AN11010

Single stage Ku band LNA using BFU730F

Rev. 1.0 — 11 January 2011 Application note

Document information

Info	Content
Keywords	BFU730F, LNA, Ku band, LNB
Abstract	The document provides circuit, layout, BOM and performance information on Ku band LNA equipped with NXP's BFU730F wide band transistor.

Revision history

Rev	Date	Description
1.0	20110111	Initial document

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1. Introduction

BFU730F is a discrete HBT produced in NXP's SiGeC QuBIC4x BiCmos process. SiGeC is a normal silicon germanium process with the addition of Carbon in the base layer of the NPN transistor. The presence of carbon in the base layer suppresses the boron diffusion during wafer processing. This allows steeper and narrower SiGe HBT base and a heavier doped base. As a result, lower base resistance, lower noise and higher cut off frequency can be achieved.

2. Requirements for Ku band LNA

The typical application for a Ku band LNA consists of amplification stage in the MW preamplifier chain of a satellite LNB.

The noise figure requirements for LNBs may vary from standard to standard, however most of them will set a figure of:

$$\mathbf{NF_{LNB} \leq 1.2dB}$$

BFU730F typical values for the minimum noise figure and maximum stable gain at Ku band frequency of 12GHz and bias of 2V / 10mA are:

NFmin = 1.1dB and Gmax = 12.5dB

This recommends the device as an alternative solution to replace pHemts in Ku band LNA applications.

IF the target spec for the BFU730F LNA noise and gain is:

NF= 1.4dB and Gain = 11.5dB

The LNB system performance is as it shows up in Table 1:

Table 1. BFU730F vs pHemt NF and Gain performance comparison

Preamplifier	1st stage NF/Gain (dB)	2nd stage NF/Gain (dB)	3rd stage NF/Gain (dB)	Mixer stage NF/Gain (dB)	LNB NF/Gain (dB)
2 stage	pHemt 0.8 / 12	pHemt 1 / 12	N/U	active 8 / 2	**0.93 / 26**
	pHemt 0.8 / 12	BFU730F 1.4 / 11.5	N/U	active 8 / 2	**0.97 / 25.5**
3 stage	pHemt 0.8 / 12	pHemt 1 / 12	pHemt 1 / 12	diode 12 / -12	**0.88 / 24**
	pHemt 0.8 / 12	pHemt 1 / 12	BFU730F 1.4 / 11.5	diode 12 / -12	**0.88 / 23.5**
	pHemt 0.8 / 12	BFU730F 1.4 / 11.5	BFU730F 1.4 / 11.5	diode 12 / -12	**0.91 / 23**

The performance of the stand-alone BFU730F amplifier is slightly worse compare to the pHemt one, however in an LNB chain it gives almost no performance change when used as LNA3, or minor acceptable degradation when used as LNA2.

3. Design

The Ku band LNA consists of one stage BFU730F amplifier. It is aimed to replace more costly pHemt transistors in the second and / or third stage of the LNB preamplifier. These stages have to compensate the higher noise of the following mixer stage, thus their gain has to be as high as possible. The driving designs criteria for the LNA is the maximization of its gain. Secondly the noise figure has to be as good as possible, with a very small compromise on gain. Due to the gain criteria, the input and output match are also optimized. Stability wise the LNA has to be unconditionally stable over very broad frequency range. In terms of linearity, the system analysis does not impose stringent requirements.

The design has been conducted using Agilent's Advanced Design System (ADS). The 2D EM Momentum tool has been used to design the microwave section and the PCB. The linear and harmonic balanced circuit tools have been used to simulate the gain, noise, match, stability and linearity performances of the LNA.

