Design guide for RF low-noise transistor in LiDAR applications

RF bipolar transistor

About this document

Scope and purpose

This application note provides an application circuit design example of broadband low-noise signal amplification with Infineon's low-noise silicon germanium carbon (SiGe:C) transistor BFR740L3RH for light detection and ranging (LiDAR). In this document the transistor circuit schematic, PCB layout and measurement results are shown.

Intended audience

This document is intended for engineers who need to design LiDAR application circuits.

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1 Introduction

1.1 LiDAR architecture

LiDAR is a remote sensing technique that measures the distance to a target and creates a 3D map of the target object. Its versatility and high resolution make it suitable for application in guidance, rangefinders, drones, laser safety scanners, architectural surveying equipment, gas analysis, retinal imaging, robotics, etc.

LiDAR uses different architectures as direct and indirect time-of-flight (ToF) measurement, or triangulation for detection and ranging. In general, LiDAR measures the distance to a target by analyzing the difference (time delay, phase difference, etc.) between the emitted reference laser signal and the signal reflected after reaching the target. For this reason, a LiDAR front end usually consists of a laser emitter and an optical receiver as shown in Figure 1. One of the most important factors of a LiDAR detection range is the optical receiver sensitivity, primarily when the emitted laser power is usually limited by the hazard regulations.

A very low noise amplifier (LNA) is required to detect the small current generated by the photo-diode as the amplitude of the return signal decreases proportionally to the square of the target distance. Moreover, the demands on ranging accuracy and resolution require very high receiver bandwidth in the range of GHz and high receiver sensitivity. Therefore, the LiDAR receiver needs a broadband amplifier with high gain and low noise figure (NF) to increase the receiver sensitivity. The design of the trans-impedance amplifier (TIA) based on the operational amplifier (op-amp) often implies a compromise between gain, noise and bandwidth. Consequently, an ultra-low-noise and high-speed op-amp is needed for increasing bandwidth which increases cost. On the other hand, broadband LNA can be built easily using an Infineon RF transistor with few external components, as an alternative optimized cost solution. The Infineon RF LNA provides very low NF and high gain for wide bandwidth (kHz to GHz). Moreover, cascaded LNA can be used to fulfill system-required gain.

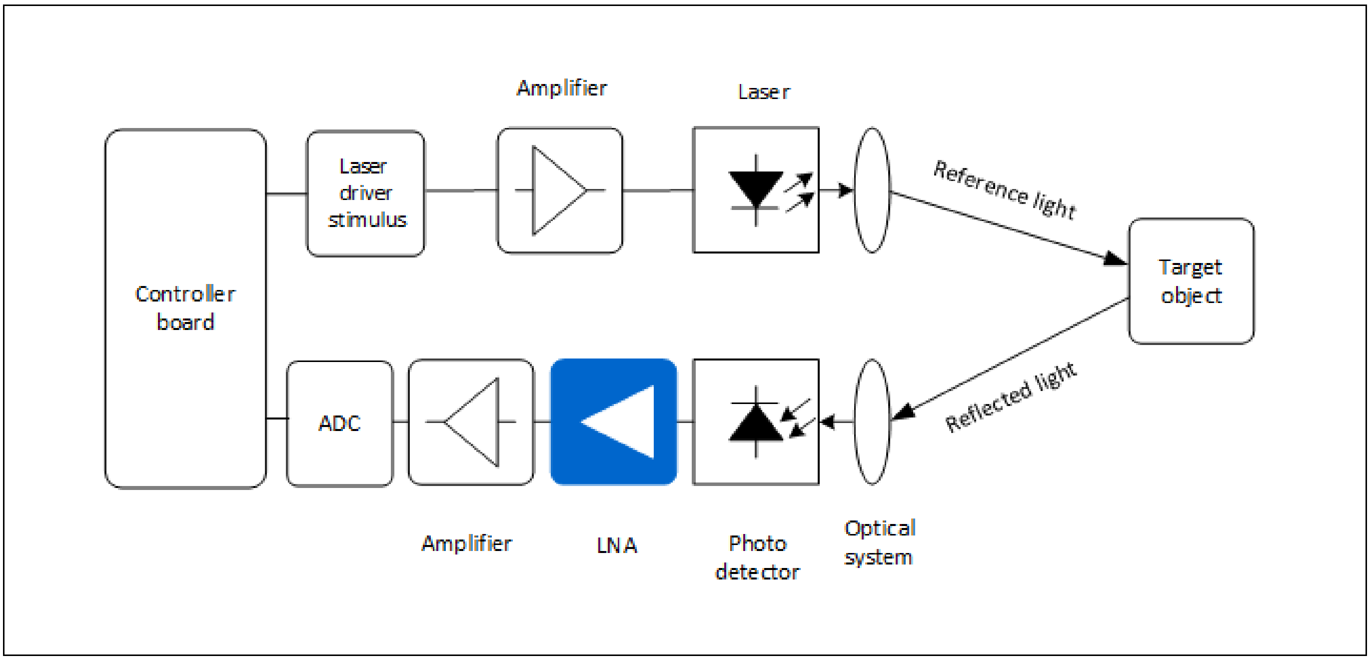

Figure 1 A block diagram example of the simplified LiDAR system

1.2 Infineon RF transistors family

Infineon Technologies provides high-performance RF transistors suitable for LiDAR LNA applications. Infineon's reliable high-volume RF transistor offers exceptionally low NF, high gain and high linearity at low power consumption levels for RF applications. The seventh-generation transistor is based on robust ultra-low-noise SiGe:C technologies. Their optimized inner transistor cell structure leads to best-in-class power gains and NFs in a broad bandwidth, including LiDAR operating frequency. The transistor optimizes design flexibility to suit customer requirements.

2 LiDAR LNA circuit with the BFR740L3RH transistor

2.1 Performance overview

The following table shows the LiDAR LNA performance with RF low-noise bipolar transistor BFR740L3RH.

