Design guide for RF transistors and diode in low noise block (LNB)

RF bipolar transistors and diode

About this document

Scope and purpose

This application note provides application circuit design examples with Infineon's low-noise transistors and Schottky diode for LNBs in satellite TV receivers. In this document the transistor-based local oscillator (LO), low-noise intermediate frequency (IF) amplifier and Schottky diode based mixer schematics, PCB layouts and measurement results are shown. This document is relevant to the following low-noise transistors and diode:

- BFP520 — Low noise transistor for LNB LO and low noise amplifier (LNA)
- BFP420F — Low noise transistor for LNB LO and LNA
- BAT15-04W — Schottky diode for microwave signal detector and mixer

Intended audience

This document is intended for engineers who need to design LNBs for satellite receiver applications.

Table of contents

1 Introduction

1.1 Introduction of LNB in satellite TV receiver

Satellite TV is one of the most popular and cost-effective TV broadcasting methods to cover large territories. Some of the satellite TV channels are assigned to the microwave frequency band from 10.7 GHz to 12.75 GHz. As high-frequency TV signals from satellites do not easily pass through roofs and walls of houses, satellite TV antennas are required to be placed outdoors. Hence, the received TV signal from the antenna needs to be passed indoors via lossy cables. When the signals are sent through coaxial cables, the lower the signal frequency, and the less loss occurs in the cable. Therefore, the received high-frequency TV signals from the satellites are amplified and down-converted to a low-frequency IF signal by the LNB working as a super-heterodyne receiver. For this purpose, the LNB is one necessary component, which is directly fixed on the satellite dish antenna.

The LNB is a combination of LNAs, frequency mixers, LOs and IF amplifiers. Figure 1 shows one LNB block diagram example. The abbreviation H (horizontal) and V (vertical) represents the electrical polarization of the electromagnetic wave. At first, the received linear polarized wave is amplified through a multi-stage LNA chain, and afterward it is down-converted to the IF signal by mixing with the signal generated in the LO. Then, the IF signal is further amplified to compensate for the followed coaxial cable loss. The frequencies of the signals from the satellite, LO and IF in a universal LNB are shown in Table 1.

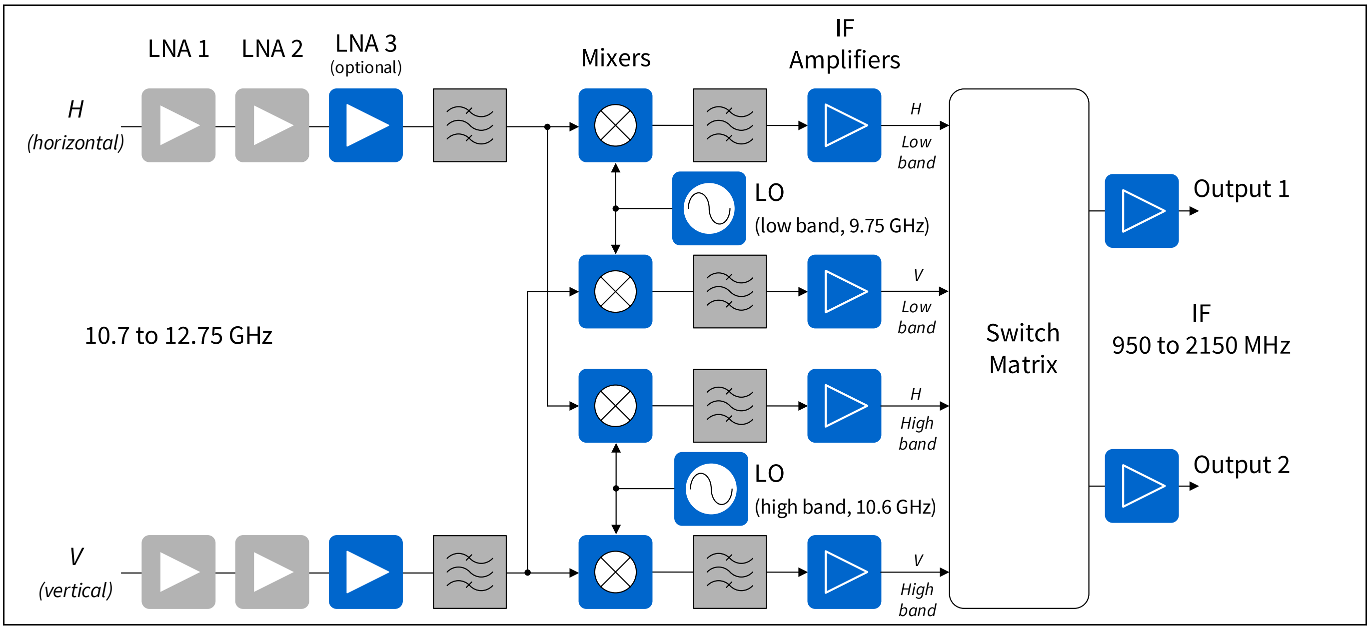


Figure 1 A universal LNB block diagram example

Table 1 Frequency relations in a universal LNB

	Low band	High band	Switching mode
Satellite signal	10.7 to 11.9 GHz	11.55 to 12.75 GHz	Switching between the low-band and high-band LO is achieved by a 22 kHz tone generated by the receiver when selecting a specific channel. Switching between horizontal and vertical polarization is done by the voltage of the power supply when selecting a specific channel.
LO frequency	9.75 GHz	10.6 GHz	
IF frequency	950 to 2150 MHz		

1.2 Infineon’s discrete RF component family

Infineon Technologies provides high-performance, high-frequency transistors targeting LNB applications. Infineon’s reliable high-volume radio frequency (RF) transistors offer exceptionally low noise figure (NF), high gain and high linearity at low power consumption levels for RF applications. The fourth- and fifth-generation transistors are based on robust silicon bipolar technology, which leads to best-in-class phase noise for oscillator applications at high frequencies.

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

2 LNB LO with BFP520

RF and microwave oscillators represent the basic high-frequency signal energy source for all radio systems such as radar, communication equipment, and satellite TV. The emphasis has been on low noise, high output-power, small size, low cost, high reliability, and high-temperature stability.

One of the key oscillator parameters is the purity of the signal produced. While the harmonics can be filtered out by a simple low-pass filter, the spurious level close to the wanted signal can only be minimized by a careful oscillator design. To design an oscillator with low phase noise, usually, a resonant circuit with a high Q-factor and an active component with low phase noise are required. The active component can be an RF transistor with the following optimized parameters:

- The lowest possible transistor transition frequency f_T ($f_T \geq 2 \times f_{oscillation}$).
- The lowest current density in the transistor.

Usually, the transistors with high $I_{C, max}$ used at low currents have the best phase noise performance. However, the f_T of a transistor drops as current decreases. Additionally, the parasitic capacitances of a high current transistor are higher due to the larger transistor structure required, which further decreases the transistor's f_T. The BFP520 is one of the low-noise transistors with f_T of 45 GHz and $I_{C, max}$ of 50 mA, which is suitable for the application of the LO in the LNB.

2.1 Performance overview

The following table shows the performance of the LNB LO with RF low-noise bipolar transistor BFP520.

Table 2 Summary of measurement results for the LNB LO with BFP520

Parameter	Symbol	Value	Unit	Notes
Device		BFP520		
Bias voltage	V_{CC}	5.0	V	
Bias current	I_{CC}	23.5	mA	
Collector-emitter voltage	V_{CE}	2.2	V	
Oscillation frequency	$f_{oscillation}$	10.6	GHz	
Frequency stability over temperature	Δf	3.1	MHz	From -20°C to 85°C
Single side-band (SSB) phase noise	$L(f)_{SSB}$	-66.5	dBc/Hz	At offset: 1 kHz
		-97.1		At offset: 10 kHz
		-121.5		At offset: 100 kHz
		-142.9		At offset: 1 MHz
Output power	P_{OUT}	1.5	dBm	

2.2 Schematic

One way to generate a stable output signal is to use a feedback mechanism in the oscillator design. The gain in the feedback loop must be greater than 1 and the phase along the loop in small-signal operation (i.e., at the first moment that the operating voltage is activated) must be an integral multiple of 2π. The initial oscillation builds up from the power supply turn-on transient or the noise present in the active device. As the oscillation amplitude grows, the active device in the circuit behaves non-linearly due to the change in the transconductance from a small signal to the large signal of the amplifier. This non-linear behavior limits the growth of the signal, and a steady-state condition is reached.

The feedback loop can be built up by coupling a high Q-factor dielectric resonator to two microstrip lines as shown in Figure 2. The cylindrical dielectric resonator reflects the electromagnetic waves at the boundary layer between the dielectric and the air within the component, producing an energy concentration at the selected frequency both inside the resonator and in its immediate proximity. The diameter of dielectric resonator defines its resonant frequency and should be carefully selected so that the oscillations are initiated at approximately 200 MHz lower than the oscillator circuit output frequency without a tuning screw or cover. It should be noted that various manufacturers define the resonant frequency of the resonator with the aid of a spacer configuration (a ceramic cylinder on which the dielectric resonator is mounted), and the specified frequency of the dielectric resonator differs from that obtained when the dielectric resonator is coupled to the microstrip lines.

