

AN11444

BFU550XR ISM 866 MHz LNA design

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Application note

Document information

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1. Abstract

In this application note an ISM band (industrial, scientific and medical) LNA design (low noise amplifier) using a BFU5xx transistor from NXP latest wideband transistor range is described. It shows the design, simulation and implementation phases. Together with measurement results, parameters measured over temperature are shown.

The application note (AN) can be a starting point for new design(s), and/or derivative designs.

2. Introduction

The BFU5xxXR transistor family is designed to meet the latest requirements on high frequency applications (up to approximately 2 GHz) such as communication, automotive and industrial equipment. As soon as fast, low noise analogue signal processing is required, combined with medium to high voltage swings the BFU5xxXR transistors are the perfect choice. Due to the high gain at low supply current those types can also be applied very well in battery powered equipment.

Compared to previous Philips / NXP transistor generations and competitor products' improvements on gain, noise and thermal properties are realized. BFU5xxXR transistors are available in various packages.

The transistors are promoted with a full promotion package, called "starter kits" (one kit type per package-type). Those kits include two PCB's (one with grounded emitter, one with emitter degeneration provision), RF connectors, transistors and simulation model parameters required to perform simulations. See the overview of available starter kits in the table below.

Table 1. Customer evaluation kits

Basic type		Customer evaluation kits
1	BFU520W, BFU530W, BFU550W	OM7960, starter kit for transistors in SOT323 package
2	BFU520A, BFU530A, BFU550A	OM7961, starter kit for transistors in SOT23 package
3	BFU520, BFU530, BFU550	OM7962, starter kit for transistors in SOT143 package
4	BFU520X, BFU530X, BFU550X	OM7963, starter kit for transistors in SOT143X package
5	BFU520XR, BFU530XR, BFU550XR	OM7964, starter kit for transistors in SOT143XR package
6	BFU580Q, BFU590Q	OM7965, starter kit for transistors in SOT89 package
7	BFU580G, BFU590G	OM7966, starter kit for transistors in SOT223 package



3. Requirements

The demonstrator circuit is designed to show the BFU550XR capabilities for a 866 MHz ISM LNA with strong focus on best possible Noise Figure at low to medium supply current. The aim of the demonstrator circuit was to design a LNA optimized for the ISM band for battery powered equipment meeting following requirements:

Supply Voltage: 3.6 Volts nominal
Supply current: 20mA at ambient temperature
Noise Figure: < 1.4dB
Gain: approx. 13dB
OIP3: priority on NF but preferably >+20dBm
Input Return-Loss: < -8dB
Output Return-Loss: < -10dB

The design is aimed at low BOM cost and small PCB area, inductors are SMD types (preferable low cost multilayer types) to enable simple tuning to other frequency bands.

4. Design considerations

In order to achieve minimum Noise Figure, with Gain still close to the maximum available gain, the source impedance has to be close to the optimum for Noise Figure and not too far from to the maximum gain impedance. Designing for optimum Noise Figure will compromise, for example, the input return loss, but this is assumed to be acceptable.

At any time the circuit should be stable, hence during the design phase the K-factor needs to be observed carefully.

5. Design approach

The design starts in the simulation phase, applying the Mextram Model (available at <http://www.nxp.com>). Agilent "Advanced Design System" (ADS) was used for this but other simulation software packages should give equal results. Spice / Gummel Poon models are available.

Once simulation results meet the requirements, the circuit is built on a universal Printed Circuit Board (PCB) and evaluated. If measurement results show significant offset from simulated results, fine tuning is required until required performance is met. To achieve better matching between simulations and measurements, the PCB parasitic properties were added in the simulation template.

Following blocks of passive components can be identified:

- 1) resistors for DC biasing
- 2) passives set up collector load
- 3) passives for output matching
- 4) passives for input matching
- 5) passives required to ensure stable operation

Each block will be discussed separately below.

5.1 Simulation steps

Following simulation / design approach can be useful:

- 1) Configure the DC bias set-up, ensuring the I_{cc} is set around desired value.
- 2) Configure the collector load circuit and output matching circuitry, optimizing the output Return Loss (RL).
- 3) Check stability.
- 4) Configure the input matching, for LNA optimize for minimum noise figure (NF) but keep close to optimum gain, if possible optimum NF gain points should be close.
- 5) Check stability.

Assumptions:

- Realistic passives are used by applying Murata design kit (0603 / 0402)
- PCB tracks represented by strip-lines

5.2 Implementation / evaluation steps

Following implementation / evaluation steps have been executed:

- 1) Implement simulated design on universal PCB.
- 2) Evaluate LNA on Gain / NF / matching / Stability at ambient temperature.
- 3) Fine tune passives if required.
- 4) In case significant differences between simulations and measured results are observed, try to modify parasitic properties in the simulation template.
- 5) Measure LNA design on RF parameters over temperature.

5.3 Setting up the DC bias circuit

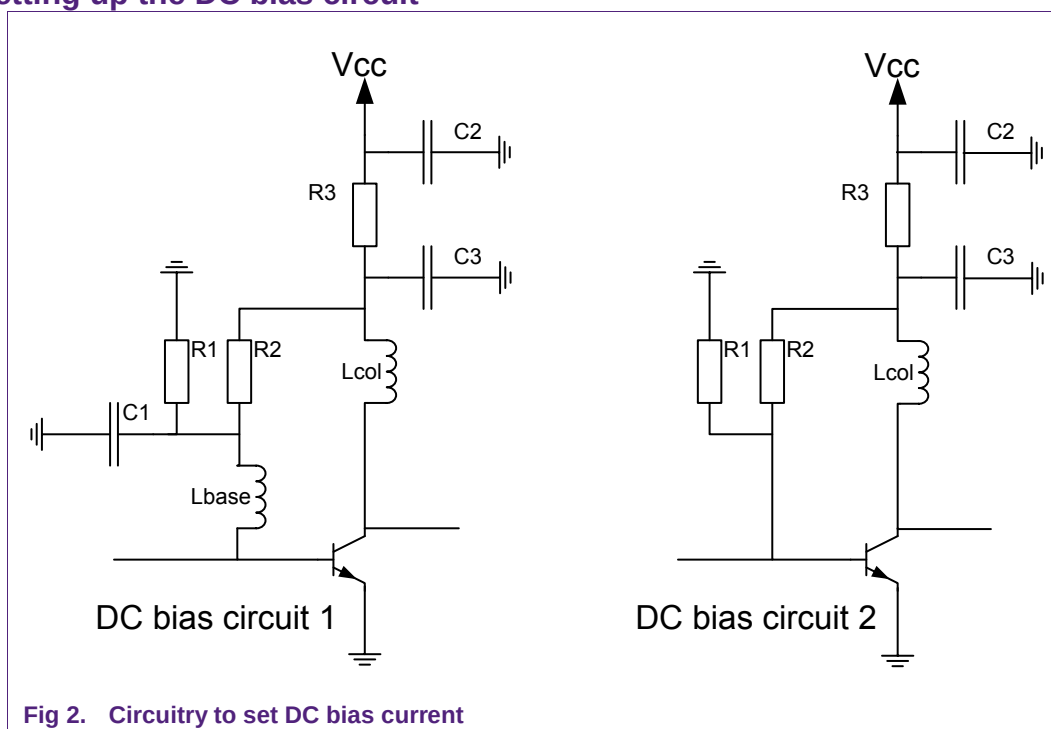


Fig 2. Circuitry to set DC bias current

Circuit 1 has the advantage that resistive noise from the resistors R1 and R2 is suppressed by capacitor C1, but at the cost of an extra inductor. This inductor can be part of the input matching.