Table 1 Summary of measurement results for the LiDAR LNA with BFR740L3RH transistor

Parameter	Symbol	Value			Unit	Notes
Device		BFR740L3RH				
Bias voltage	V_{CC}	3.3			V	
Bias current	I_{CC}	13			mA	
3 dB bandwidth	$f_{3\,dB}$	2.8 kHz - 450 MHz				
Frequency	f	10	200	400	MHz	
Gain	G	22.2	21.8	20.6	dB	
NF	NF	1.0	1.0	1.0	dB	
Input return loss	RL_{in}	17.2	16	17.9	dB	
Output return loss	RL_{out}	22.1	16.1	12.7	dB	
Reverse isolation	ISO_{rev}	26.9	27.1	27.5	dB	
Output 1 dB compression point	OP_{1dB}	0.4	0.0	0.2	dBm	
Output third order interception point	OIP_3	9.2	7.3	5.6	dBm	Power at input: -35 dBm, Tone spacing: 1 MHz
Stability	K	>1				Measured from 300 kHz to 10 GHz

2.2 Schematic

The following figure shows the general schematic of the LiDAR LNA with BFR740L3RH RF low-noise transistor. In the LNA circuit, resistors R1, R2 and R3 stand for transistor voltage and current bias; meanwhile, R1 and R3 form a negative DC feedback mechanism to stabilize the transistor bias points in various conditions. Resistor R4 and capacitor C6 serve as the negative feedback to improve input and output impedance matching and in conjunction with the resistor R3 achieve flat gain over the operating frequency. The transistor's input matching is performed by the capacitors C1, C6 and the resistor R4. The network of R3, C3, C4, C5, L1 and L2 matches the transistor to the output port. Capacitor C2 works as an RF bypass which also suppresses low-frequency noise. In general, resistors R3 and R4 stabilize the circuit, whose stability is measured up to 10 GHz.

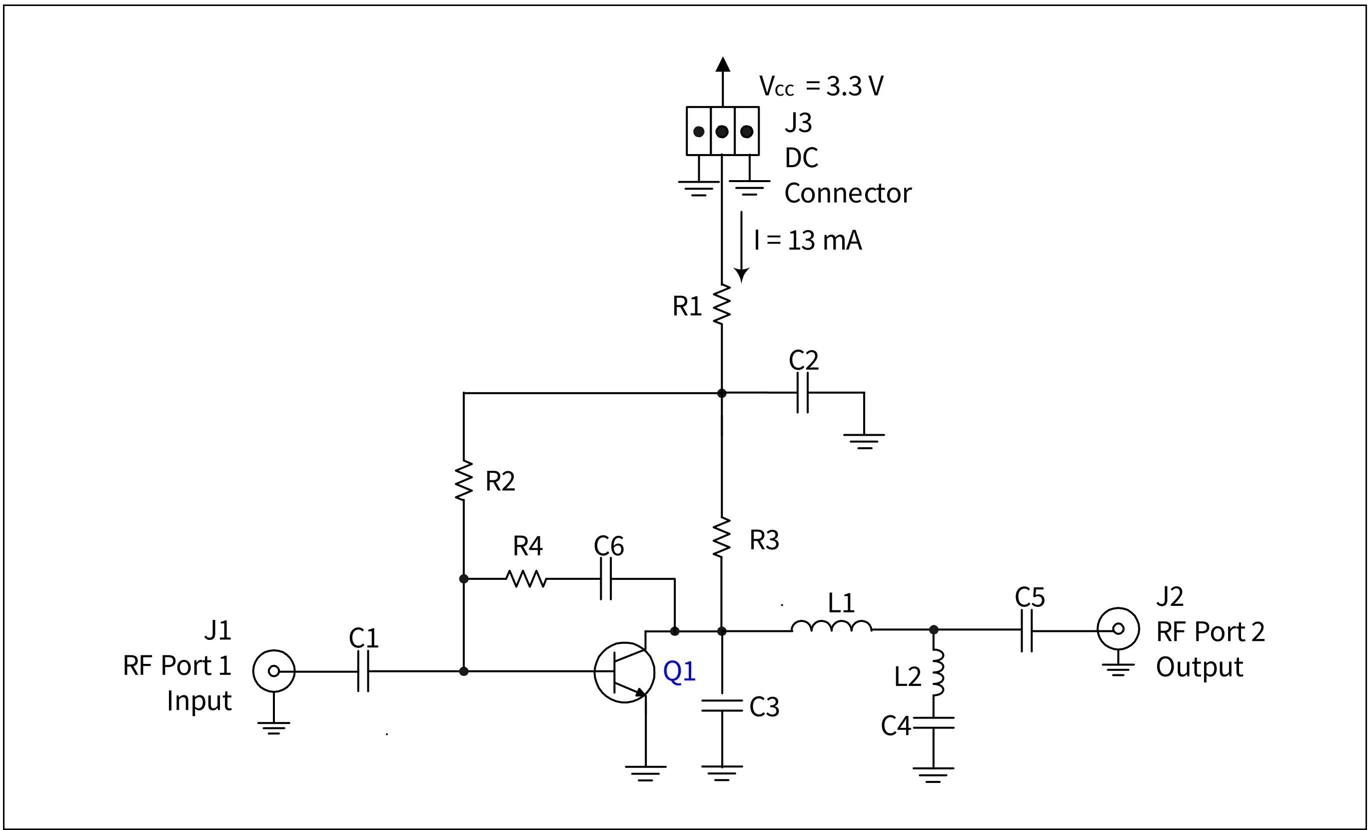

Figure 2 Schematic of the LiDAR LNA with BFR740L3RH transistor

2.3 Bill of materials (BOM)

Table 2 BOM of the LiDAR LNA with BFR740L3RH transistor

Symbol	Value	Unit	Package	Manufacturer	Comment
Q1	BFR740L3RH		TSLP-3-9	Infineon	SiGe: C low-noise transistor
C1	1	µF	0402	Various	Input matching and DC blocking
C2	220	nF	0402	Various	RF bypass
C3	8.2	pF	0402	Various	Output matching
C4	4.7	pF	0201	Various	Output matching
C5	1	µF	0402	Various	Output matching and DC blocking
C6	220	nF	0402	Various	DC blocking
R1	47	Ω	0402	Various	DC biasing
R2	39	kΩ	0402	Various	DC biasing
R3	160	Ω	0402	Various	Output matching and stability improvement
R4	910	Ω	0402	Various	Feedback
L1	22	nH	0402	Murata LQG	Output matching
L2	9.1	nH	0201	Murata LQG	Output matching

2.4 Evaluation board and layout information

The evaluation board for the LiDAR LNA with BFR740L3RH transistor:

- PCB material: FR4
- PCB marking: M140326

Images of the evaluation board and the detailed description of emitter degeneration are shown in the following figure.