In the oscillator circuit, the dielectric resonator feedback loop connects just in front of the transistor's base and collector. The resistor R1 stands for transistor base bias, while R2 serves as the DC negative feedback to stabilize the transistor's biasing point. The capacitor C1 works as DC blocking. It is important that the feedback from the transistor base to the V_{CC} pad and the collector port is minimized by filtering. Capacitors C2, C3, C4, C5 and C6 serve as both the filtering and the RF bypass.

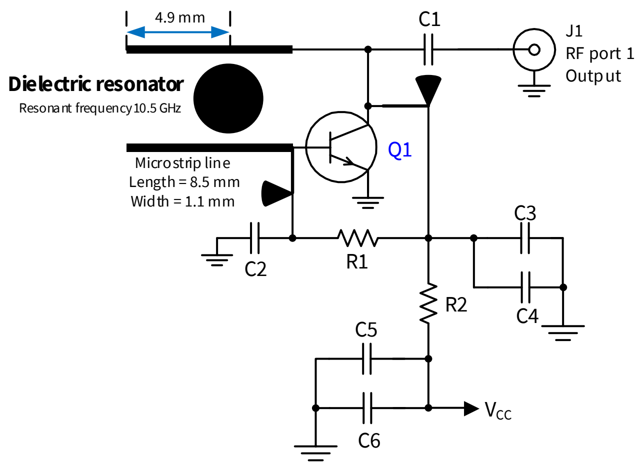


Figure 2 Schematic of the LNB LO with BFP520

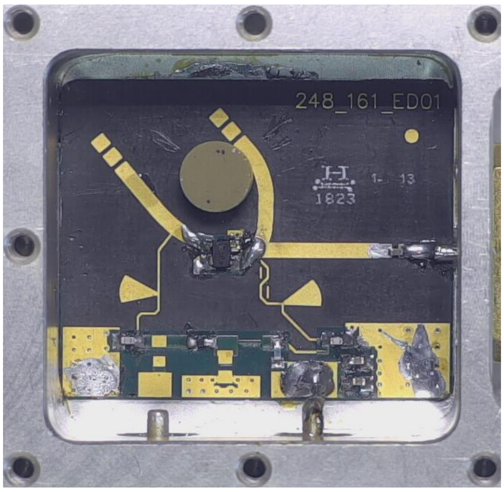
2.3 Bill of materials (BOM)

Table 3 BOM of the LNB LO with BFP520

Symbol	Value	Unit	Package	Manufacturer	Comment
Q1	BFP520		SOT343	Infineon	Low-noise transistor
C1	10	nF	0402	ATC520L series	DC block
C2	1	pF	0402	Various	RF decoupling
C3	1	pF	0402	Various	RF decoupling
C4	1	nF	0402	Various	RF decoupling
C5	100	pF	0402	Various	RF decoupling
C6	10	nF	0402	Various	RF decoupling
R1	5.6	kΩ	0402	Various	DC bias
R2	120	Ω	0402	Various	DC bias
Dielectric resonator	DRT-10.5	–	–	–	High Q-factor feedback

2.4 Evaluation board and layout information

Images of the evaluation board including the detailed dimensions and the PCB stack information are shown in the following figures.



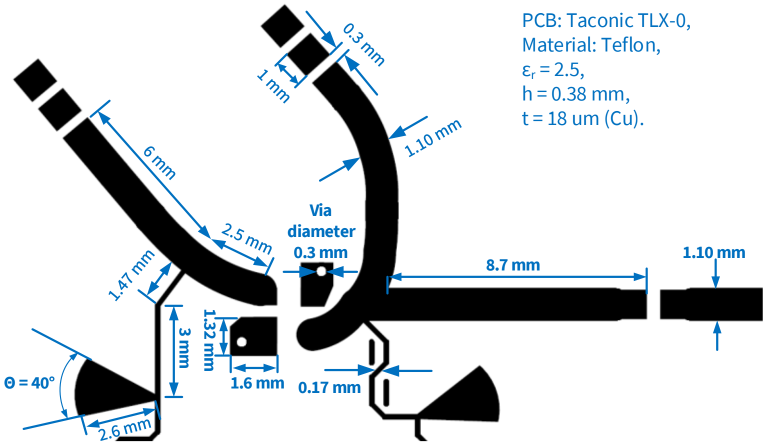


Figure 3 Photo of the LNB LO evaluation board with BFP520 (left) and detail of PCB layout dimension (right)

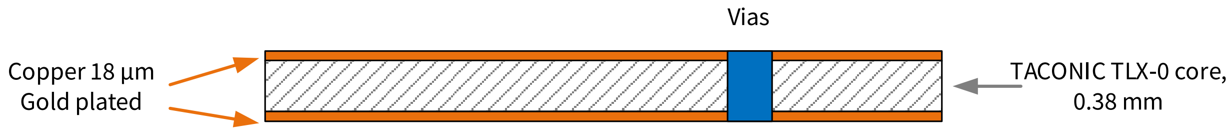


Figure 4 The PCB stack information for the LNB LO evaluation board with BFP520

2.5 Measurement graphs

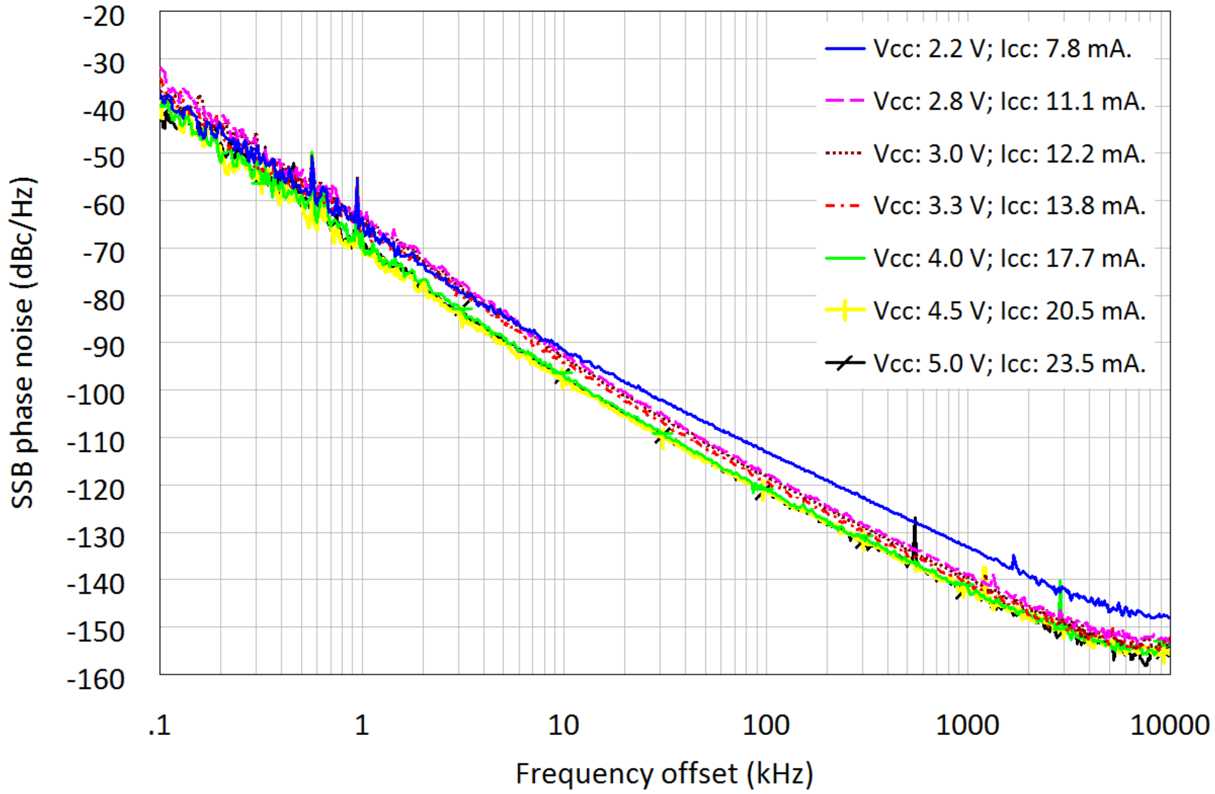


Figure 5 The SSB phase noise spectrum from the BFP520 LNB LO with different bias voltage and current