Circuit 2 is commonly used and saves two passive components. Both circuits tend to have increasing collector current (I_{CC}) with increasing temperature, partly stabilized by R3. Increasing R3 will have impact on the linearity (OIP3, P1dB).

5.4 Definition of collector load and output match

The configuration used and simulation display is shown below (ADS).

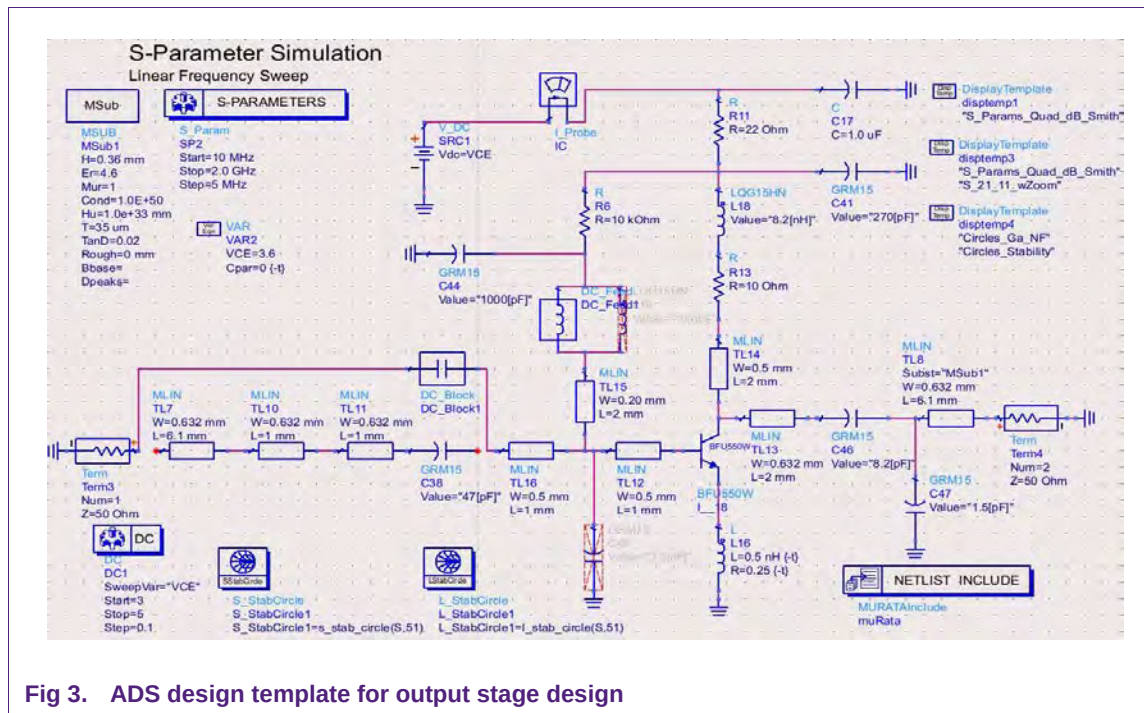
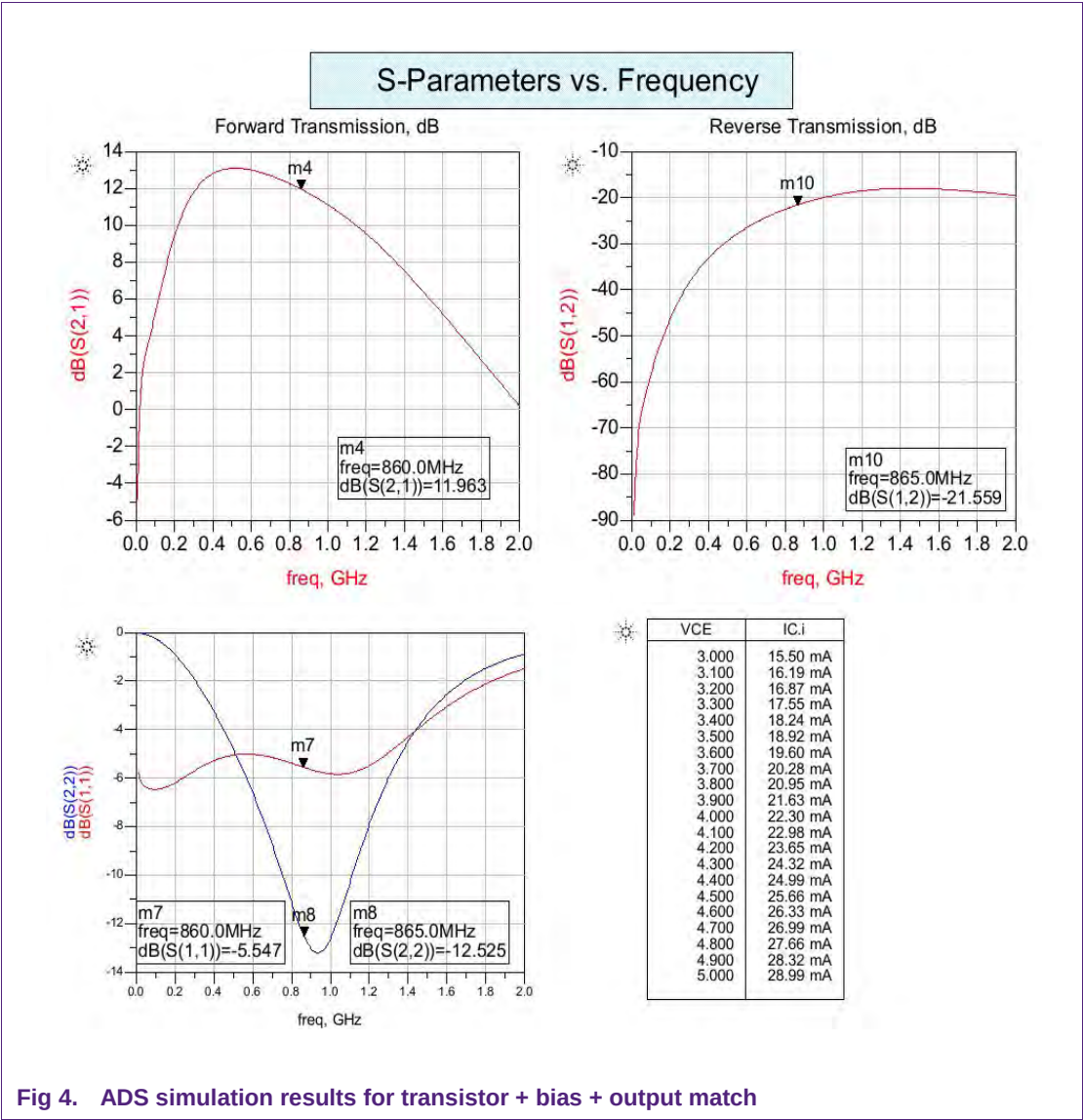


