and at the receiver, a frequency higher than the transmitted frequency is measured. In the opposite condition, the wave gets decelerated and the frequency at the receiver becomes lower than the transmitted frequency. This phenomenon is called the Doppler effect and it is why this radar model is also called "Doppler radar". At the receiver, a signal with the Doppler frequency between the transmitted and received frequencies comes out. Applying the Doppler formula, the relative velocity of the target can be found:

$$f_d \approx \frac{2f_t}{c} v \qquad (1)$$

(f_d: Doppler frequency, f_t : transmit frequency, c: velocity of light (m/s), v: target velocity (m/s))

The local oscillator output is used in both the transmitter and the receiver. The mixer is used to extract the Doppler shift, which has the desired information from the transmit frequency.

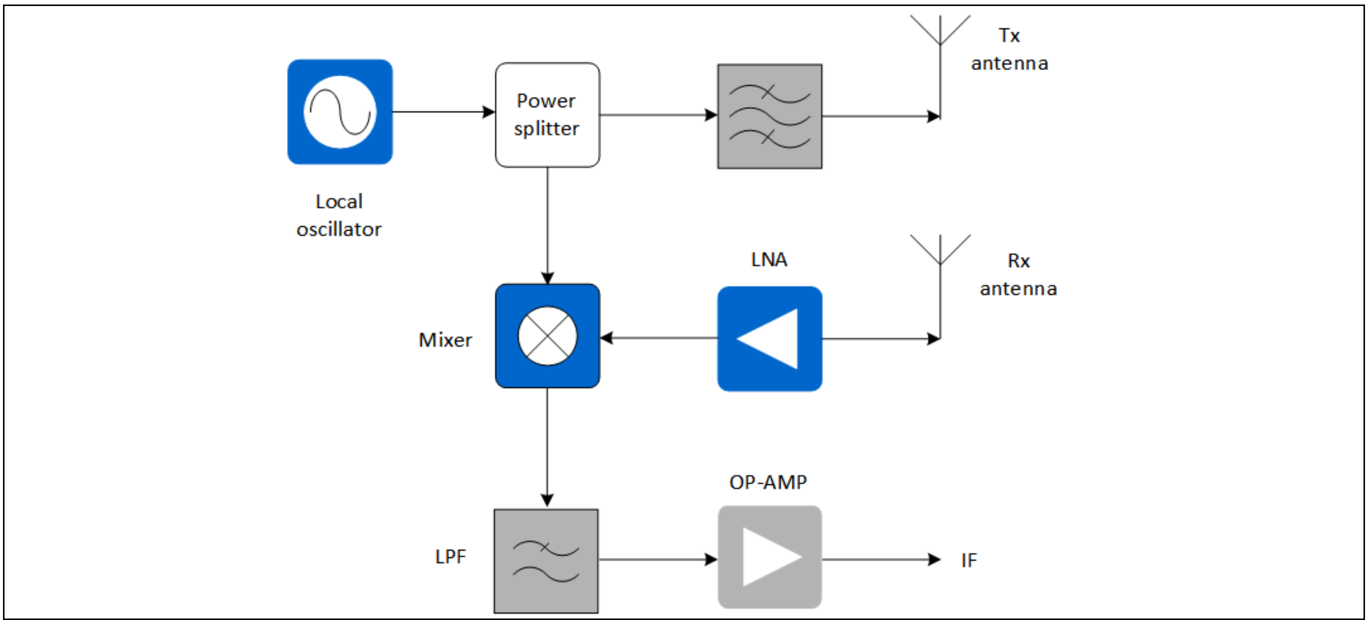

Figure 1 Simplified Doppler radar RF front-end schematic

In Figure 2, the Doppler frequency in terms of radial speed of the target relative to the radar is illustrated for 5.8 GHz carrier frequency using the equation above. As the application of the radar is mainly for pedestrian detection, speed measurement and distance extraction, the speed of interest is between 1 km/h and 20 km/h.

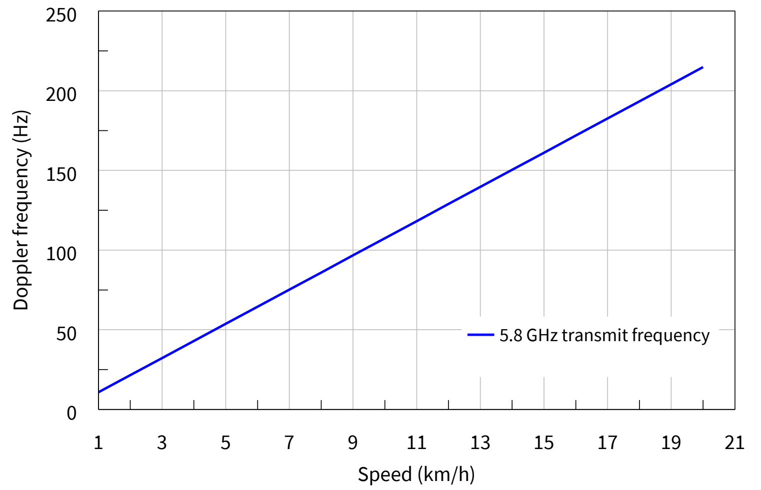

Figure 2 Doppler frequency depending on the relative target speed for 5.8 GHz radar

1.2 Mixer theory

Mixers are among the most necessary circuit elements in wireless communication, radar, radio, sensors, and all circuits where there is a need to move a band of the signal from one center frequency to another. A mixer is a three-port device that has two inputs and one output port. In the simplest way, it creates output with a frequency that is either the sum of or the difference between the two input signals. The basic function of a mixer is shown in Figure 3. RF and local oscillator (LO) are inputs for the mixer, and the intermediate frequency (IF) is either the sum of or difference between the RF and LO frequencies.