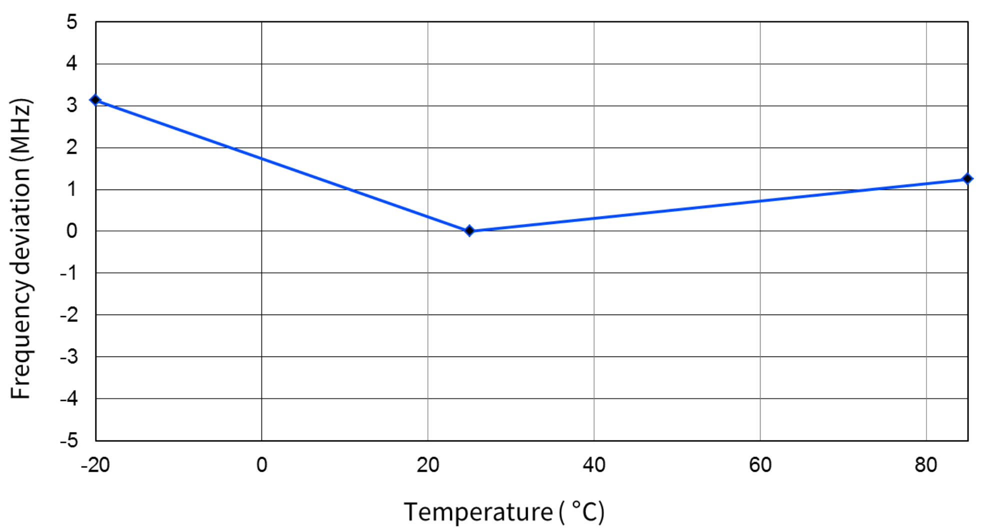


Figure 6 The measurement of the BFP520 LNB LO frequency deviation over temperature

3 LNB mixer with Schottky diode BAT15-04W

Mixers are one of the most necessary circuit elements in radio systems like LNBs for the needs of moving a band of the signal from one center frequency to another. A mixer is a three-port device that has two inputs (RF and LO) and one output port (IF). Most simply, it creates output that has the frequency that is either the sum of or the difference between the two input signals.

A Schottky diode is one of the popular options for the non-linear device selection for mixers. It provides a low-cost option for mixer configuration. With the help of the non-linear characteristics, it can create new signals at the combinations of the sum and difference from the two original input signals. The device characteristic of the Schottky diode is similar to a typical PN diode and follows 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 belong to a minority of semiconductor devices suffering from the low recombination velocity of the minority carriers in the space charge region, whereas the Schottky diodes are controlled by the charge transport over the barrier from the majority carriers. This control mechanism leads to the very fast switching action of the Schottky diodes and makes them very attractive for application in the millimeter-wave-range-like mixers.

3.1 Performance overview

The following table summarizes the performance of the LNB mixer with series configured Schottky diodes BAT15-04W.

Table 4 Summary of measurement results of the LNB mixer with BAT15-04W

Parameter	Symbol	Value	Unit	Notes
Conversion loss	CL	10.7	dB	IF frequency = 1.1 GHz LO frequency = 10.6 GHz at 7 dBm RF frequency = 11.7 GHz at -30 dBm
		10		IF frequency = 1.5 GHz LO frequency = 10.6 GHz at 7 dBm RF frequency = 12.1 GHz at -30 dBm
		8.5		IF frequency = 2 GHz LO frequency = 10.6 GHz at 7 dBm RF frequency = 12.6 GHz at -30 dBm
LO to RF isolation	ISO_{LO-RF}	6.3[1)] 13.3[2)] 15.1[3)]	dB	1) Measured at 10.6 GHz, LO at 7dBm 2) Measured at 11.7 GHz, LO at 7dBm 3) Measured at 12.6 GHz, LO at 7dBm
LO to IF isolation	ISO_{LO-IF}	24.4[1)] 33.6[2)] 41.9[3)]	dB	
RF to IF isolation	ISO_{RF-IF}	26.9[1)] 34.8[2)] 41.4[3)]	dB	

3.2 Schematic

The schematic of the single balanced mixer is shown in the following figure. The first element in the mixer is the branch line coupler for feeding the RF and LO signals into the mixer with required isolation from each other. The amplified RF signal and the LO signal are applied at the sum port and the delta port of the coupler, respectively. The 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 to the IF output port. Additionally, a radial open stub suppresses the RF and LO signal at the IF output.

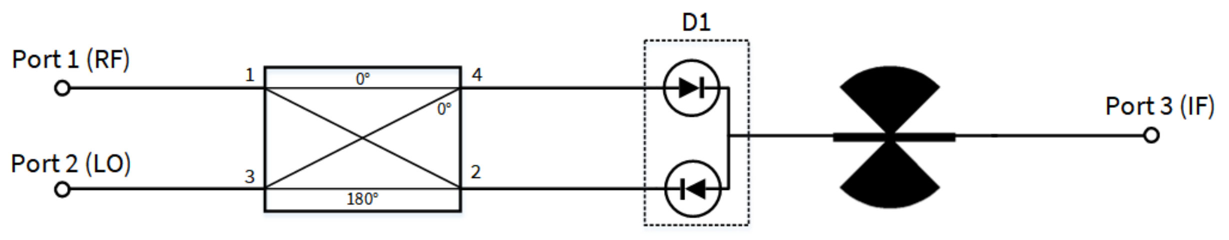


Figure 7 Schematic of the LNB mixer with BAT15-04W

3.3 Evaluation board and layout information

Images of the evaluation board and the PCB stack information of the LNB mixer with BAT15-04W are shown in the following figures.

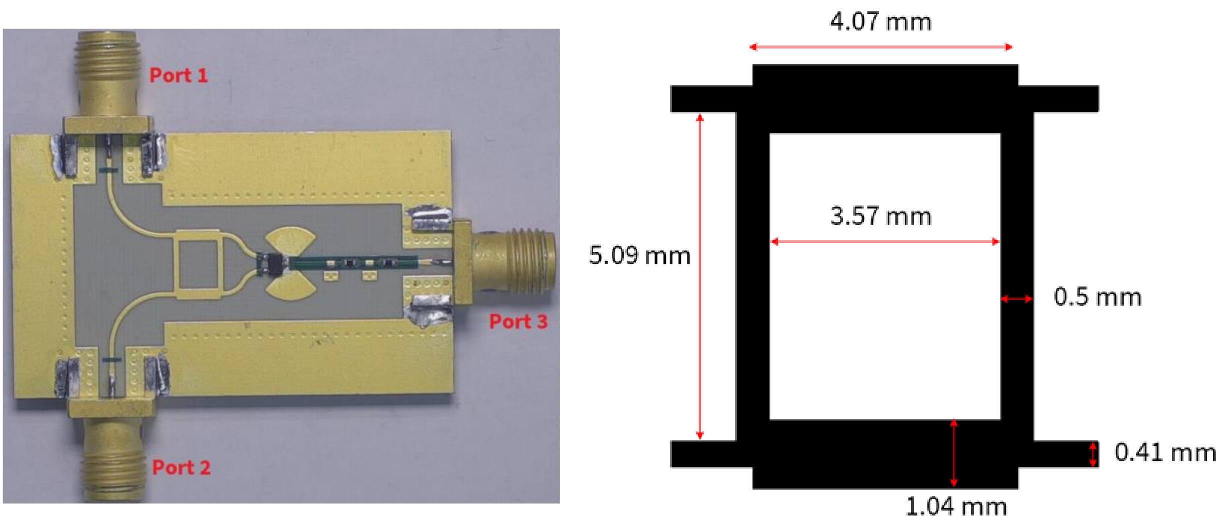


Figure 8 Photo of the LNB mixer with BAT15-04W (left) and branch line coupler dimensions (right)