Fig 3. ADS design template for output stage design

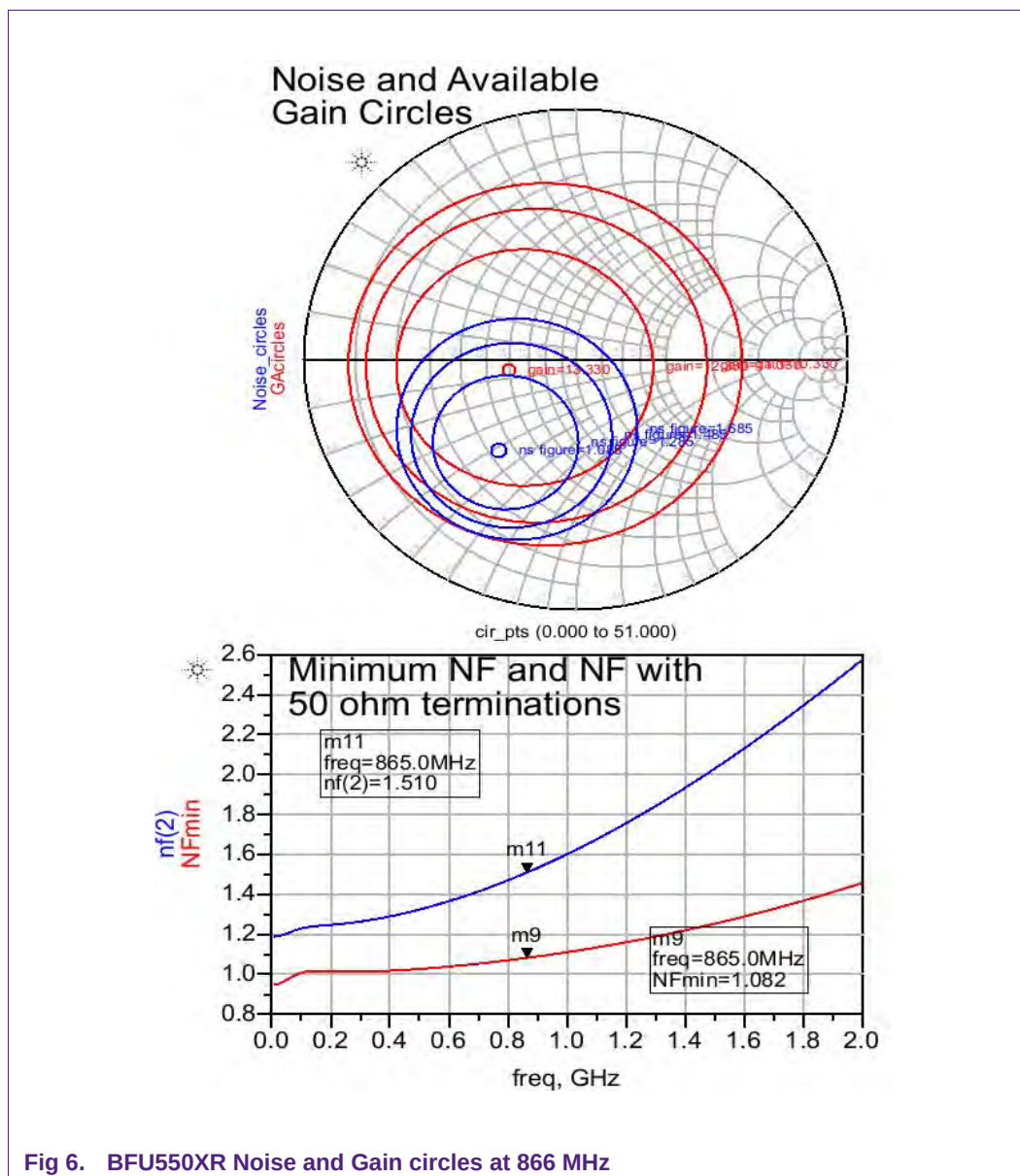
In this simulation for the 866 MHz ISM Band the input matching circuit is bypassed. The components L18, C46, C47 are tuned to get a match in the required frequency band.



5.5 Definition of input / source matching circuit

In case the amplifier has to be designed to get minimum noise figure, the “noise and gain circles” can be applied.

See figure below: In the noise circles plot you can find the area for optimum source impedance, as should be seen by the base of the transistor, to achieve lowest noise figure.



In the next figure the simulation template to optimize for best source impedance is shown. Please note that the active part of the circuit is bypassed. We want to observe the S22 which is the source impedance for the transistor applied.

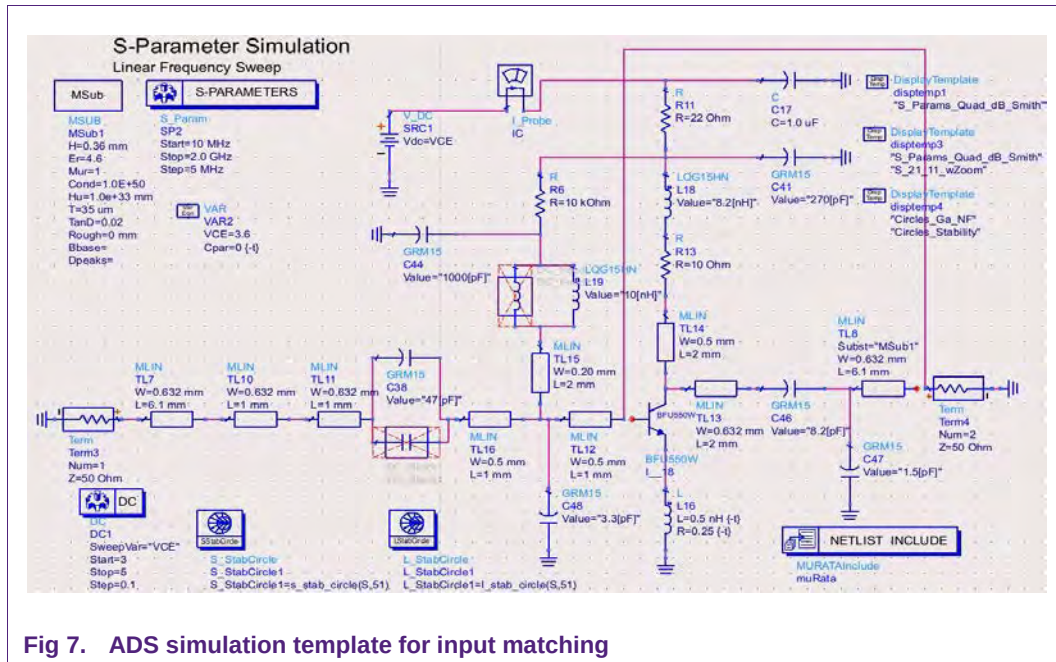


Fig 7. ADS simulation template for input matching

By tuning the components L19, C48 you could move the source impedance towards required area.