3.1 BFU730F Ku LNA - ADS simulation circuit

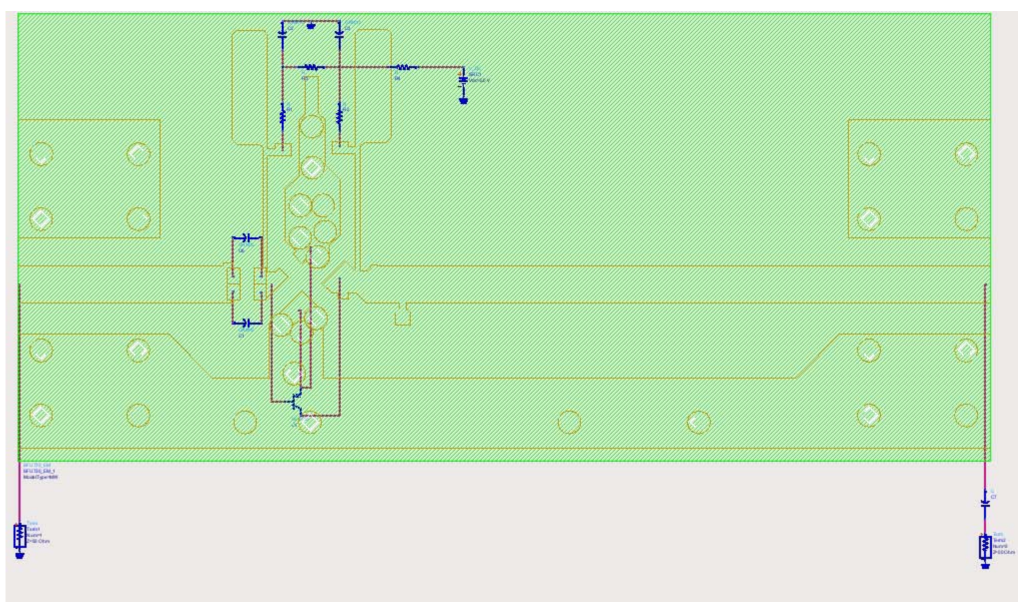


Fig 1. ADS simulation circuit for BFU730F Ku band LNA

3.2 BFU730F Ku LNA - ADS Gain and match simulation results

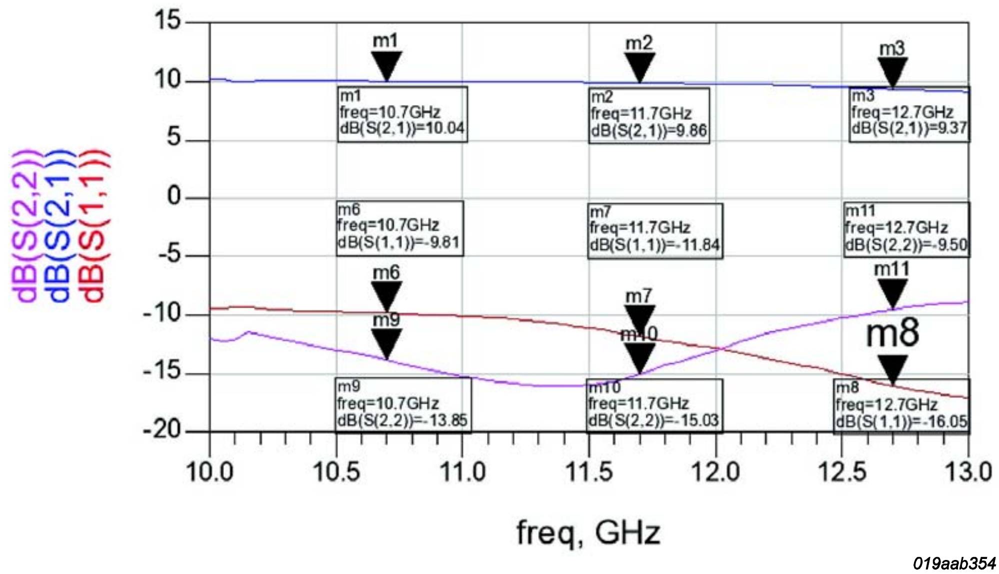


Fig 2. ADS Gain and match simulation results for BFU730F Ku band LNA