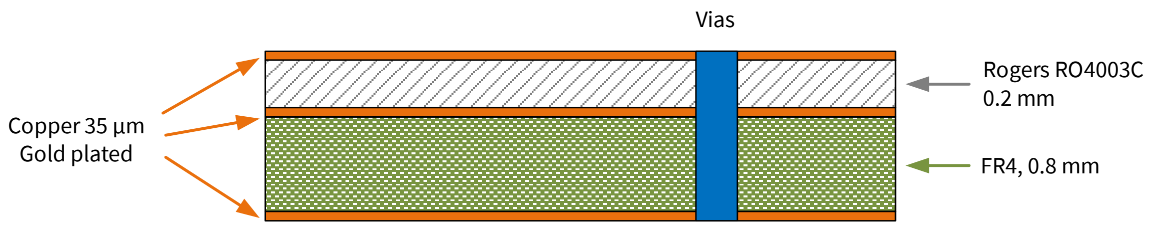


Figure 9 PCB stack information for the LNB mixer evaluation board

3.4 Measurement graphs

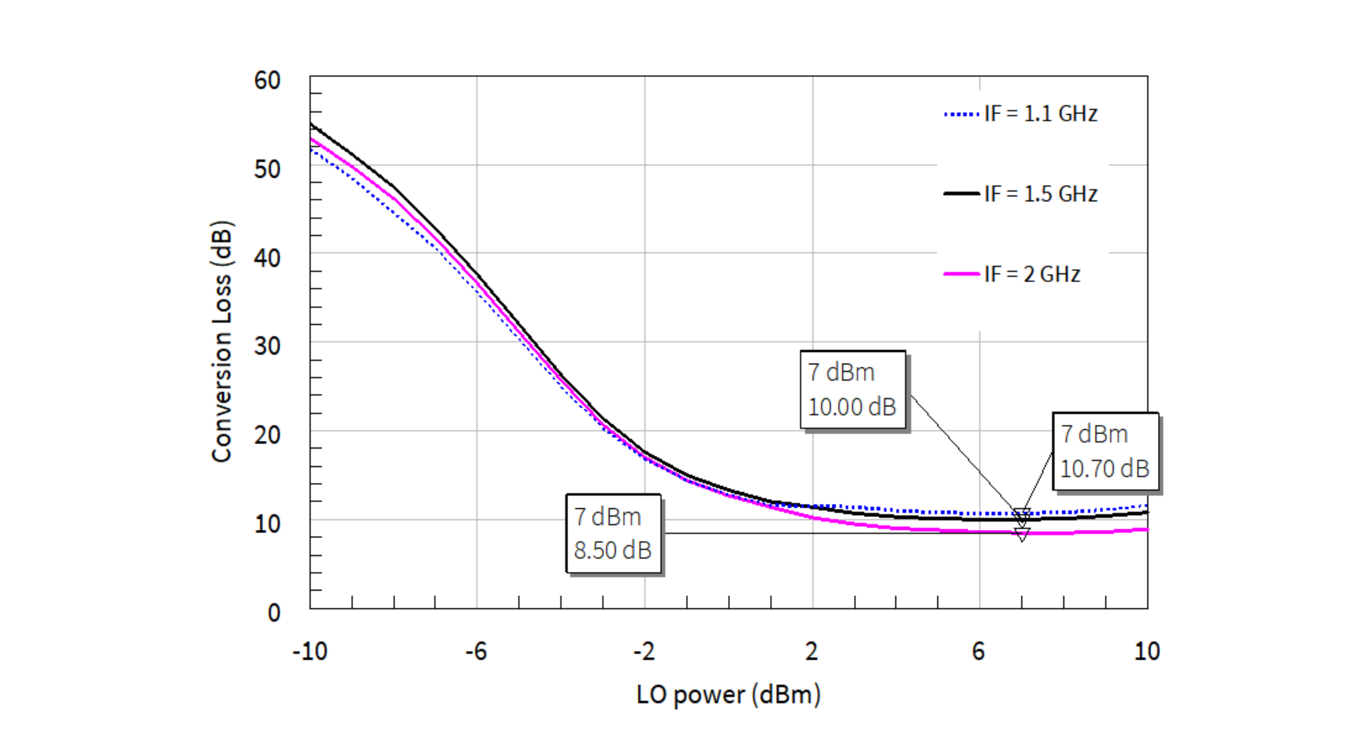


Figure 10 Measured conversion loss of the LNB mixer with BAT15-04W

4 LNB IF amplifier with BFP420F

4.1 Performance overview

The following table shows the performance of the LNB IF amplifier with BFP420F.

Table 5 Summary of measurement results of the LNB IF amplifier with BFP420F

Parameter	Symbol	Value			Unit	Notes
Device		BFP420F				
Bias voltage	V_{CC}	5.0			V	
Bias current	I_{CC}	26.9			mA	
Frequency	f	950	1450	2150	MHz	
Gain	G	21.1	18.1	14.7	dB	
NF	NF	2.1	2.2	2.3	dB	
Input return loss	RL_{in}	9.7	11.7	15.3	dB	
Output return loss	RL_{out}	24.2	14.4	10.4	dB	
Reverse isolation	ISO_{rev}	26.7	24.5	22.0	dB	
Output 1 dB compression point	OP_{1dB}	–	11.5	–	dBm	Measured at 1450 MHz
Output third-order intercept point	OIP_3	–	23.6	–	dBm	Power at input: -20 dBm per tone f_1 = 1450 MHz, f_2 = 1451 MHz
Stability	K	>1				From 10 MHz to 10 GHz

4.2 Schematic

The following figure shows the schematic of the LNB IF amplifier with BFP420F. In the schematic, resistors R2 and R3 stand for transistor voltage and current bias and form a negative DC feedback mechanism to stabilize the transistor bias points in various conditions. The resistor R1 and the capacitor C2 serve as the negative feedback to improve the input and output impedance matching. The capacitor C3 serves as the RF bypass. The transistor input matching is achieved by C1. The output matching network is formed by the inductor L1 and the capacitor C4.

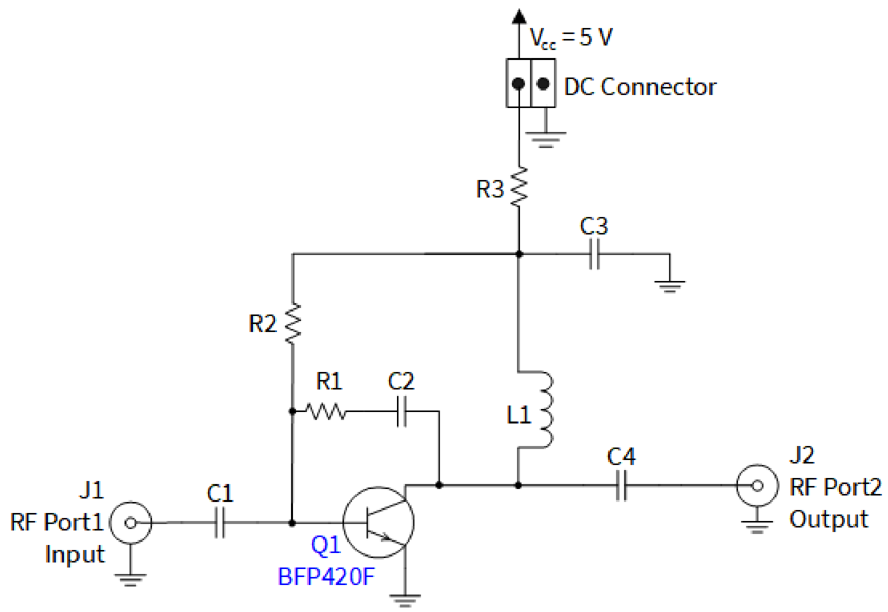


Figure 11 Schematic of the LNB IF amplifier with BFP420F

4.3 BOM

Table 6 BOM of the LNB IF amplifier with BFP420F

Symbol	Value	Unit	Package	Manufacturer	Comment
Q1	BFP420F		TSFP-4-1	Infineon	Low noise transistor
C1	100	pF	0402	Various	Input matching and DC block
C2	33	pF	0402	Various	DC block for RF feedback path
C3	220	nF	0402	Various	RF decoupling
C4	10	pF	0402	Various	Output matching and DC blocking
R1	1	kΩ	0402	Various	RF feedback
R2	6.2	kΩ	0402	Various	Base bias
R3	75	Ω	0402	Various	DC bias
L1	18	nH	0402	Murata LQG series	Output matching and RF choke

4.4 Evaluation board and layout information

The evaluation board for the LNB IF amplifier with BFP420F:

- PCB material: FR4
- PCB marking: M101022

Images of the evaluation board for the LNB IF amplifier with BFP420F and the detailed description of the PCB stack are shown in the following figures.