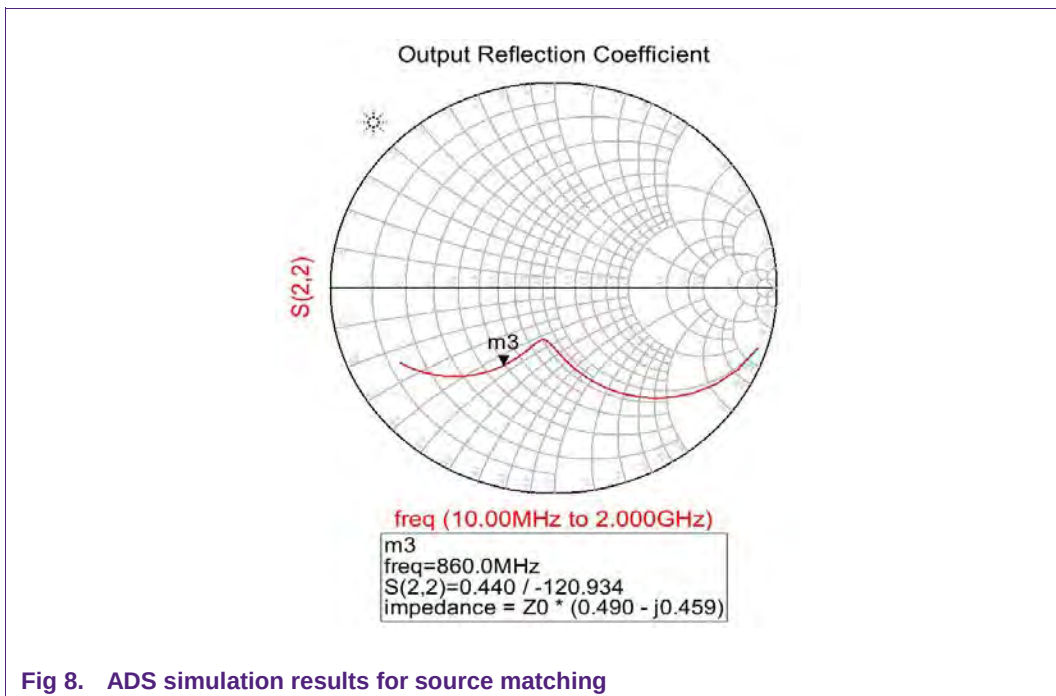


Fig 8. ADS simulation results for source matching

From this figure we see the source impedance at 866 MHz is in the area we want.

5.6 Overall LNA simulation

ADS template used:

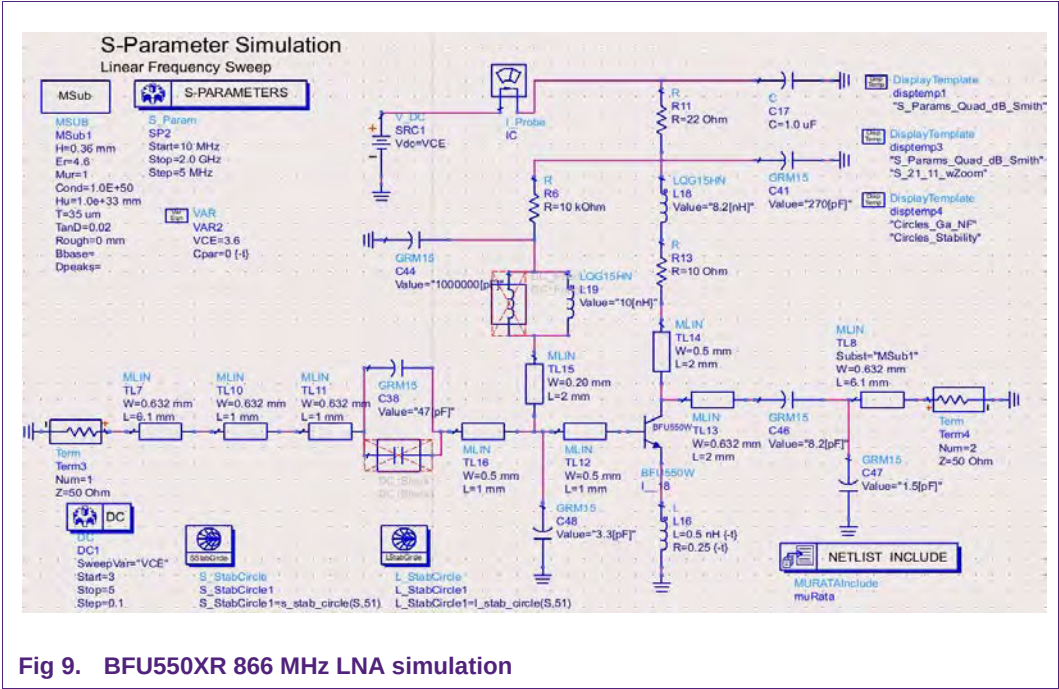
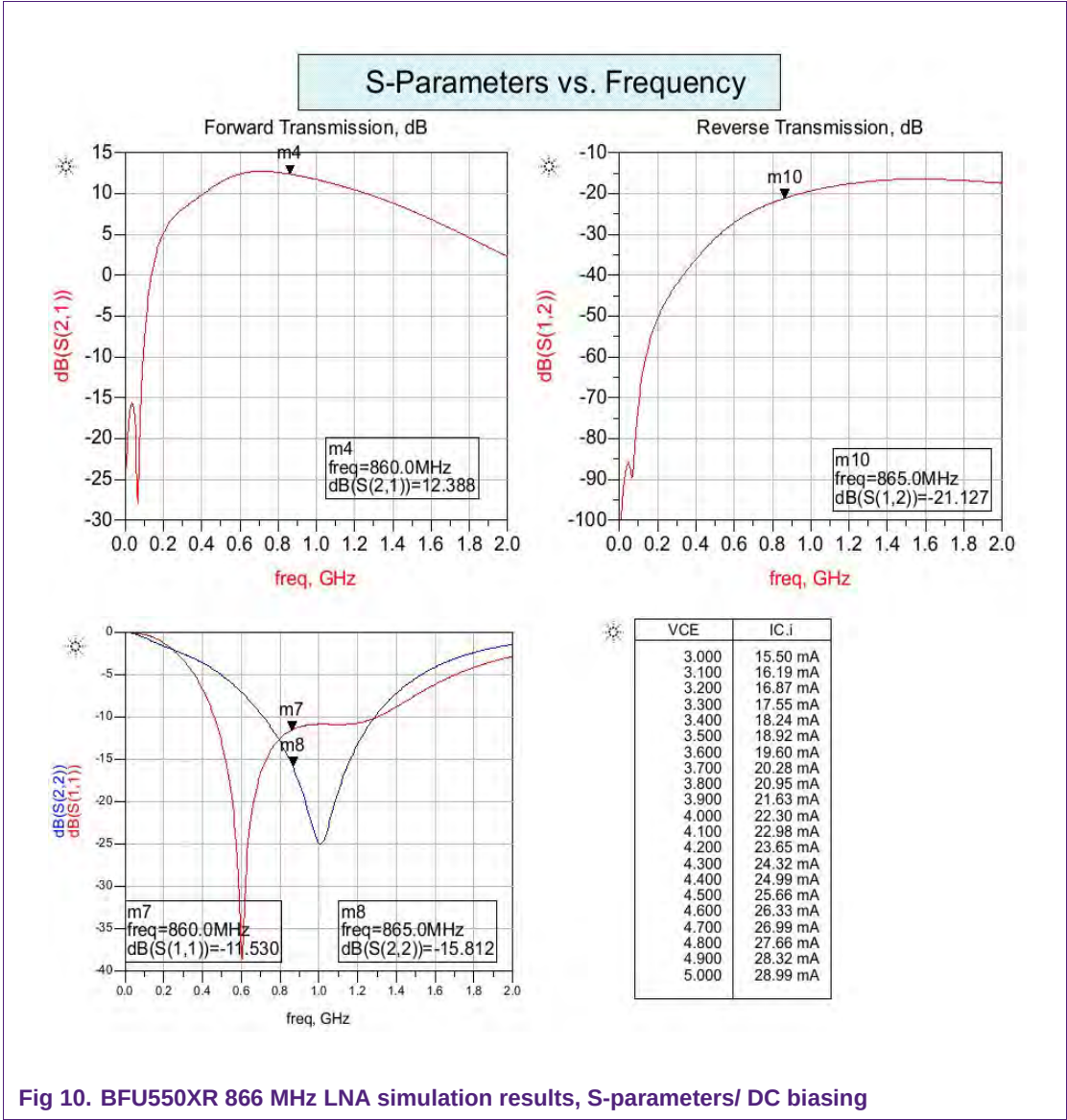
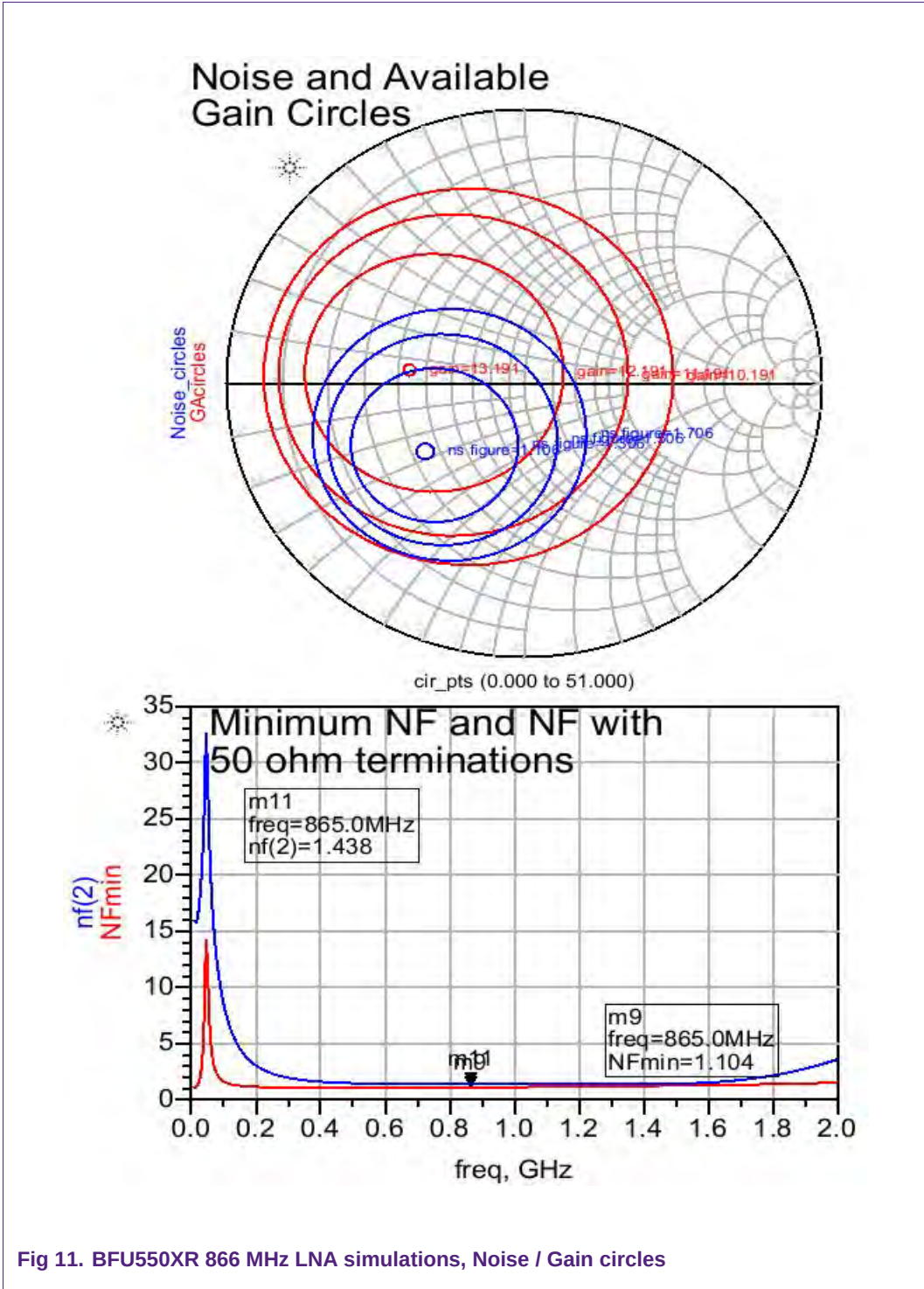


Fig 9. BFU550XR 866 MHz LNA simulation

Simulation results:





Compared to the noise circles of the unmatched circuit (section 5.5), we can clearly see the optimum noise point has moved towards the ideal 50R point.

6. Application circuit

The circuit diagram of the evaluation board is shown in Fig 12 PCB schematic.