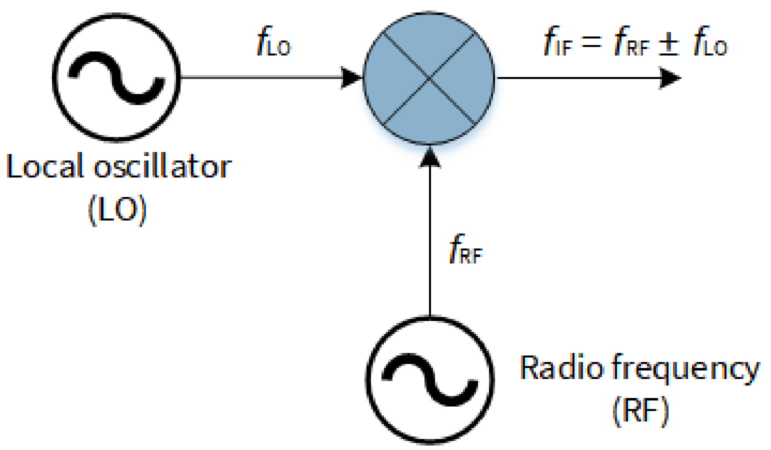

Figure 3 Basic function of a mixer

A Schottky diode is one of the popular options among non-linear devices for mixers. With the help of the non-linear characteristics, it can create different combinations of input signals. The characteristics of the Schottky diode are similar to a typical PN diode and follow similar current voltage characteristics. The key advantage of a Schottky diode compared to a PN diode is that it shows a lower forward voltage drop (0.15 V to 0.45 V) than the PN diode (0.7 V to 1.7 V). This lower forward voltage drop allows higher switching speeds and better sensitivity and efficiency for Schottky diodes. Furthermore, PN junction diodes are minority semiconductor devices suffering from the low recombination velocity of the minority carriers in the space charge region, whereas Schottky diodes are controlled by the charge transport over the barrier from the majority carriers. This leads to very fast switching action of the Schottky diodes and makes them very attractive for RF applications in the millimeter wave range, like mixers.

1.3 Infineon RF Schottky diodes

Infineon RF Schottky diodes are silicon low barrier N-type devices and they come in industry-standard 0201, 0402 or traditional packages with various junction diode configurations. Their low barrier height and very small forward voltage, along with low junction capacitance, make this series of devices an adequate choice for power detection and mixer functions at frequencies as high as 24 GHz.

The main parameters of the Schottky diode used in this application note are listed in the following table.

Table 1 Schottky diode – main parameters

Product type	V_R (max) [V]	I_F (max) [mA]	C_T [pF]	V_F at 1mA [mV]	Package	Configuration
BAT15-04W	4	110	0.30	250	SOT323	Double diode, series

2 Single balanced mixer design

2.1 Schematic

The schematic of the single balanced mixer is shown in Figure 4. The first element in the mixer is the coupler. For feeding the two signals, a hybrid ring (rat-race coupler) is used. The amplified RF signal and the LO signal are applied at the sum port and the delta port of the coupler. The balanced LO signal at the coupler's output drives the two Schottky diodes included in the BAT15-04W device. The IF signal is fed from the common pin of the two diodes though a low pass filter (LPF) to the IF output port. Additionally a capacitor (C1) suppresses the RF and LO signals at the IF output.

At higher LO power levels, the diodes are self-biased and show undesired conversion loss and isolation values. To avoid this situation, a DC ground needs to be implemented to the system without affecting RF characteristics. It is done by using an RF choke (RFC), as shown in Figure 4. Two shorted stubs of λ/4 length at RF and LO frequency (5.8 GHz) are used to provide the IF mixing products on the RF side of the mixer with a path to ground, while providing a high impedance at LO and RF frequency.