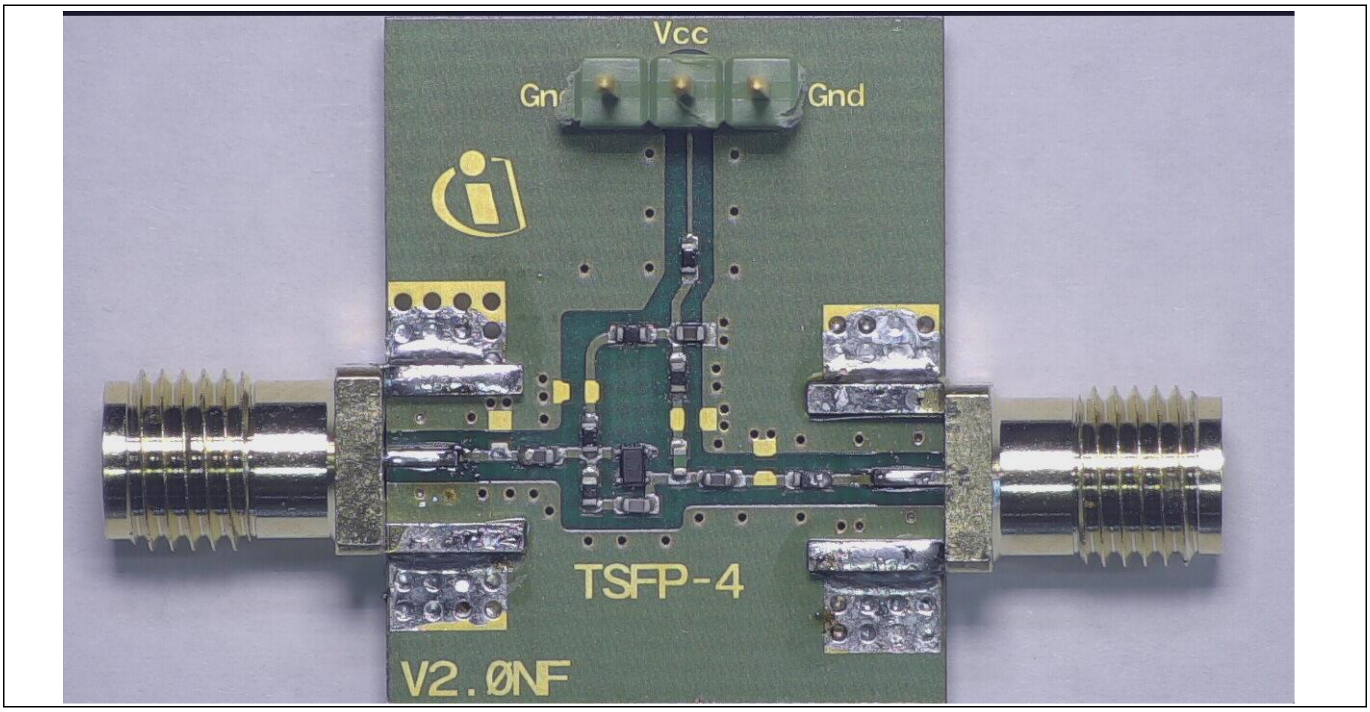


Figure 12 Photo of the LNB IF amplifier evaluation board with BFP420F

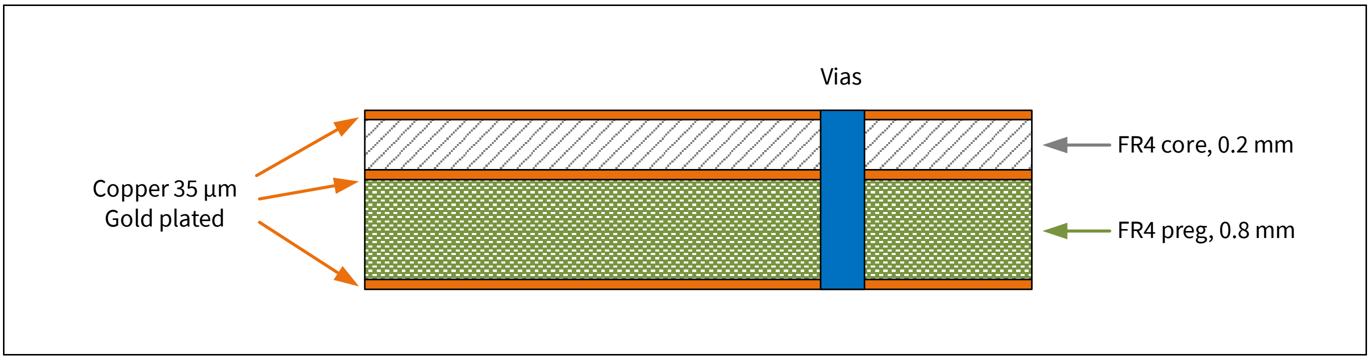


Figure 13 The PCB stack information for the evaluation board with PCB marking M101022

4.5 Measurement graphs

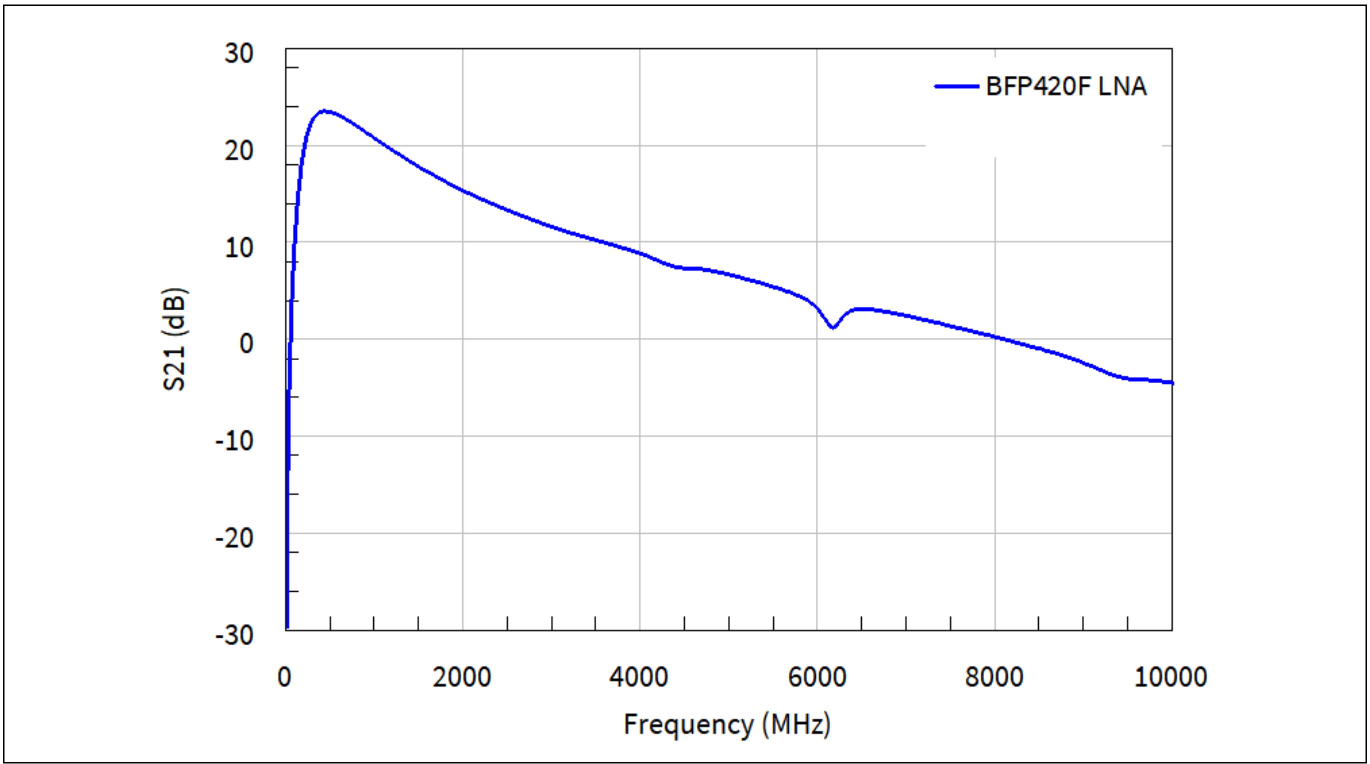


Figure 14 Small-signal gain of the LNB IF amplifier with BFP420F

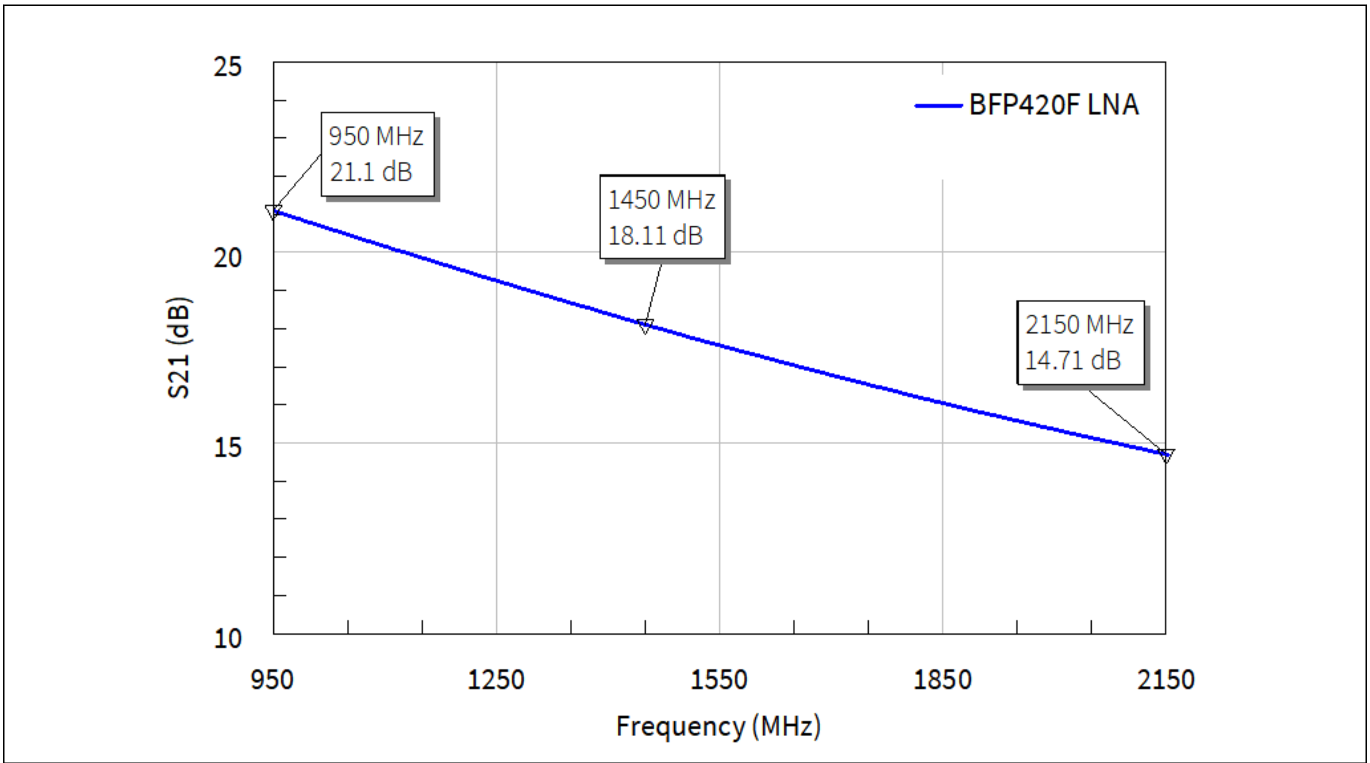


Figure 15 Small-signal gain of the LNB IF amplifier with BFP420F (detail view)