6.1 BFU550XR 866 MHz ISM LNA schematic

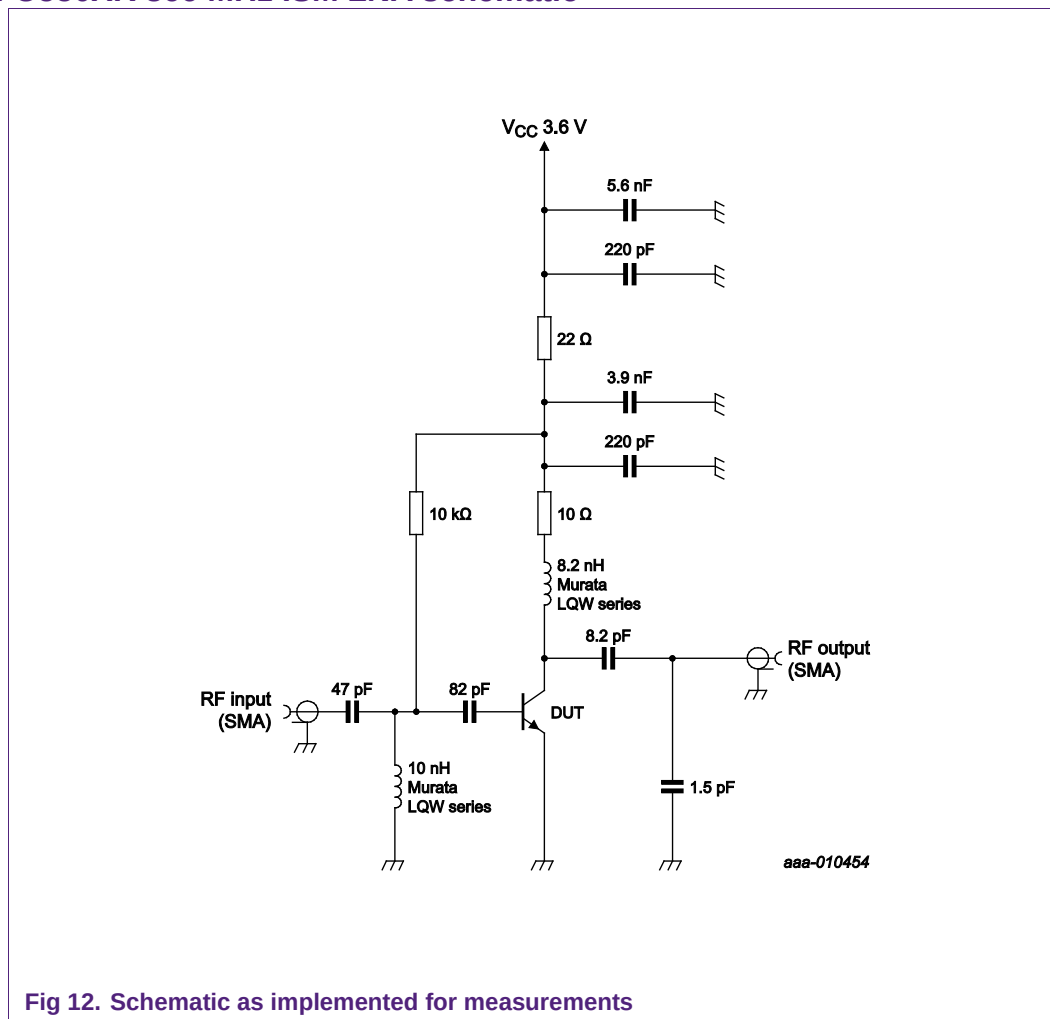


Fig 12. Schematic as implemented for measurements

The PCB layout used for our internal evaluations did not accommodate the 33nH inductor to be in the bias path (as shown in the ADS schematics) the input matching inductor was placed to ground (GND) and an additional DC blocking capacitor (220pF) was used. This should give equal results and a slight improvement on the Noise Figure can be expected as the resistive noise from the two bias resistors is not suppressed by a blocking capacitor to GND.

6.2 BFU550XR 866 MHz ISM LNA PCB drawing

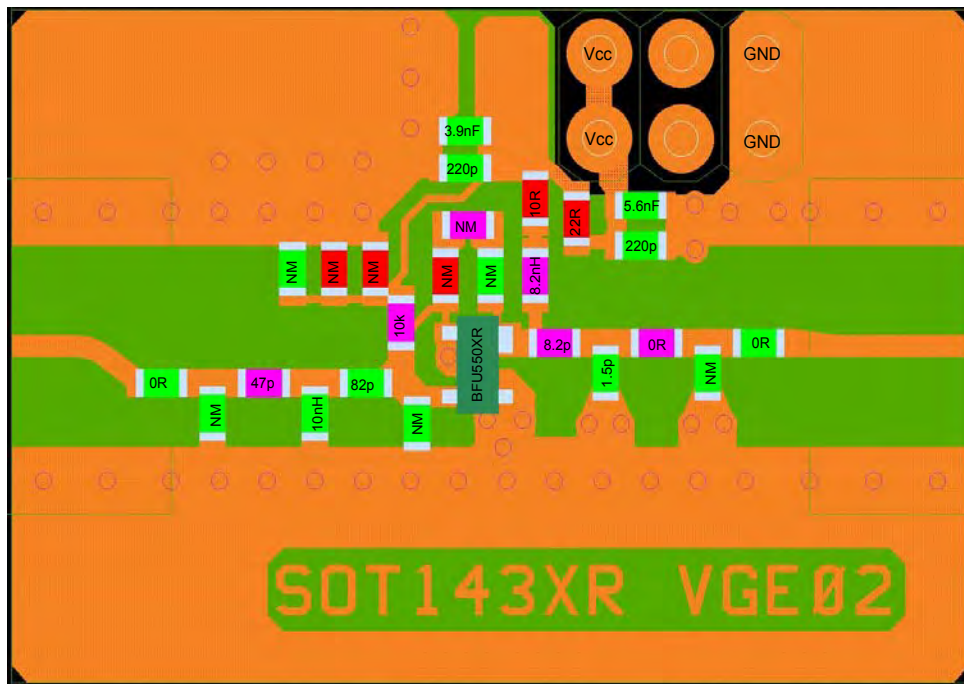


Fig 13. PCB implementation for measurements

Remarks:

0R = SMD jumper

NM = component not mounted.

This layout, as delivered with the Starter kit, accommodates the possibility to implement the biasing as shown in the ADS schematics.