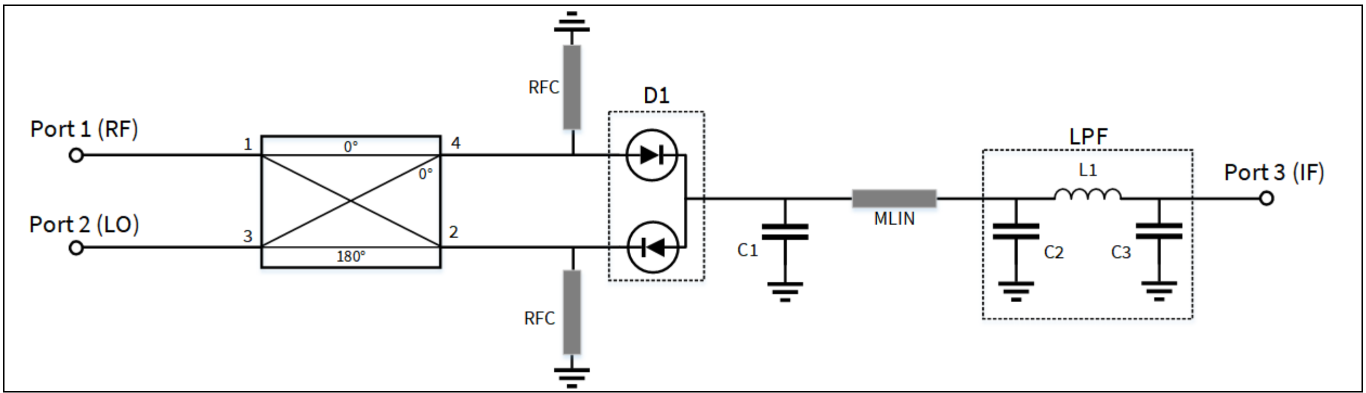

Figure 4 Schematic of the single balanced diode mixer

BAT15-04W is a series, double diode version in a compact SOT323 package, as shown in Figure 5. This compact version facilitates the assembly of single balanced mixer.

Figure 5 BAT15-04W double diode, SOT323 package

2.2 Performance overview

Table 2 Summary of measurement results at 5.8 GHz for single balanced mixer

Parameter	Symbol	Value	Unit	Notes
Conversion loss	C_L	6.8	dB	10 Hz offset between RF and LO frequency, LO at 4 dBm and RF at -40 dBm
		6.8		100 Hz offset between RF and LO frequency, LO at 4 dBm and RF at -40 dBm
		6.8		200 Hz offset between RF and LO frequency, LO at 4 dBm and RF at -40 dBm
LO to RF isolation	ISO_{LO-RF}	23.1	dB	LO at 4 dBm
LO to IF isolation	ISO_{LO-IF}	55.1	dB	LO at 4 dBm
RF to IF isolation	ISO_{RF-IF}	50.9	dB	LO at 4 dBm
Input 1 dB compression point	IP_{1dB}	1.1	dBm	100 Hz offset between RF and LO frequency and LO at 4 dBm

2.3 Bill of Materials (BOM)

Table 3 BOM of single balanced mixer

Symbol	Value	Size	Manufacture	Notes
D1	–	SOT323	Infineon	Schottky diode BAT15-04W
C1	2.7 pF	0402	Various	Bypass capacitor
C2	1 µF	0402	Various	LPF at the IF output
C3	1 µF	0402	Various	LPF at the IF output
L1	120 nH	0402	Murata LQW	LPF at the IF output