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

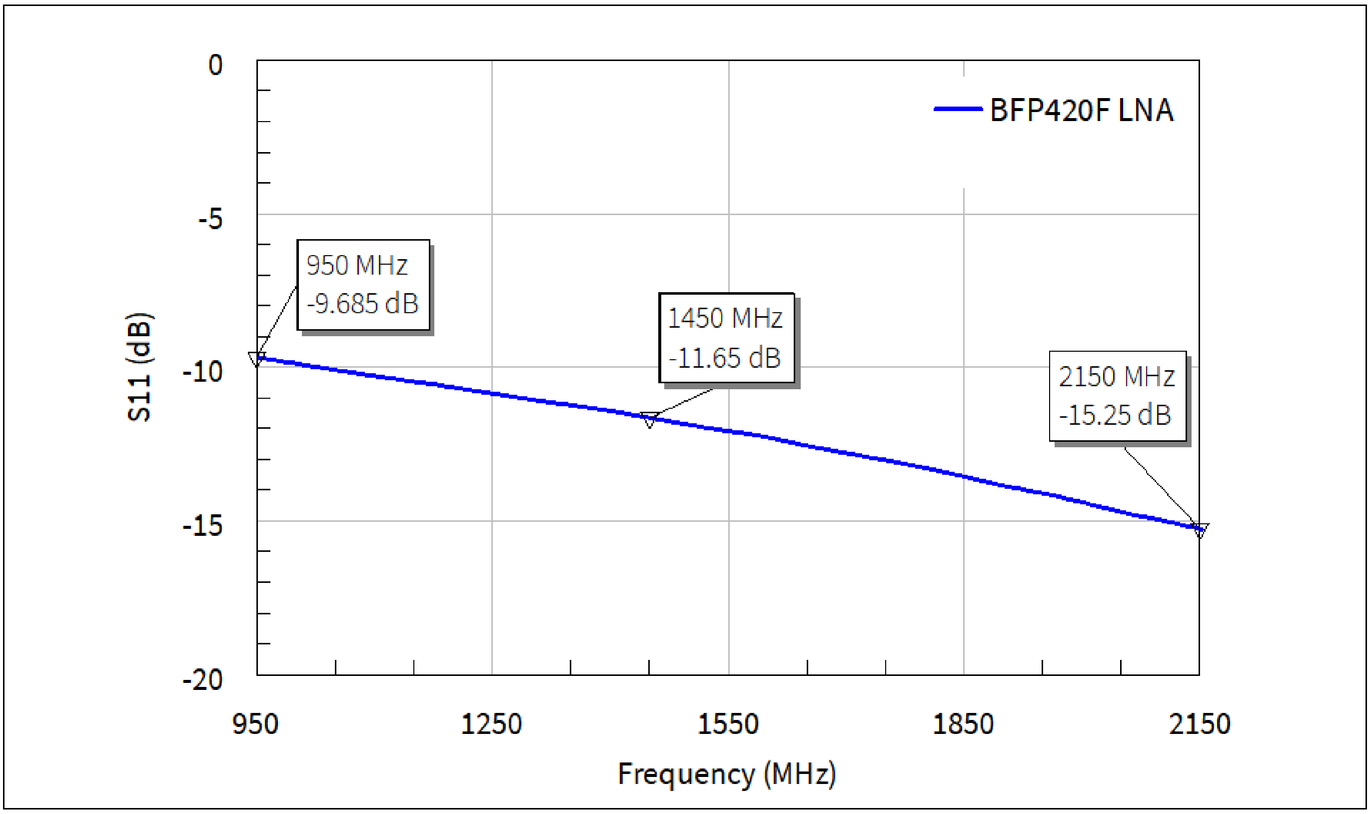


Figure 16 Input return loss measurement of the LNB IF amplifier with BFP420F

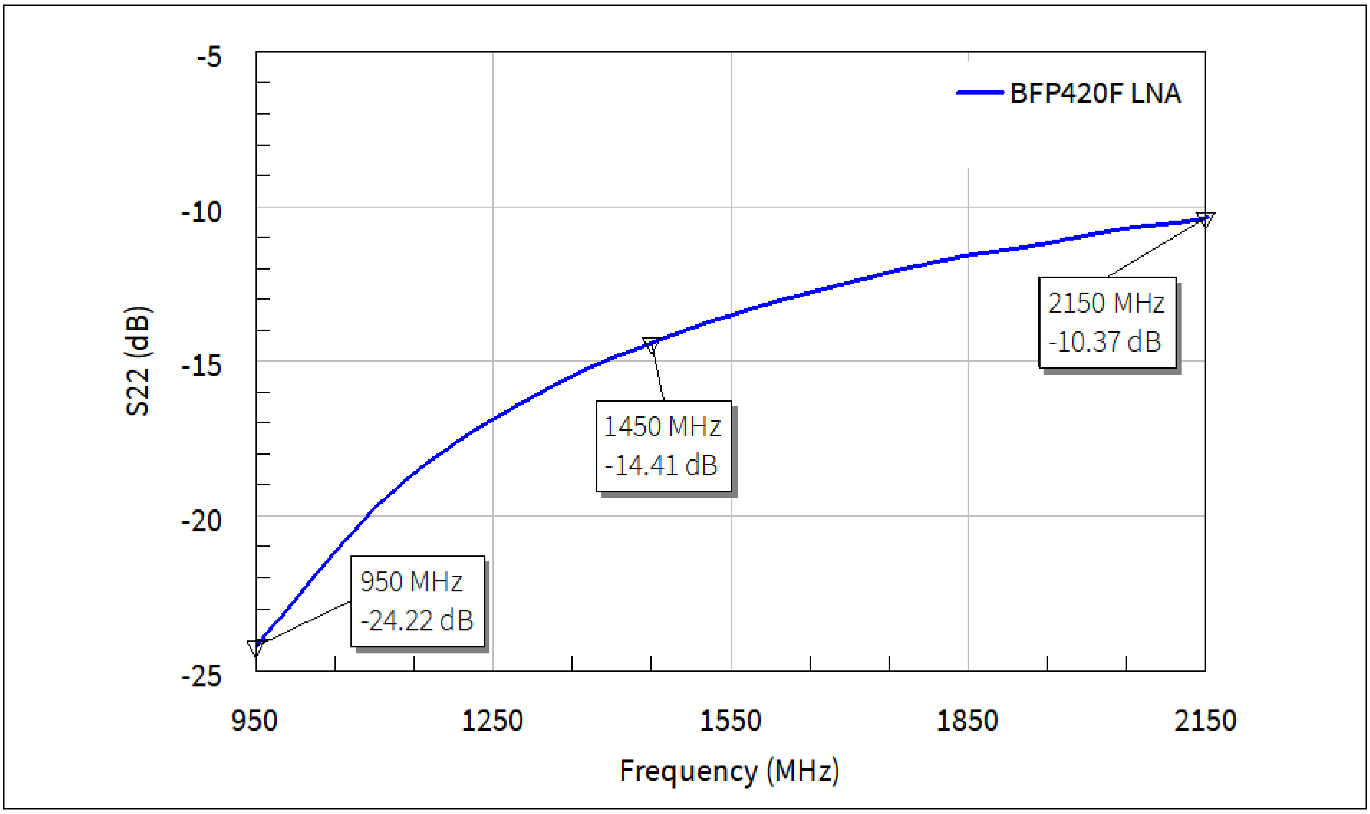


Figure 17 Output return loss measurement of the LNB IF amplifier with BFP420F

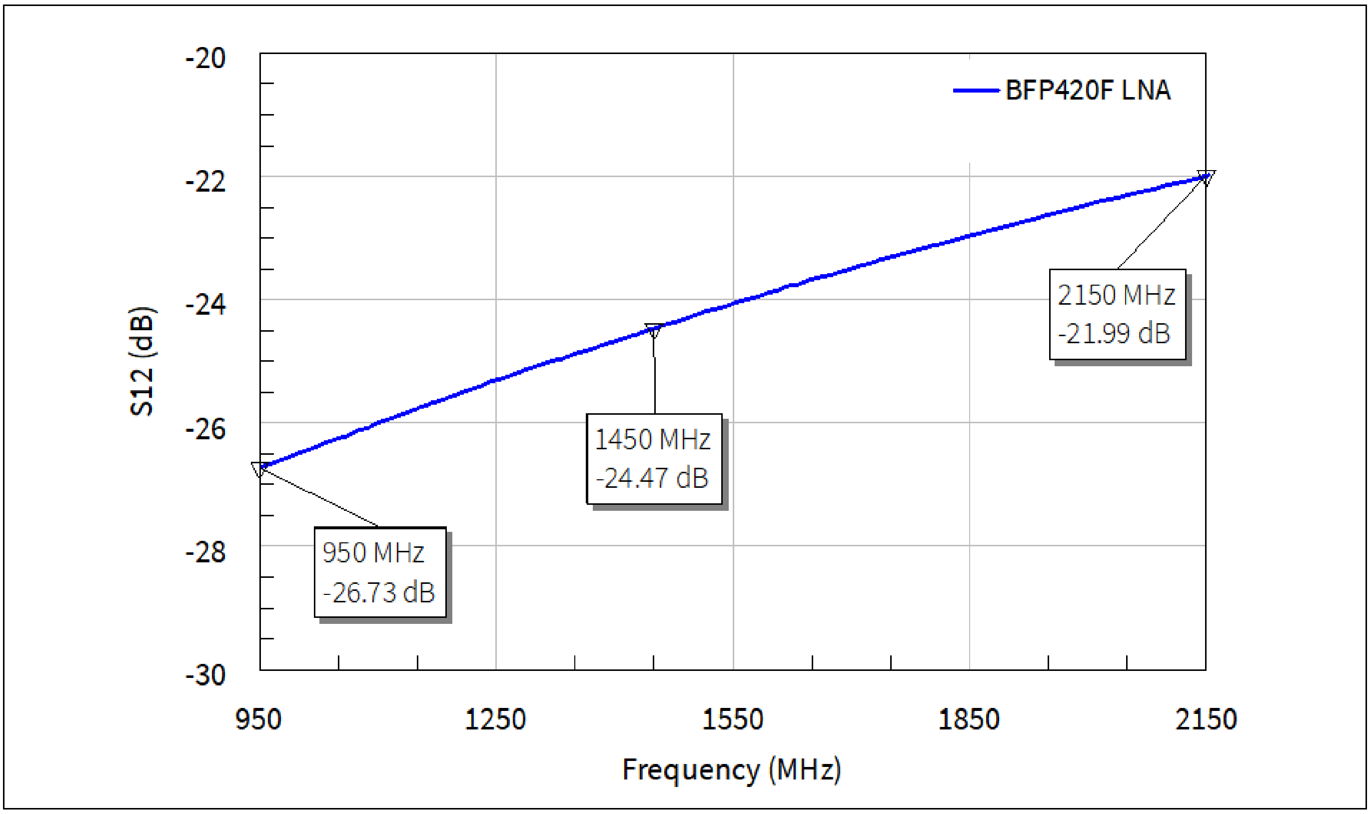