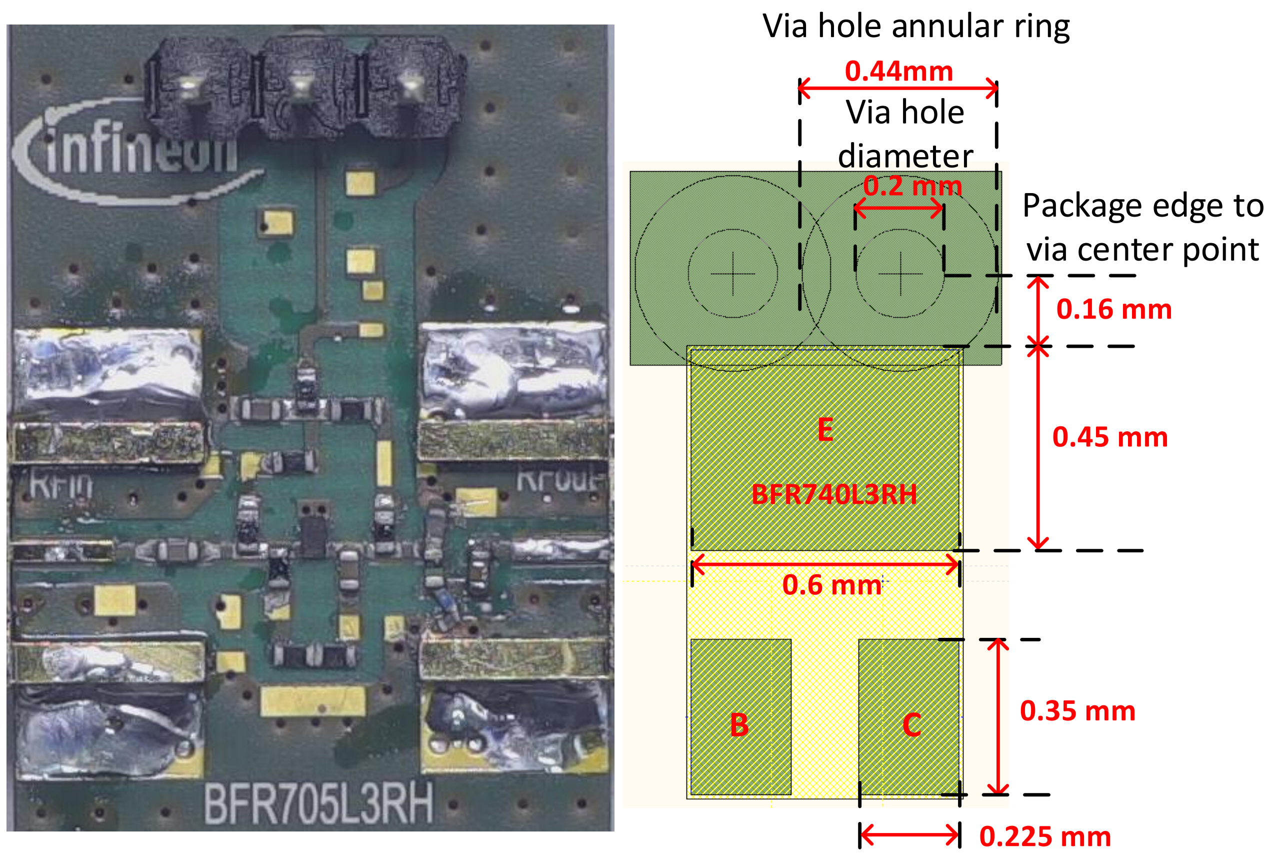

Figure 3 Photo of the BFR740L3RH transistor LNA evaluation board (left) and emitter degeneration details (right)