2.4 Evaluation board and PCB layout

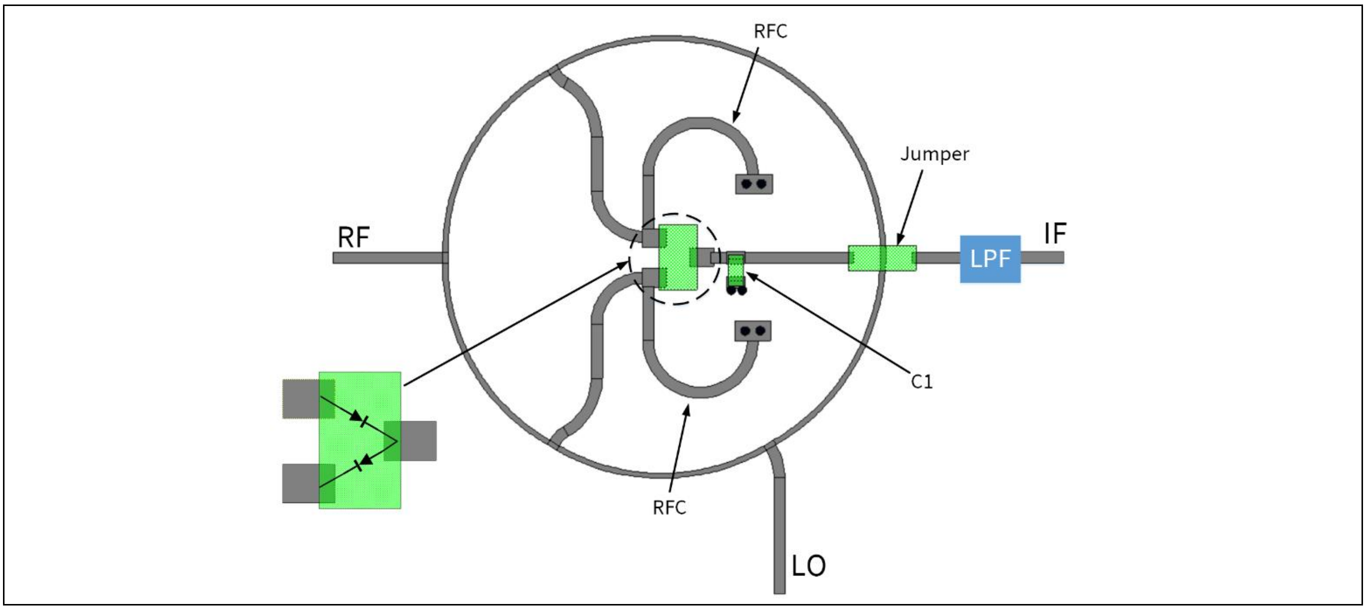

Figure 6 Layout of the single balanced diode mixer

Single balanced mixer design

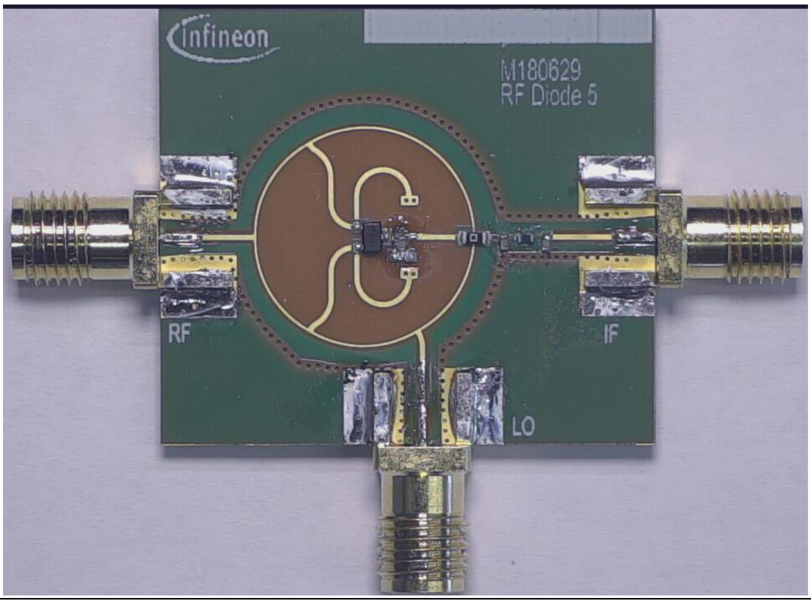

Figure 7 **Photo of the evaluation board for single balanced diode mixer**

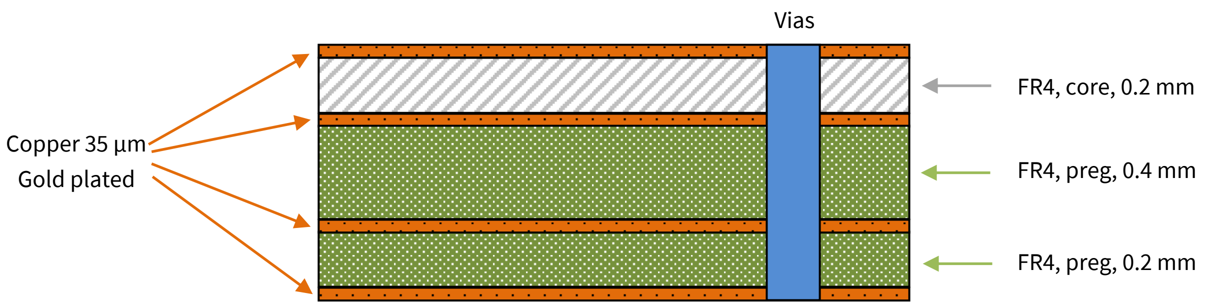

Figure 8 **PCB stack information of evaluation board for single balanced diode mixer**