3.3 BFU730F Ku LNA - ADS NF simulation results

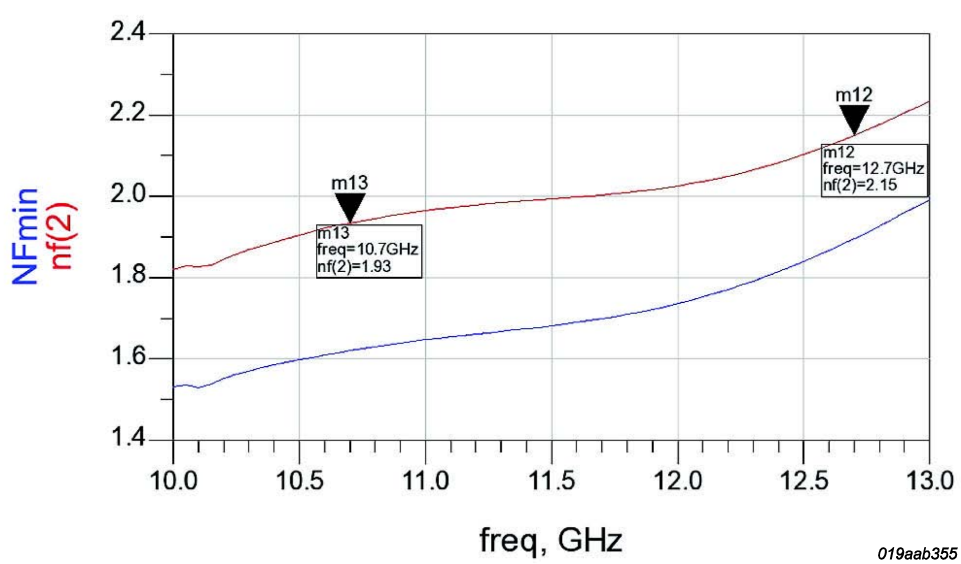
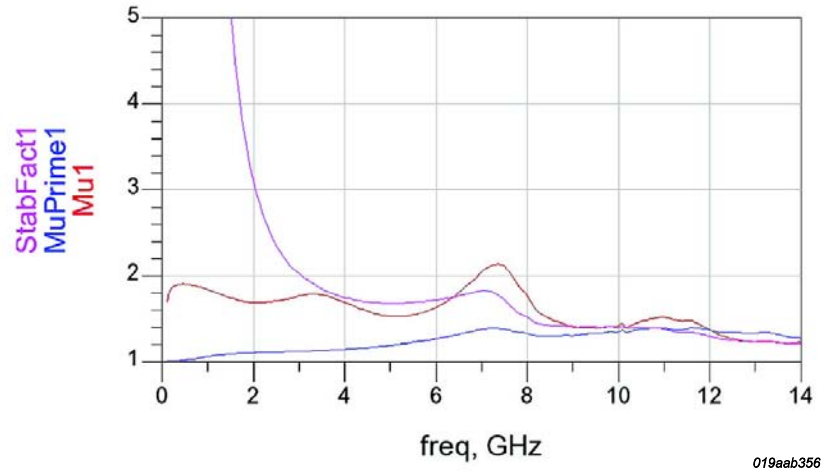


Fig 3. ADS Noise Figure simulation results for Ku band LNA

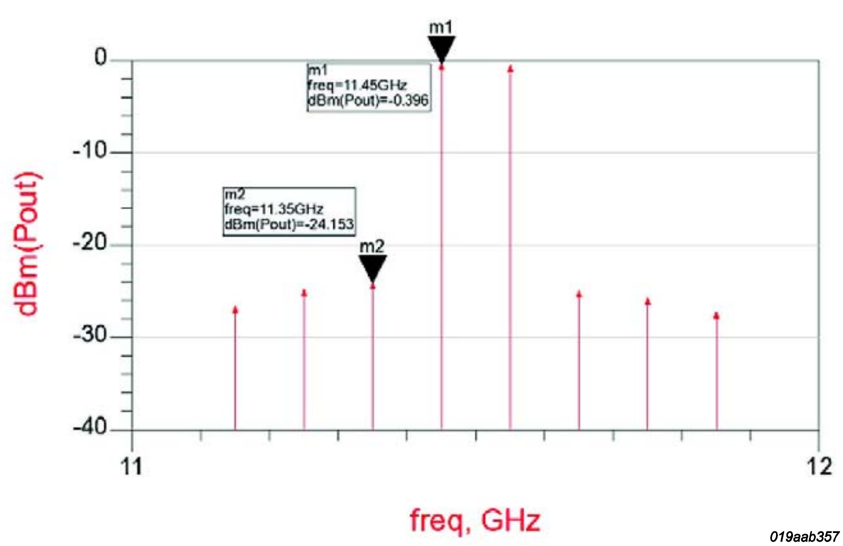
3.4 BFU730F Ku band LNA - ADS stability simulation results