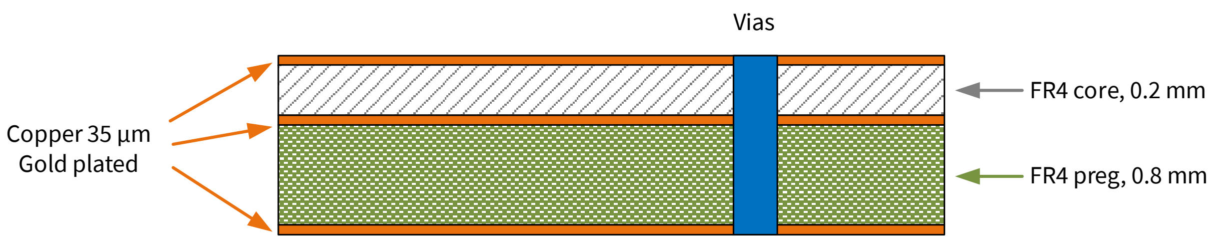

Figure 4 The PCB stack information for the evaluation board M140326

2.5 Measurement results of the LiDAR LNA with BFR740L3RH transistor

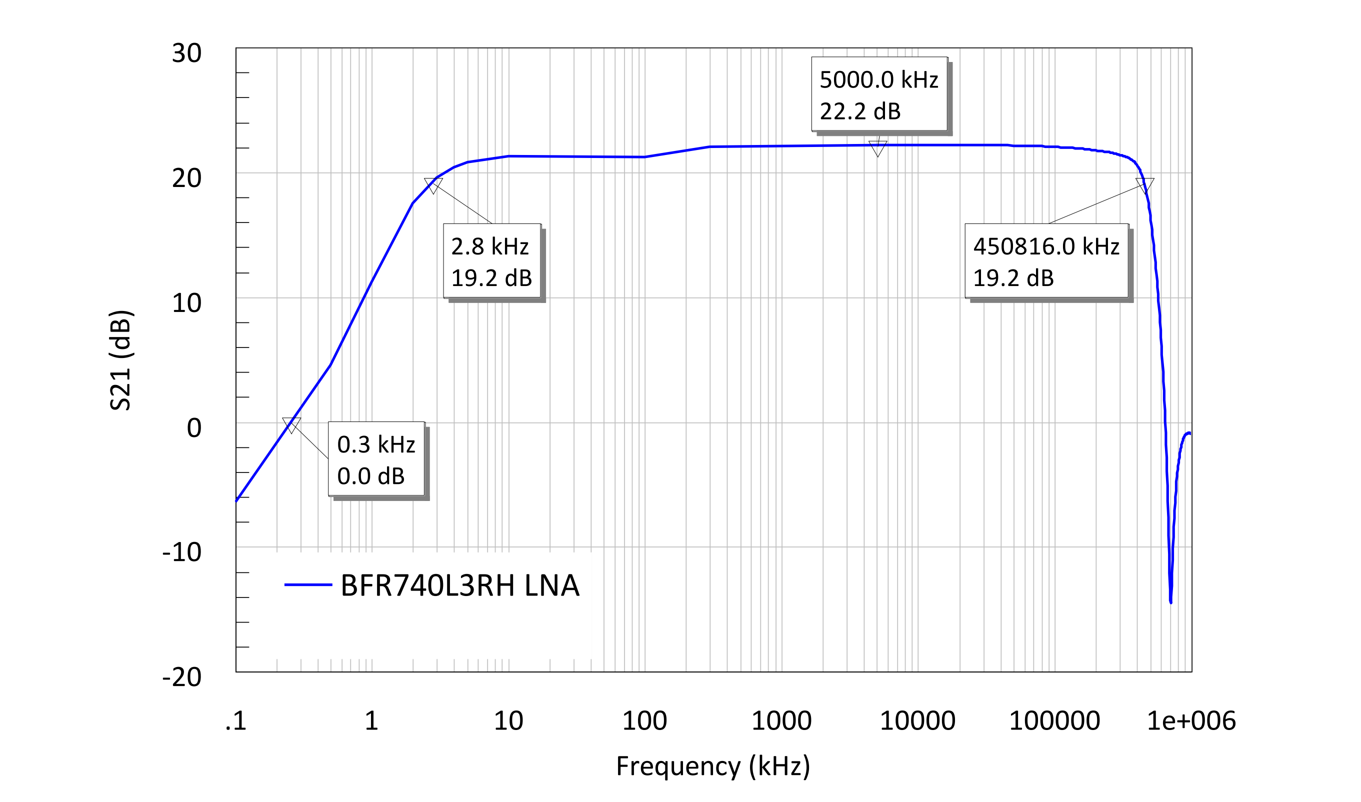

Figure 5 Small signal gain of the LiDAR LNA with BFR740L3RH transistor