6.3 PCB properties, layer stack

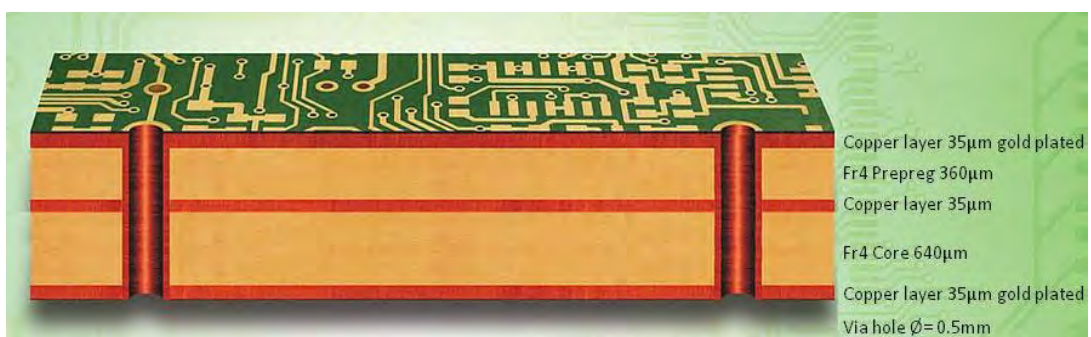


Fig 14. PCB layers used for Evaluation Boards in Starter kit

6.1 Typical LNA evaluation board results

Table 2. Typical results measured on the evaluation boards

Operating Frequency is $f = 866$ MHz unless otherwise specified; Temp = 25 °C

Parameter	Symbol	EVB	Unit	Remarks
Supply Voltage	V_{CC}	3.6	V	
Supply Current	I_{CC}	20	mA	
Noise Figure	NF	1.4	dB	
Power Gain	G_p	15	dB	
Input Return Loss	RL_{in}	-8	dB	
Output Return Loss	RL_{out}	-12	dB	
Output third order intercept point	OIP3	19	dBm	

Table 3. Bill Of Materials

Value	Description	Footprint	Manufacturer
BFU550XR	Transistor	SOT143XR	NXP Semiconductors
1.5 pF	Capacitor	0603	Various
8.2 pF	Capacitor	0603	Various
47 pF	Capacitor	0603	Various
82 pF	Capacitor	0603	Various
220 pF	Capacitor	0603	Various
220 pF	Capacitor	0603	Various
3.9nF	Capacitor	0603	Various
5.6 nF	Capacitor	0603	Various
10 Ω	Resistor	0603	Various
22 Ω	Resistor	0603	Various
10 k Ω	Resistor	0603	Various
8.2 nH	Inductor	0603	Murata LQW18A
10 nH	Inductor	0603	Murata LQW18A

7. Characterization of LNA over temperature and supply voltage

7.1 Gain (S_{21}) = f (freq)

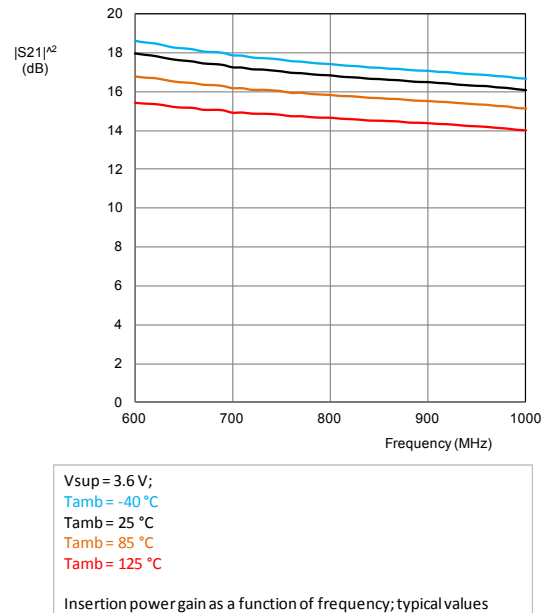


Fig 15. Measured S_{21} over frequency for different temperatures

7.2 Input return-loss (S_{11}) = f (freq)

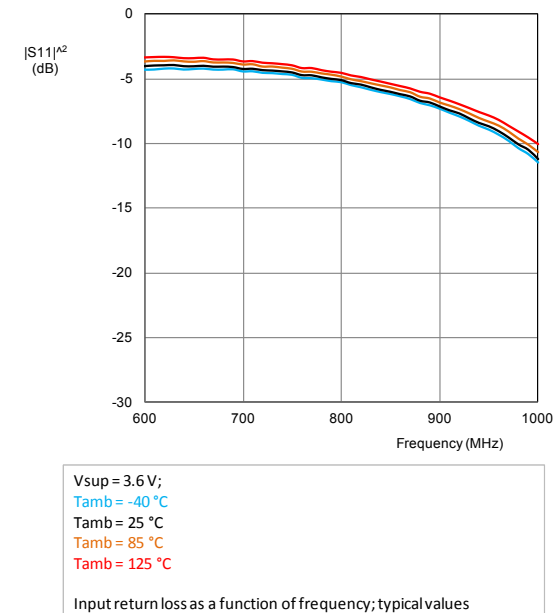
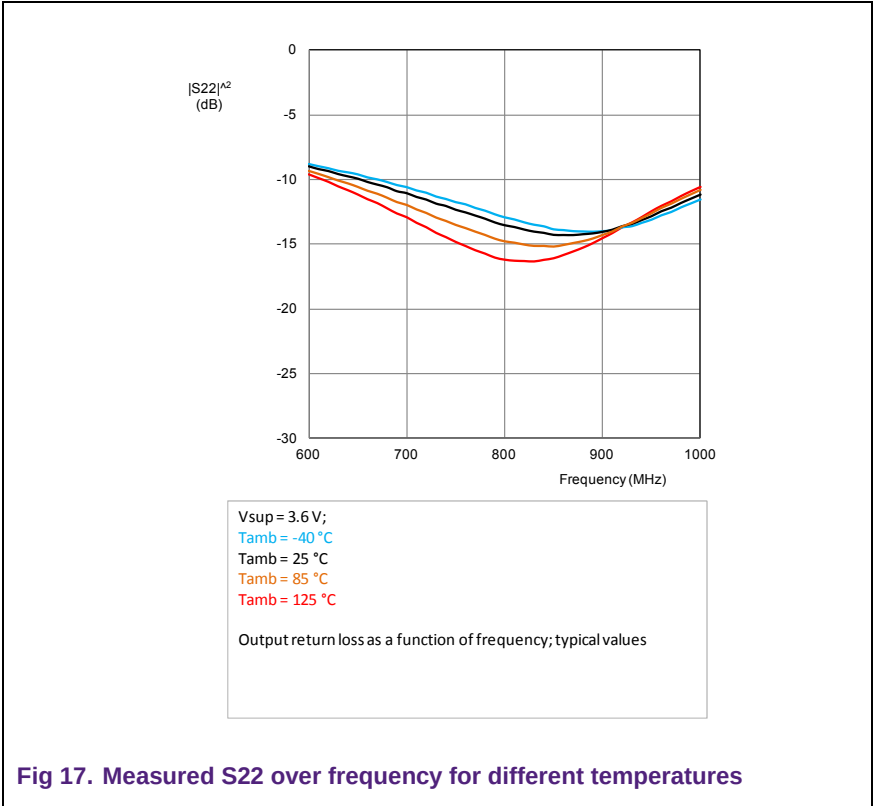
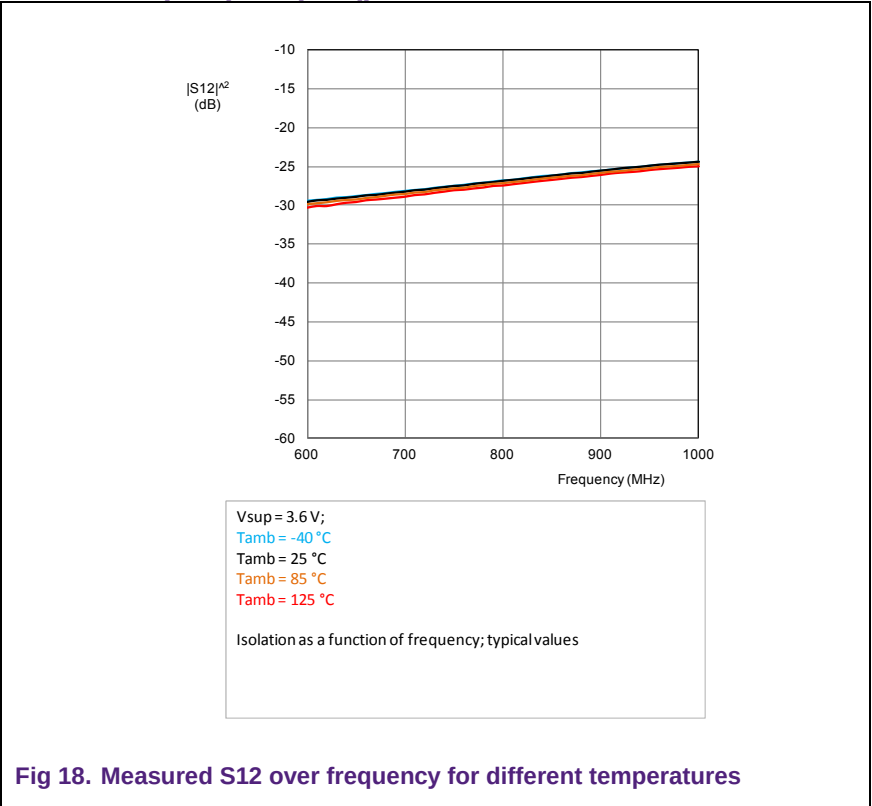