Figure 18 Reverse isolation measurement of the LNB IF amplifier with BFP420F

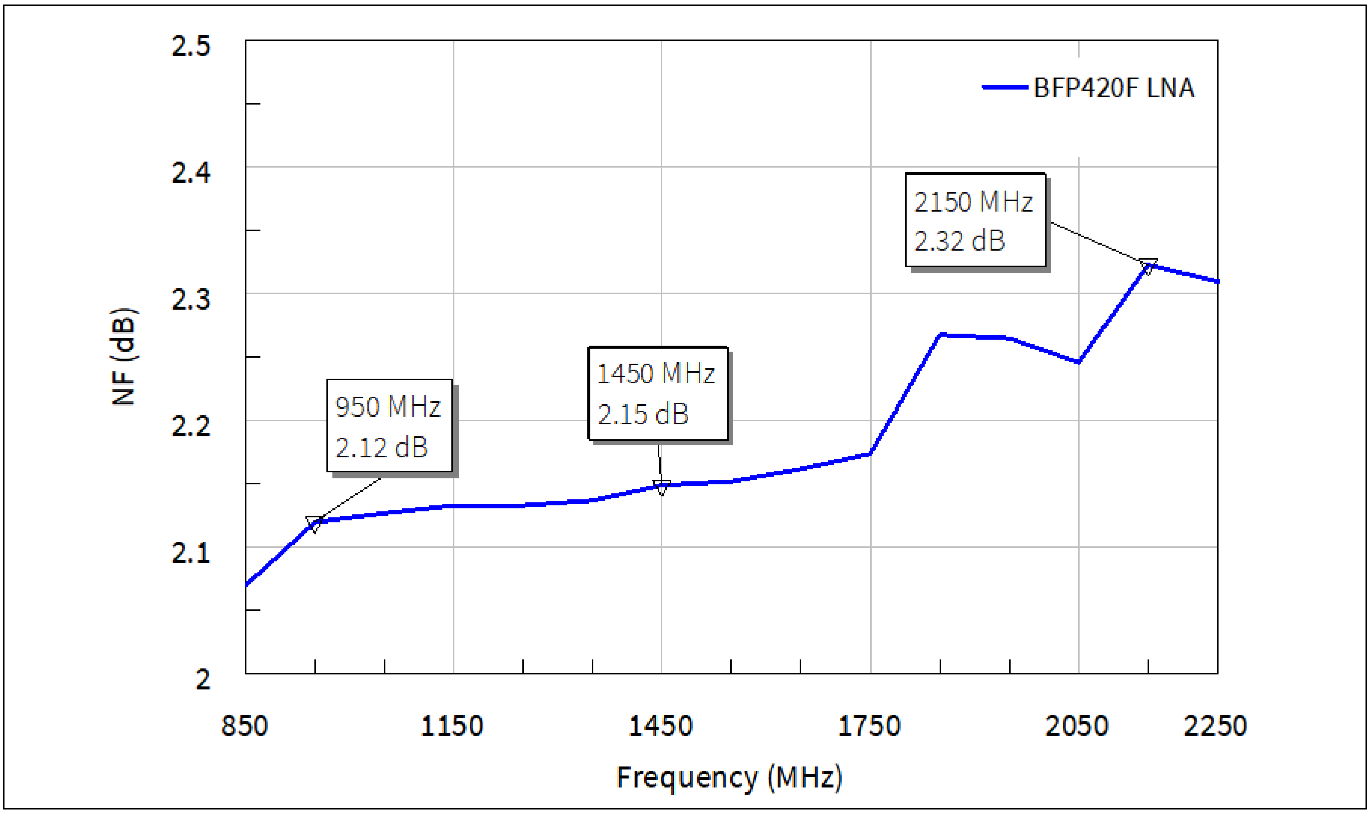


Figure 19 NF measurement of the LNB IF amplifier with BFP420F

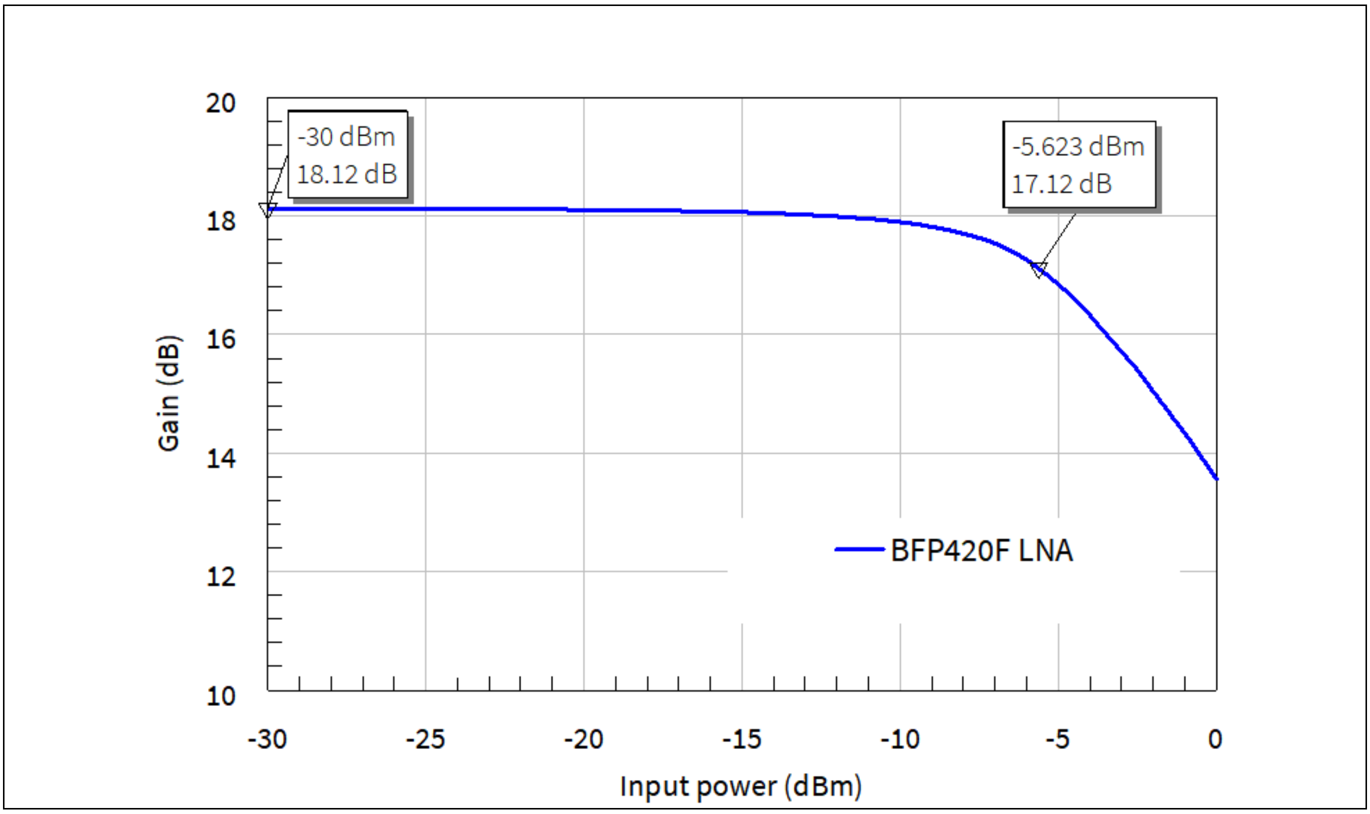


Figure 20 Input 1 dB compression point measurement of the LNB IF amplifier with BFP420F