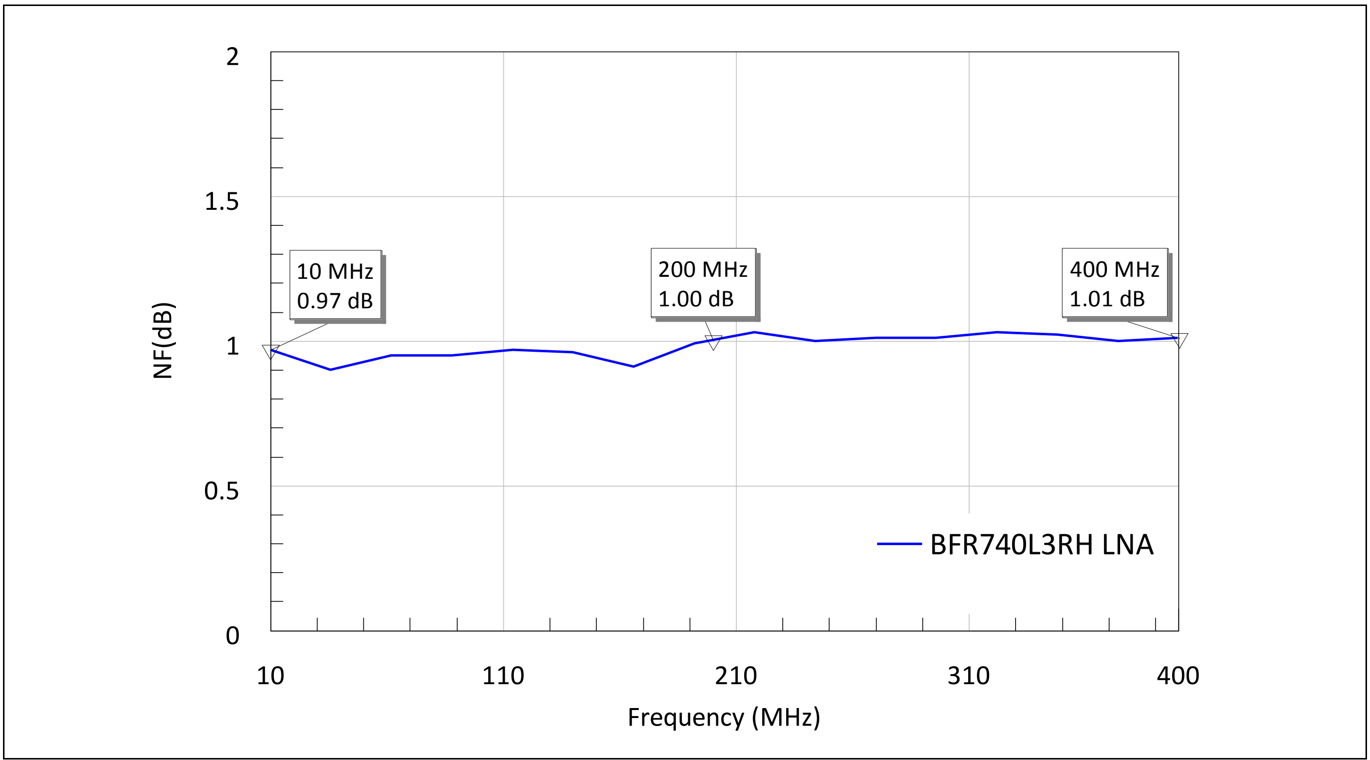

Figure 6 NF measurement of the LiDAR LNA with BFR740L3RH transistor

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

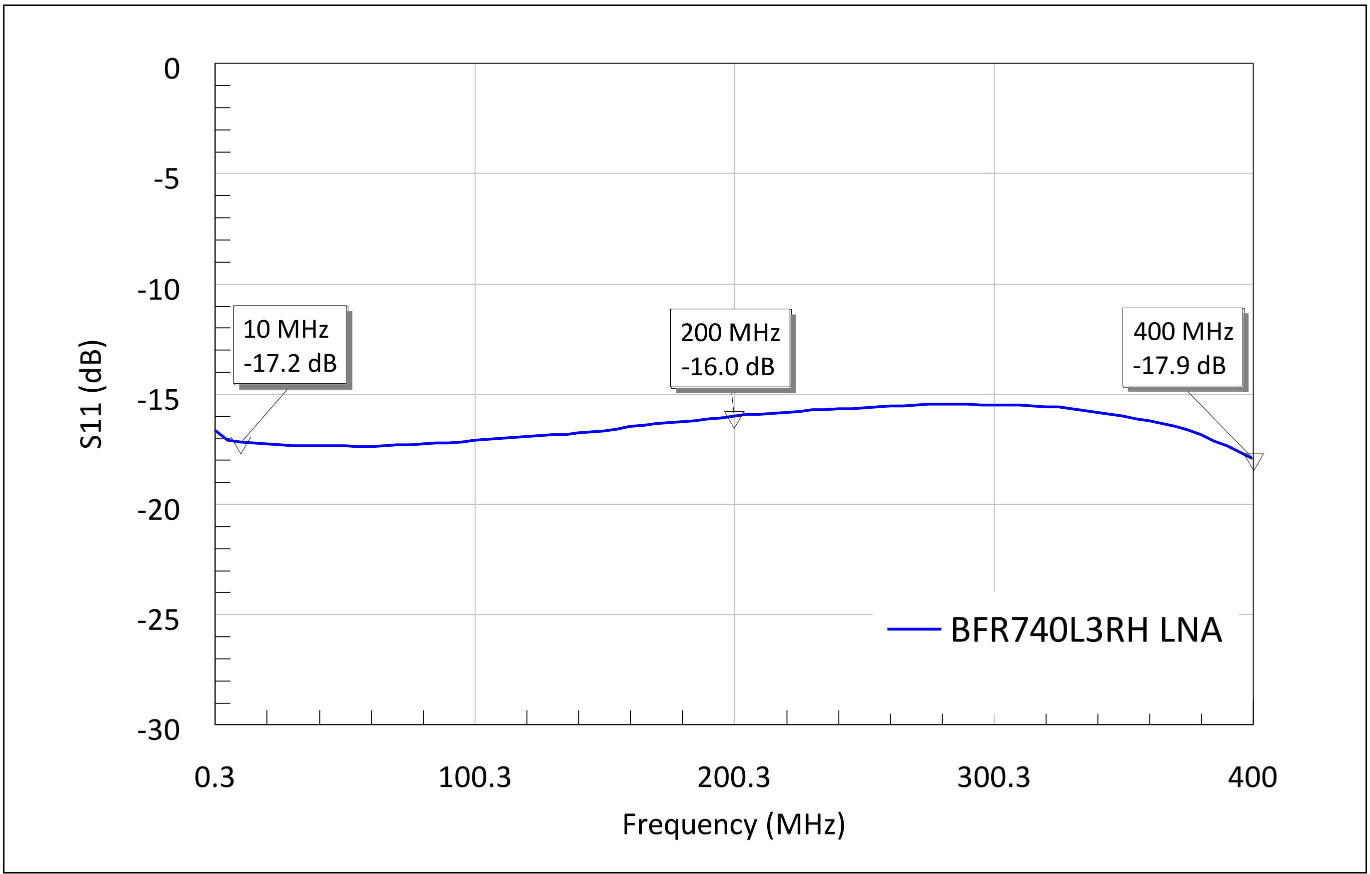

Figure 7 Input return loss of the LiDAR LNA with BFR740L3RH transistor

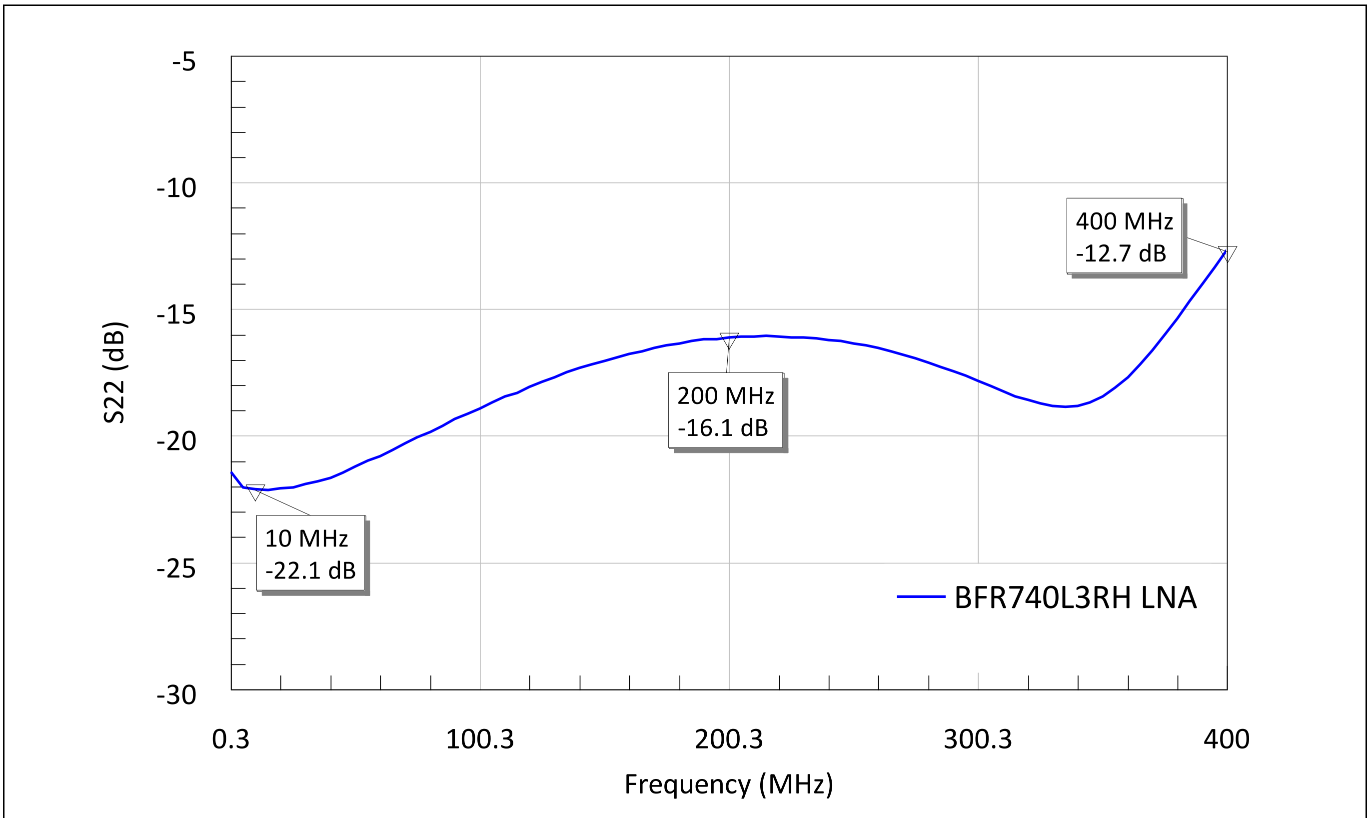