As K≥1 and Mu≥1, the LNA is unconditionally stable for the whole frequency band

Fig 4. ADS stability simulation results for Ku band LNA

3.5 BFU730F Ku band LNA - ADS linearity simulation results



$OIP3 = P_{f1}+(P_{f1}-P_{2f1\_f2})/2$ = -0.4dBm + (-0.4 + 24.2)/2dB = 11.5dBm

IIO3 = OIP3 – Gain = 11.5dBm – 10.2dB = 1.3dBm

Fig 5. ADS linearity simulation results for Ku band LNA

4. Implementation

4.1 Schematic

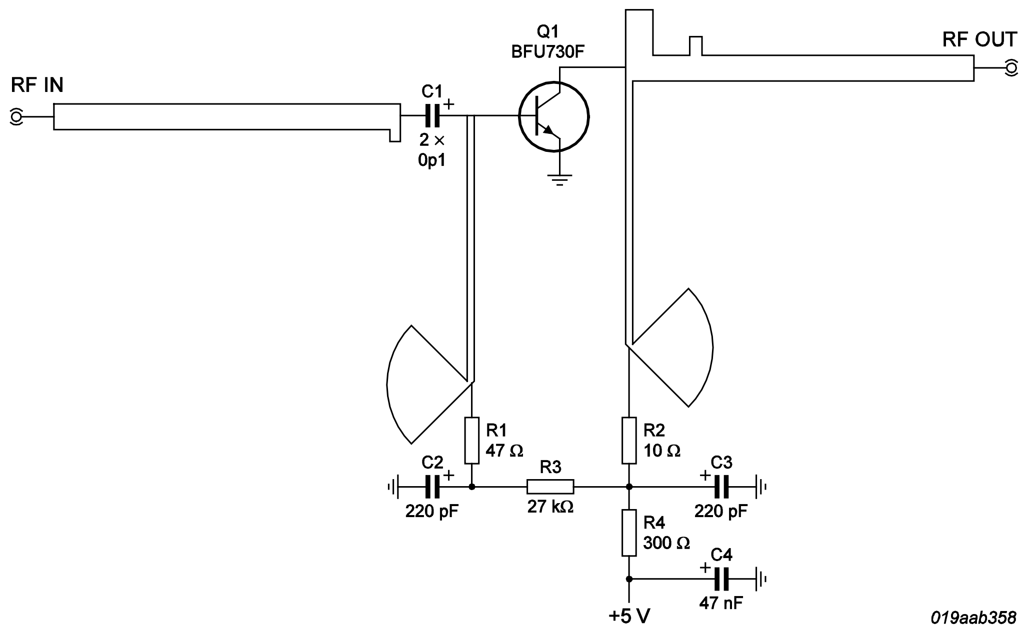


Fig 6. Schematic for BFU730F Ku band LNA EvB

4.2 Layout and assembly

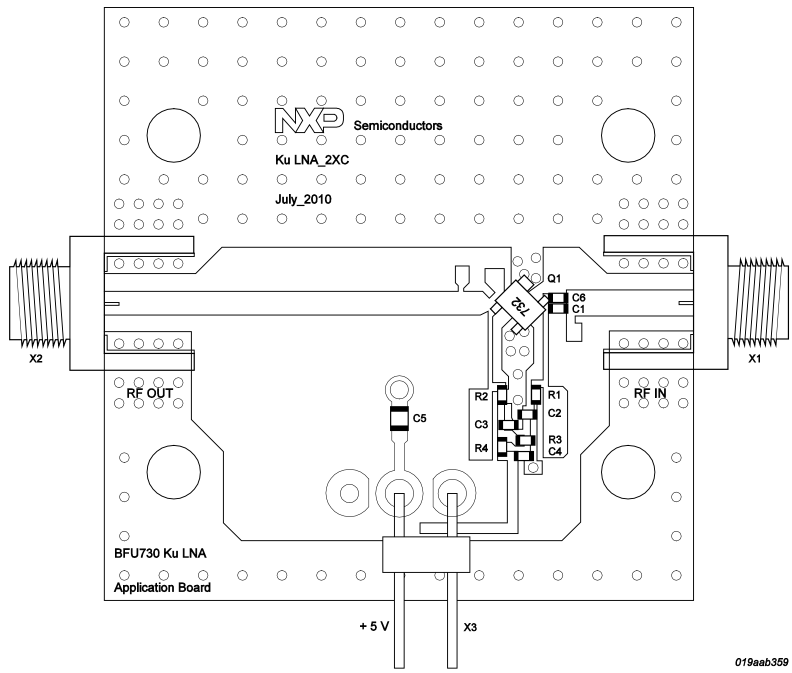


Fig 7. Layout and assembly information for BFU730F Ku band LNA EvB

Table 2. Bill of materials

Designator	Description	Size	Value	Type	Note
Q1	BFU730F	2X2mm		NXP Semiconductors	HBT
PCB		30X30mm			