3 Measurement graphs

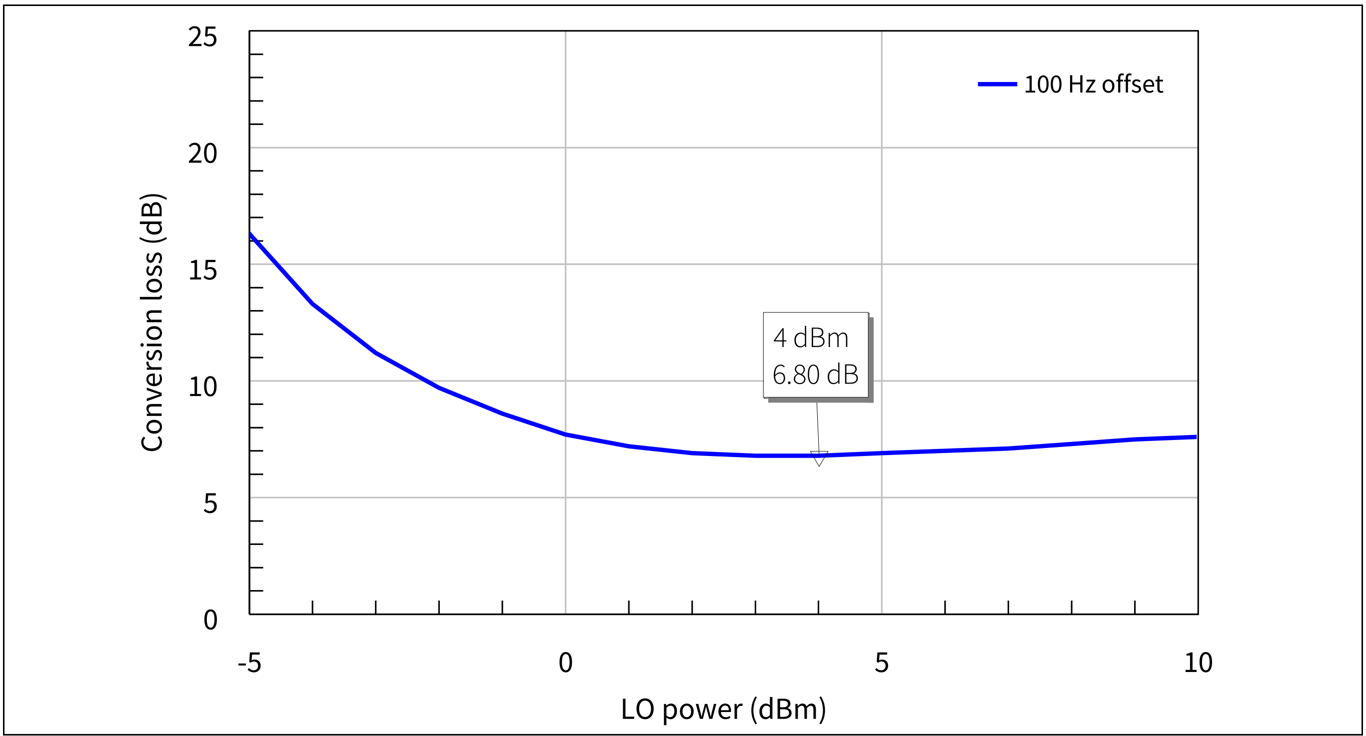

Figure 9 Conversion loss measurement of the single balanced mixer with LO at 5.8 GHz, offset between LO and RF of 100 Hz and RF power of -40 dBm

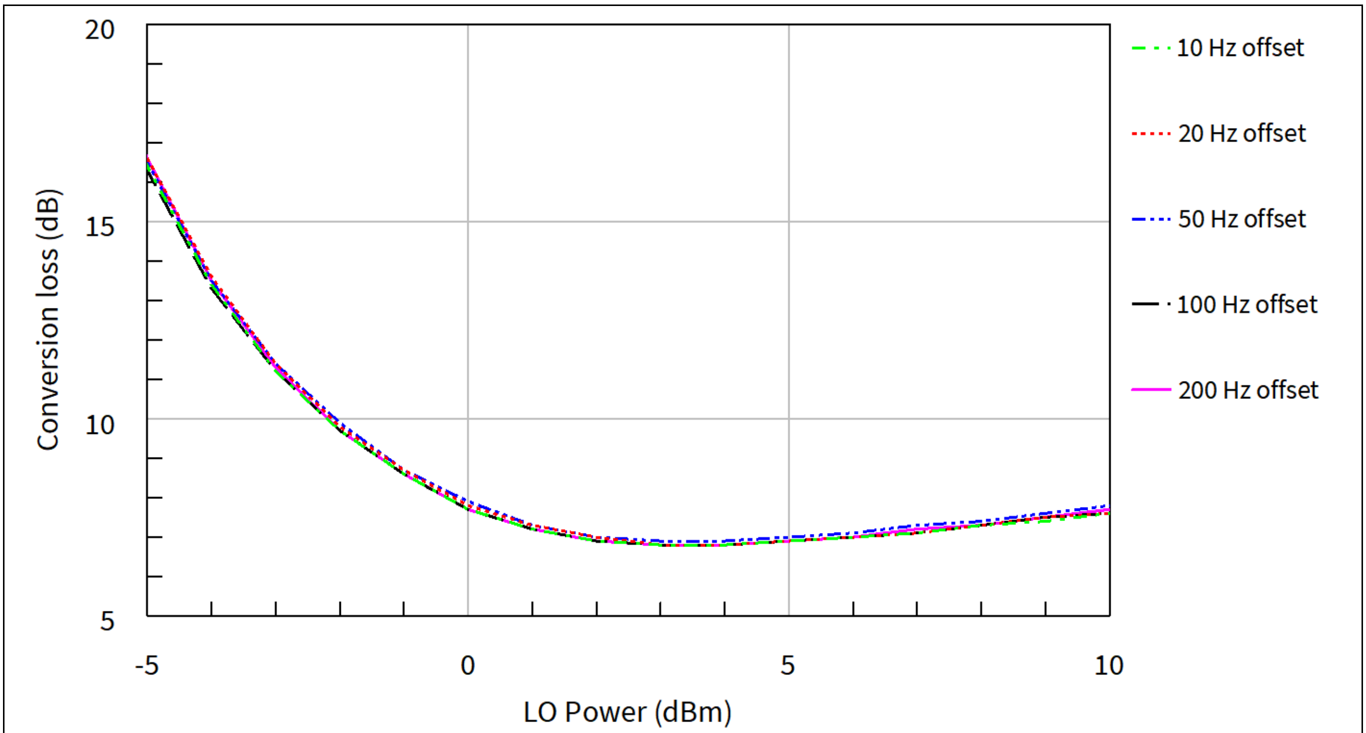

Figure 10 Conversion loss measurement of the single balanced mixer with LO at 5.8 GHz, different values of offset between LO and RF and RF power of -40 dBm

Note: The graphs are generated with the AWR electronic design automation (EDA) software Microwave Office®.