Figure 8 Output return loss of the LiDAR LNA with BFR740L3RH transistor

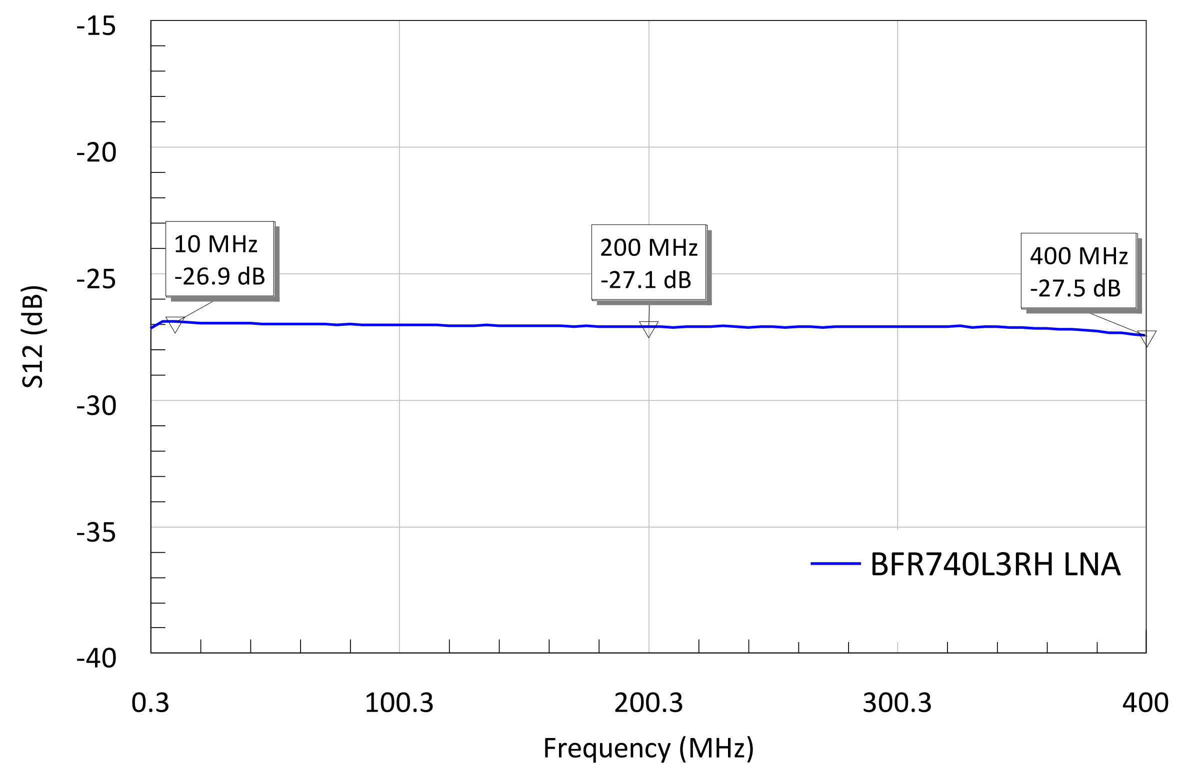

Figure 9 Reverse isolation of the LiDAR LNA with BFR740L3RH transistor

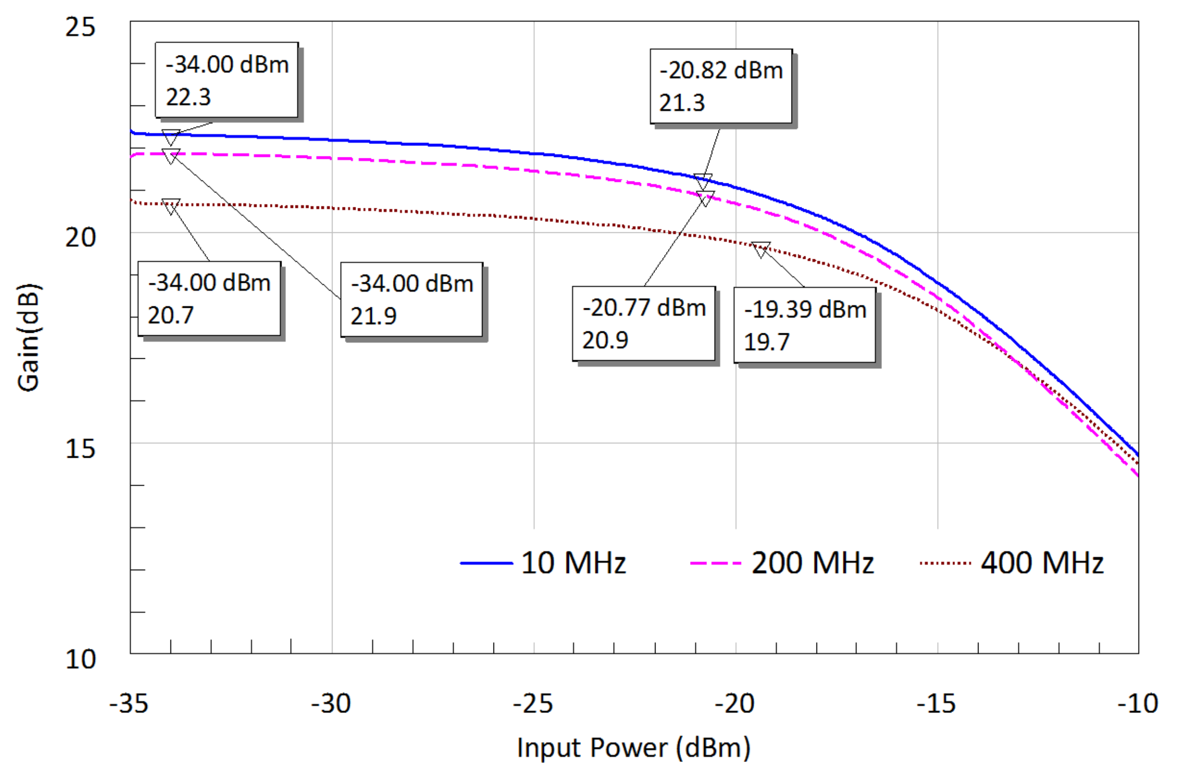

Figure 10 Input 1 dB compression point of the LiDAR LNA with BFR740L3RH transistor