Fig 16. Measured S_{11} over frequency for different temperatures

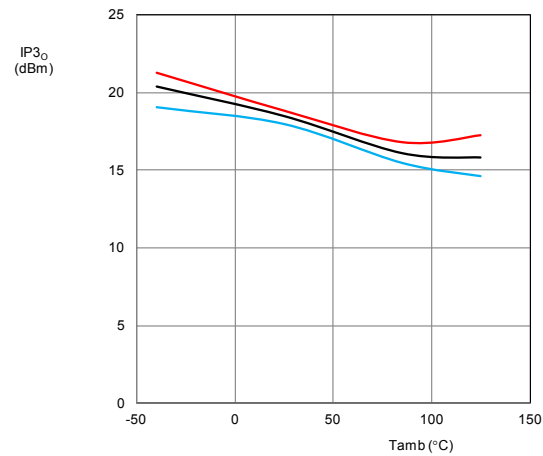
7.3 Output return-loss (S22) = f (freq)



7.4 Isolation (S12) = f (freq)



7.5 Output third-order intercept point (OIP3) = f (Tamb)



f1=433MHz, f2=433.1MHz

Vsup = 3.2 V

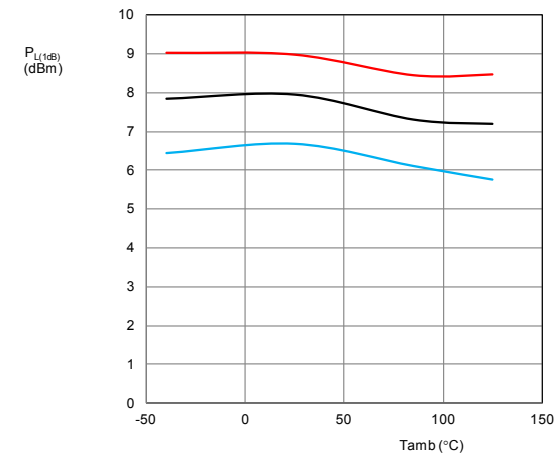
Vsup = 3.6 V

Vsup = 4.0 V

Third order intercept point as a function of ambient temperature; typical values

Fig 19. Measured OIP3 over temperature for different supply voltages

7.6 Output Power at 1 dB compression (P1dB) = f (Tamb)



Vsup = 3.2 V

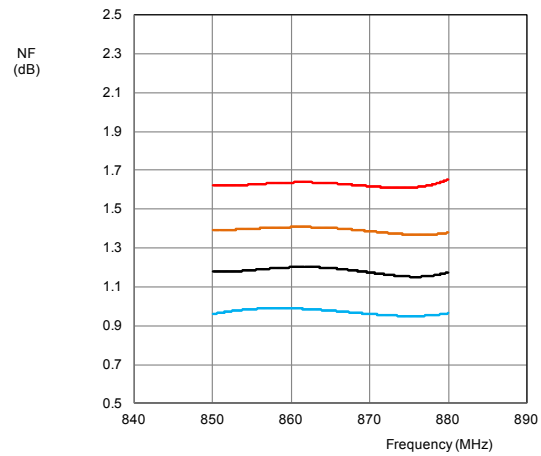
Vsup = 3.6 V

Vsup = 4.0 V

Output power at 1dB gain compression as a function of ambient temperature; typical values

Fig 20. Measured 1dB compression point over temperature for different supply voltages

7.7 Noise Figure = f (Freq)



Vsup = 3.6 V;
Tamb = -40 °C
Tamb = 25 °C
Tamb = 85 °C
Tamb = 125 °C

NF as a function of frequency; typical values

Fig 21. Measured Noise Figure over temperature for different supply voltages

8. Conclusions / recommendations

With BFU550XR a ISM 866 MHz LNA design with NF close to 1.4dB can be implemented, for this the input return loss has to be compromised. The circuit can be used as a base for derivative designs, matching to other frequencies can be done by tuning relevant capacitors and inductors.

For improvements on linearity it could be recommended to increase the DC biasing current and increase values for decoupling capacitors to GND, for example on the biasing network in case the matching inductor is in the configuration as shown in the ADS schematics.

	BFU520 series	BFU530 series	BFU550 series
Lowest Noise at low supply current	x		
Low Noise and medium Linearity		x	
Low Noise and high Linearity, high Icc			x

8.1 Tuning the design for other frequencies

This LNA can be tuned to other frequencies as well. The presented configuration has been designed for a low bandwidth application (Center frequency/required bandwidth = approx 10-100 depending on the used components).

The LNA can be tuned to other frequencies following section 5.4 till 5.6. The use of printed inductors or micro-strip elements is recommended above 1GHz to prevent gain drop.

For wideband amplifiers a feedback is recommended which can be implemented on the existing board.

A reference design for a wideband amplifier, applying feedback, is planned to be issued. Please regularly visit the NXP PIP pages to monitor availability of BFU5- series related AN's.

9. References

BFU550XR datasheet

BFU5xxXR starter-kit (OM7964) User Manual, UM10772

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