Measurement graphs

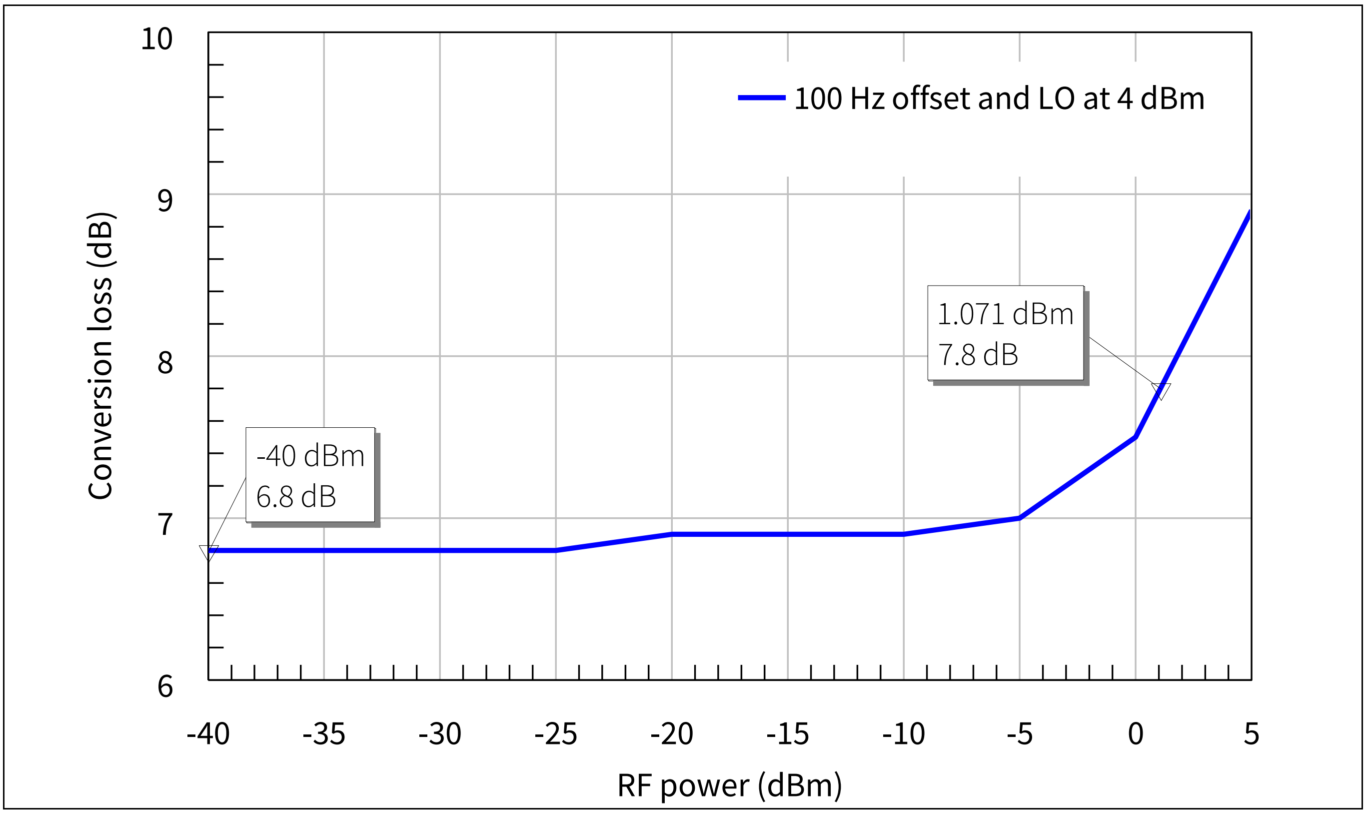

Figure 11 **Input 1 dB compression point measurement of the single balanced mixer with LO at 5.8 GHz, offset between LO and RF of 100 Hz and LO power of 4 dBm**