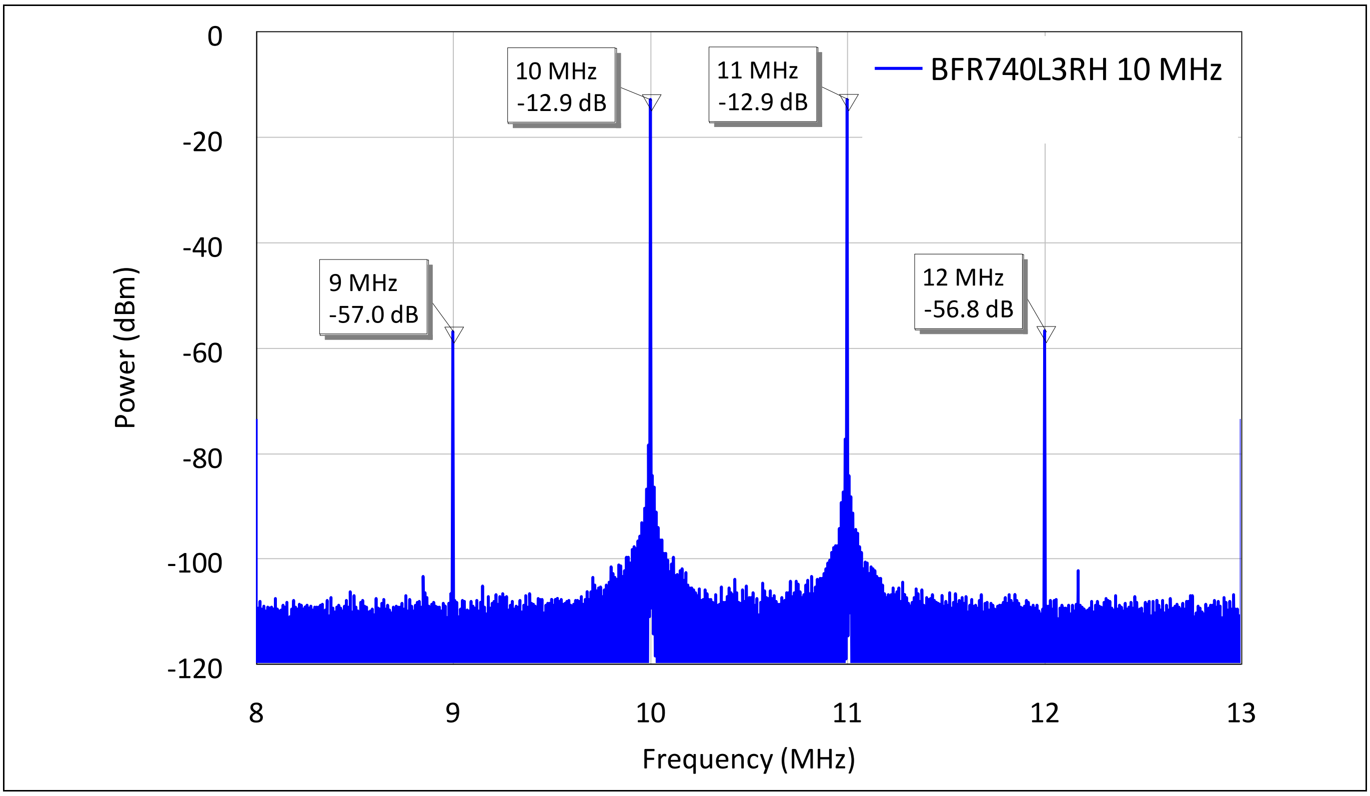

Figure 11 Output third-order intermodulation products of the LiDAR LNA with BFR740L3RH transistor at 10 MHz

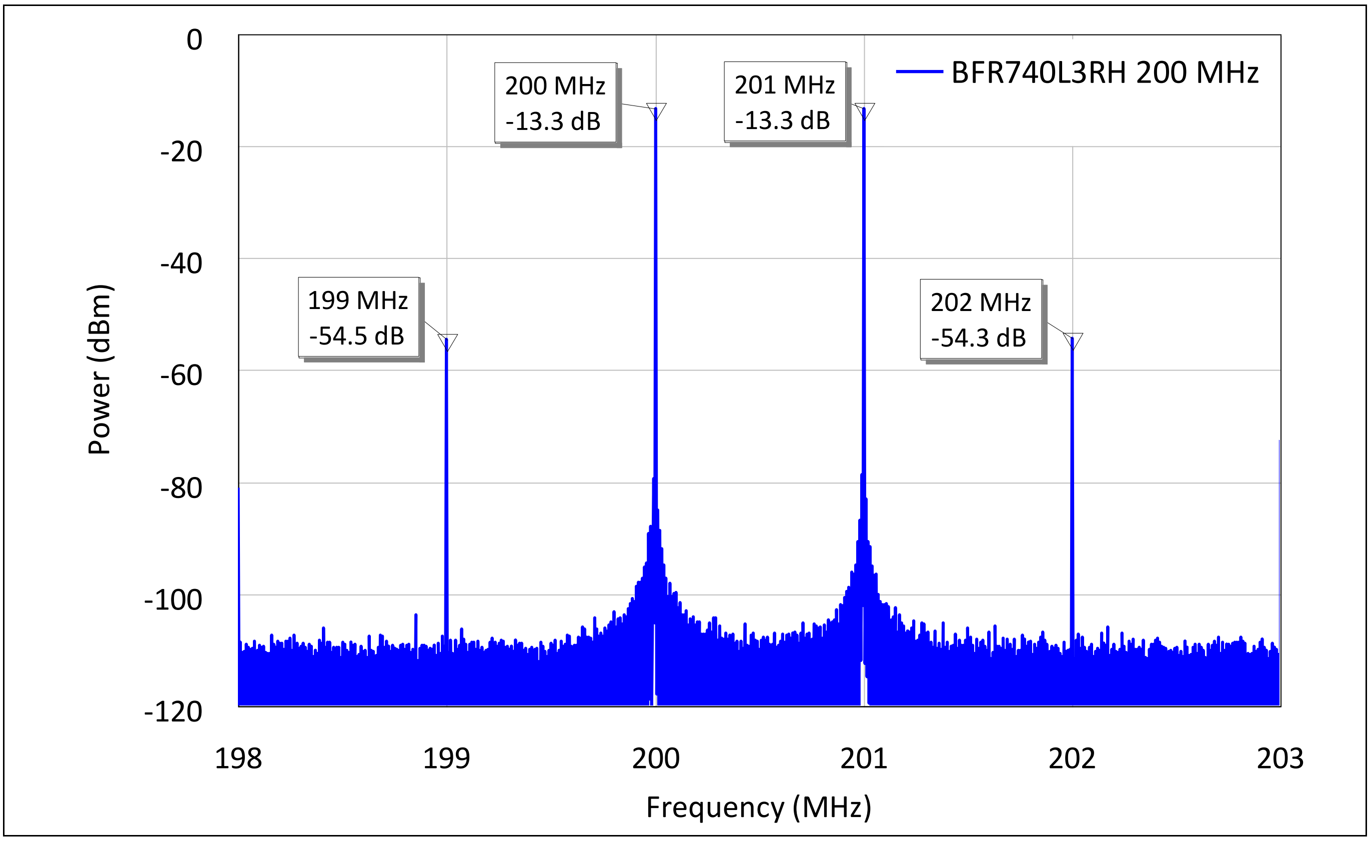

Figure 12 Output third-order intermodulation products of the LiDAR LNA with BFR740L3RH transistor at 200 MHz