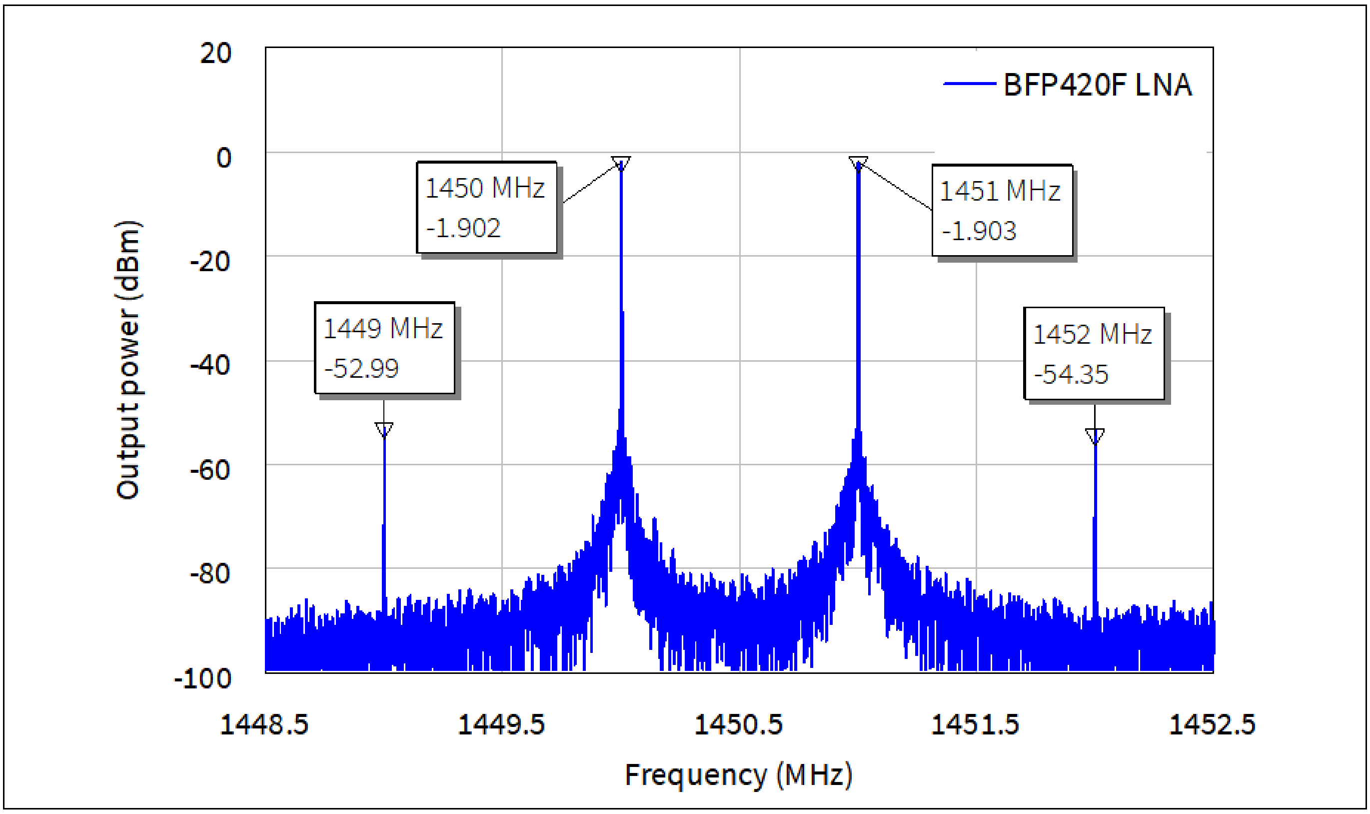


Figure 21 Output third-order intermodulation products of the LNB IF amplifier with BFP420F

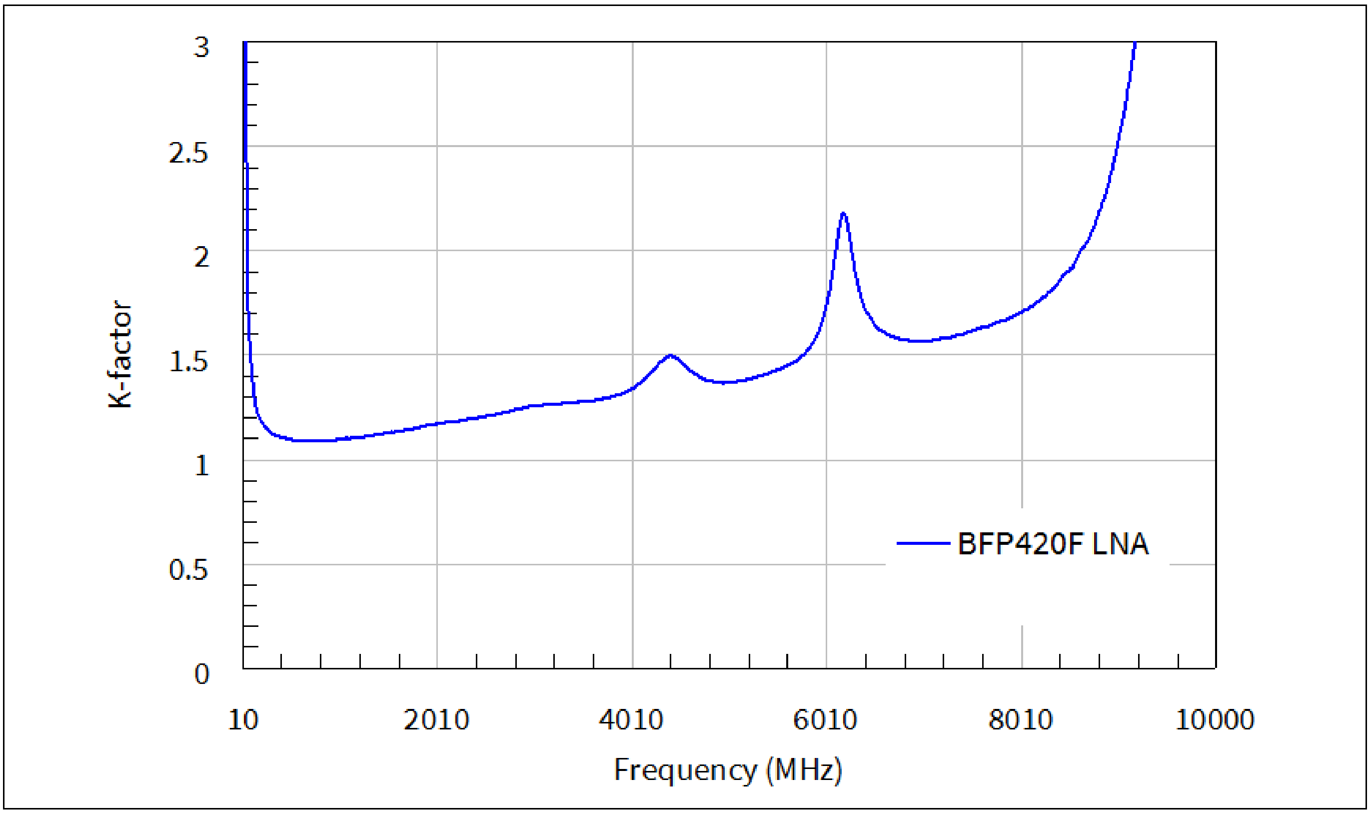


Figure 22 Stability K-factor measurement of the LNB IF amplifier with BFP420F

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