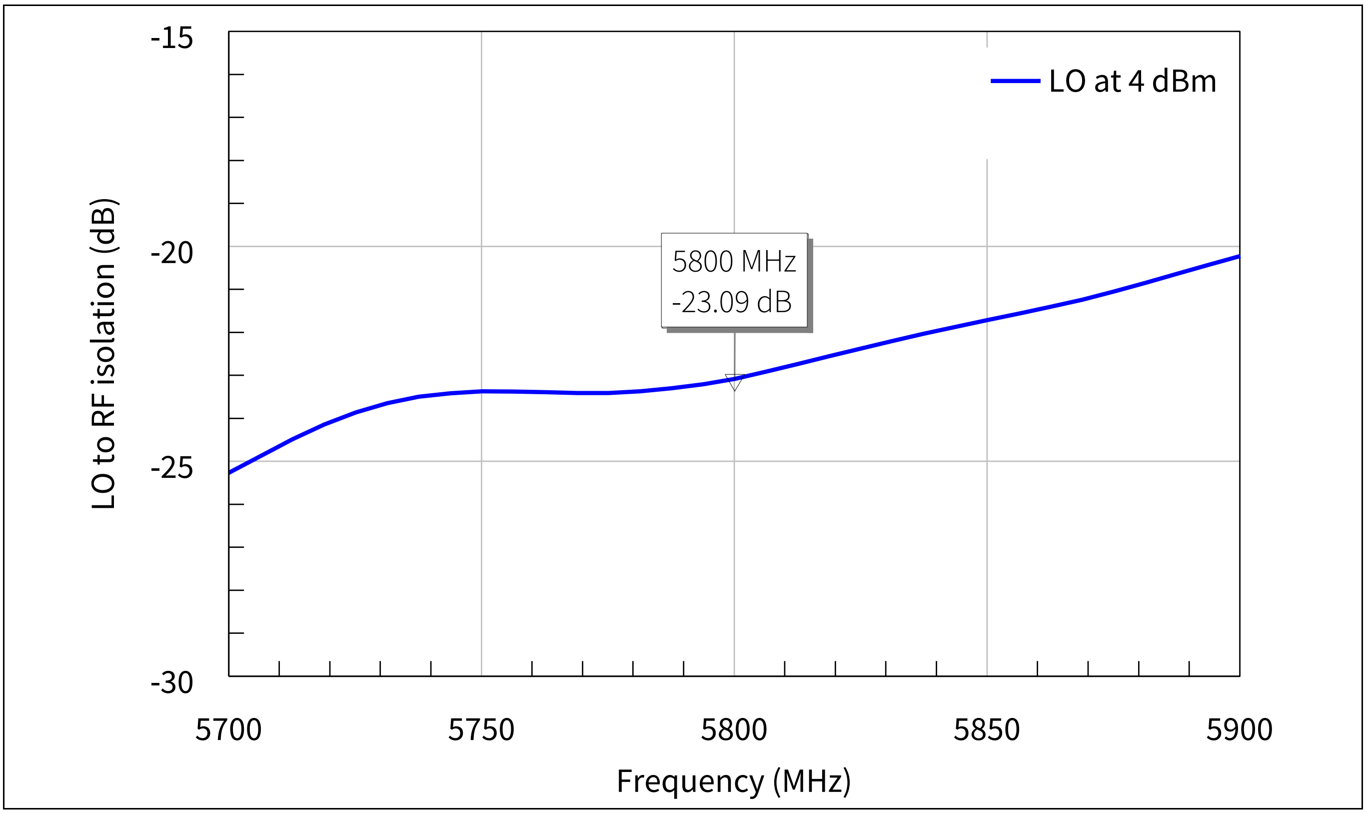

Figure 12 **LO to RF isolation measurement of the single balanced mixer with LO power of 4 dBm**