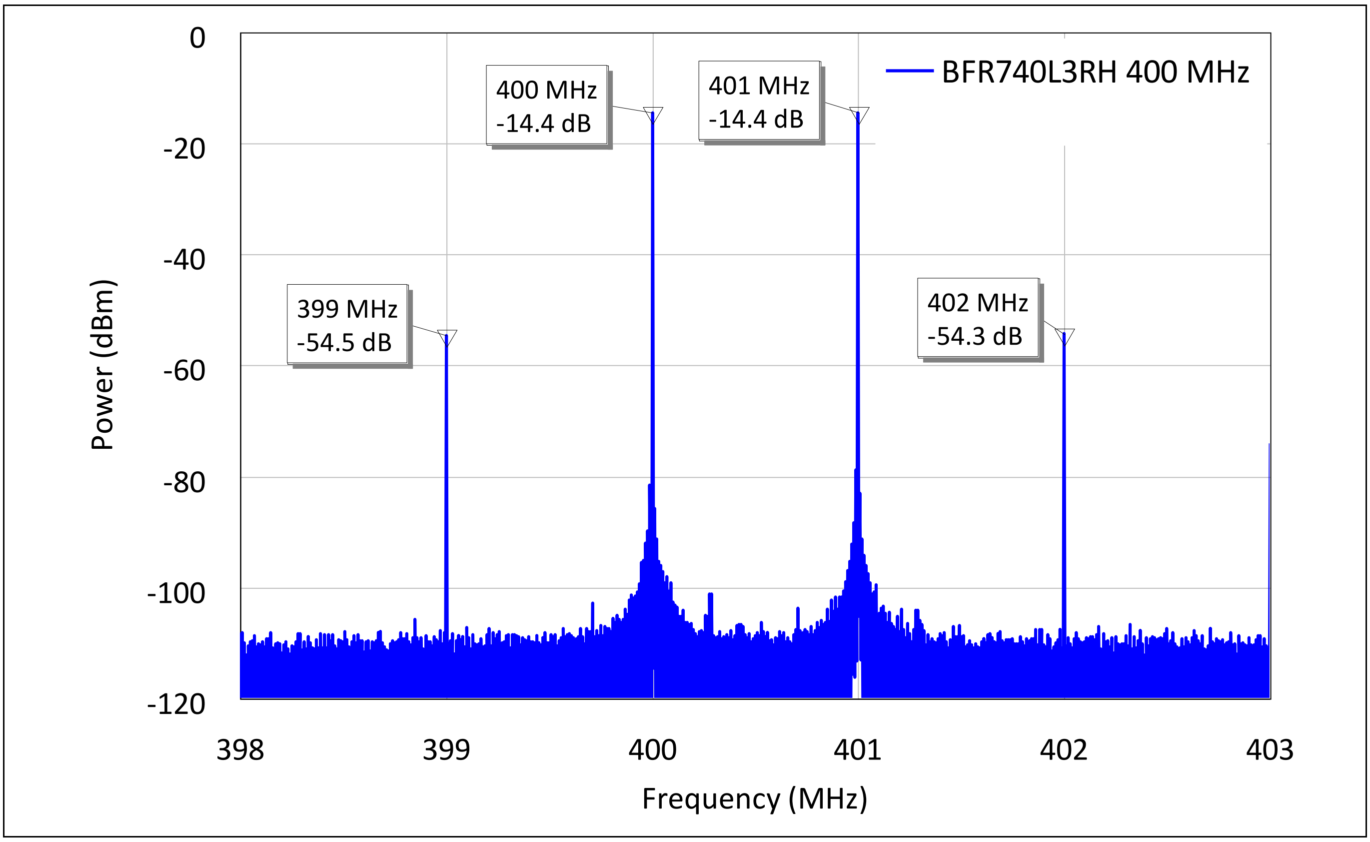

Figure 13 Output third-order intermodulation products of the LiDAR LNA with BFR740L3RH transistor at 400 MHz

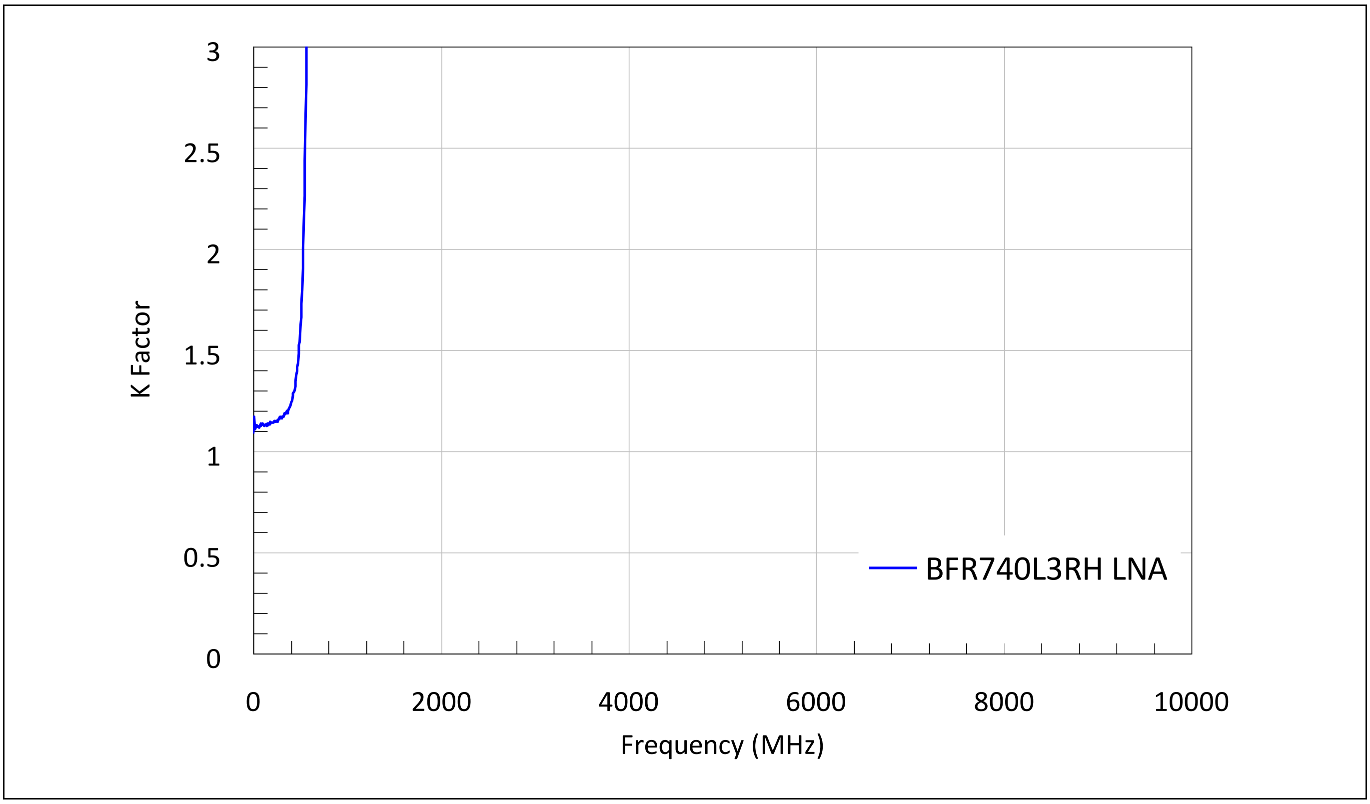

Figure 14 K-factor measurement of the LiDAR LNA with BFR740L3RH transistor

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Revision history

Document version	Date of release	Description of changes

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