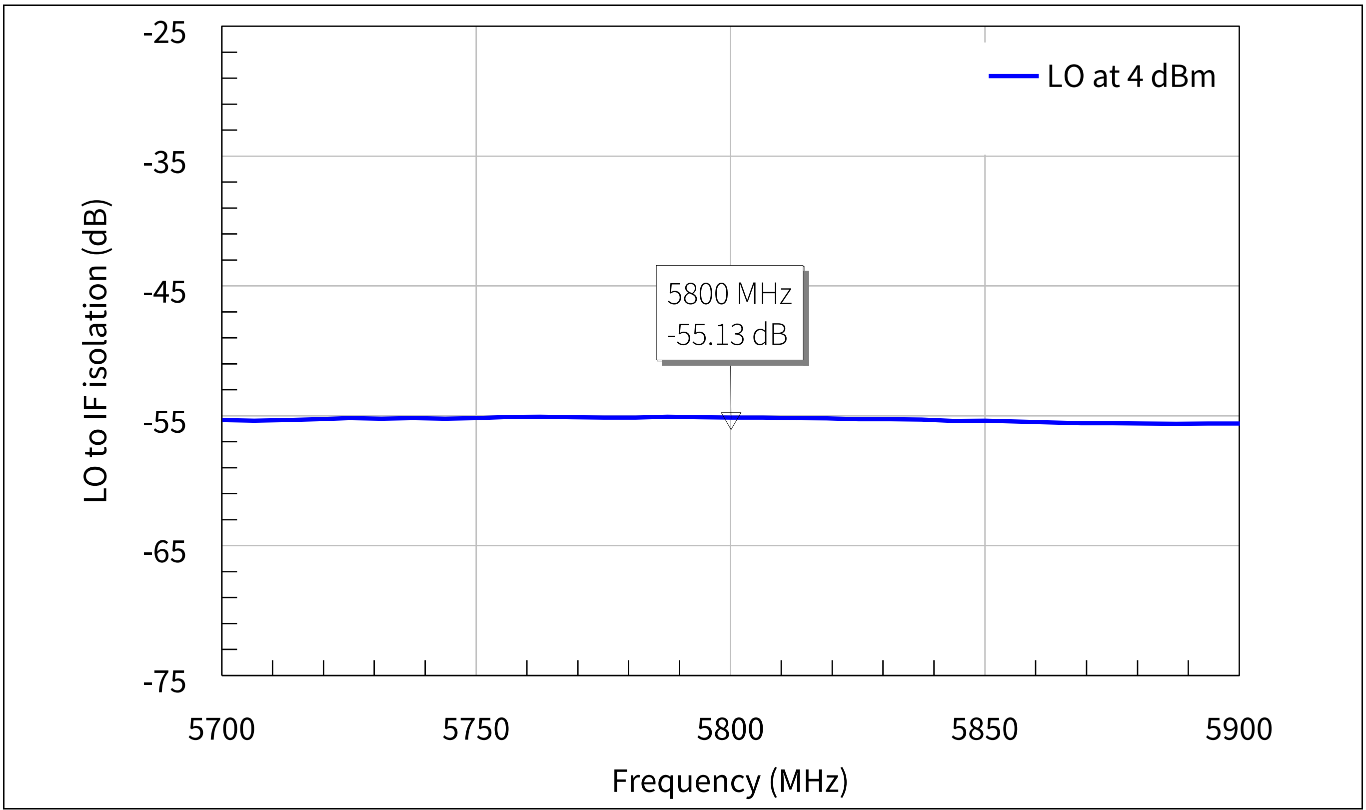

Figure 13 LO to IF isolation measurement of the single balanced mixer with LO power of 4 dBm

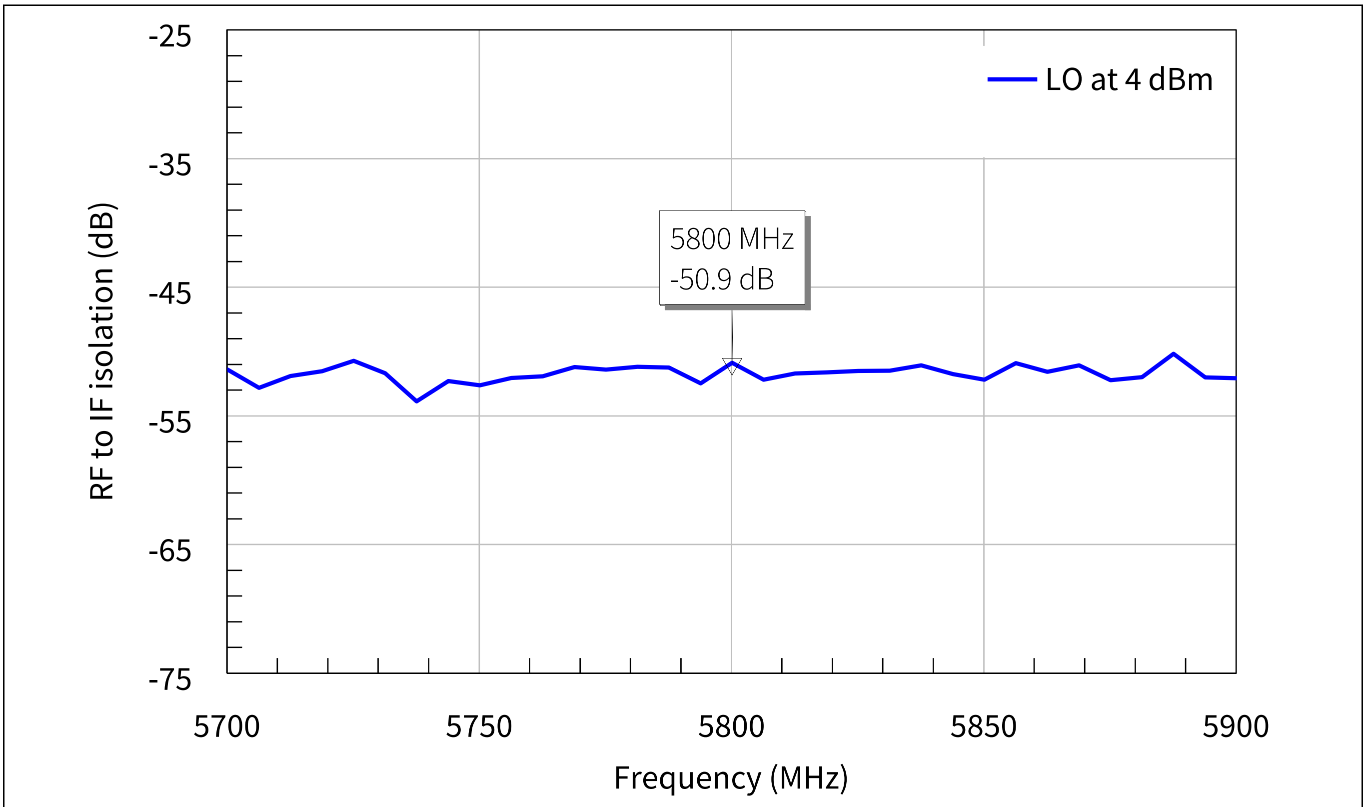

Figure 14 RF to IF isolation measurement of the single balanced mixer with LO power of 4 dBm

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Revision history

Document version	Date of release	Description of changes

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Edition 2018-08-07

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference
AN_1808_PL32_1809_130625