C1, C6	Capacitor	0402	2X 0.1pF (0.2pF)	Murata GRM1555C1HR10BA01 GRM1555C1HR20BA01	Input match
C2, C3	Capacitor	0402	220pF		Decoupling
C4	Capacitor	0402	47nF		Decoupling
R1	Resistor	0402	47R		Stability
R2	Resistor	0402	10R		Stability
R3	Resistor	0402	27k		Bias
R4	Resistor	0402	300R		Bias
X1, X2	SMA RF connector			Giga Lane PSF-S01	RF connector
X3	DC connector			Molex, PCB header 2way	Bias

4.3 Printed Circuit Board details

The PCB material used for this LNA Evaluation Board is Rogers RO4003. The PC board consists of: 0.35um top metal layer, 0.5mm thickness low loss dielectric layer with ε_R = 3.38 and TanD=0.0024 and 0.35um bottom metal layer

4.4 LNA view

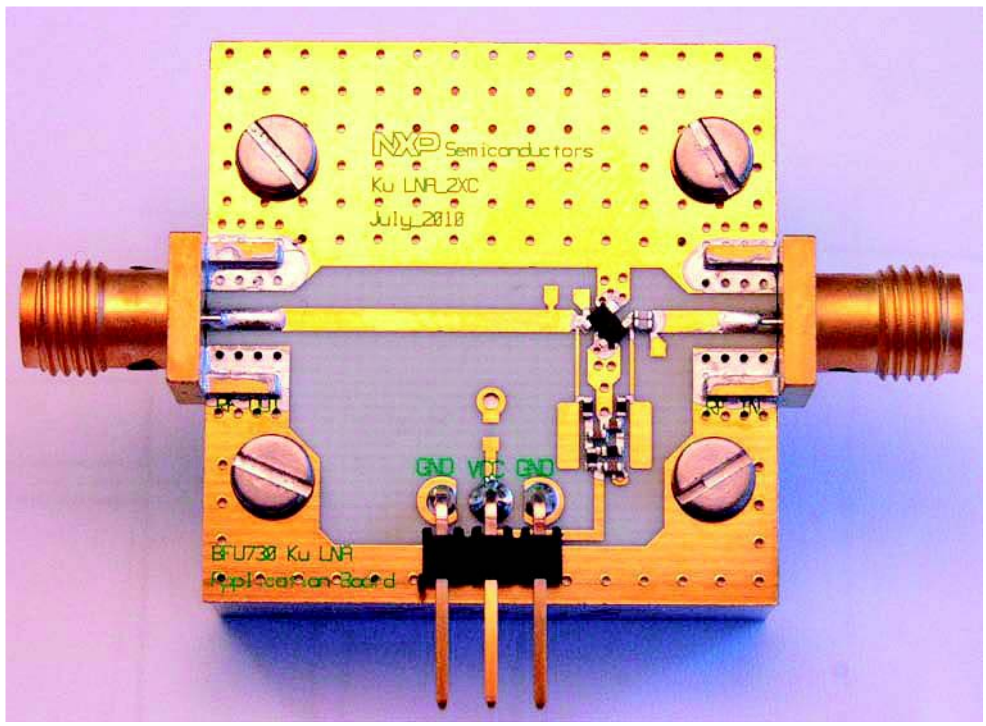


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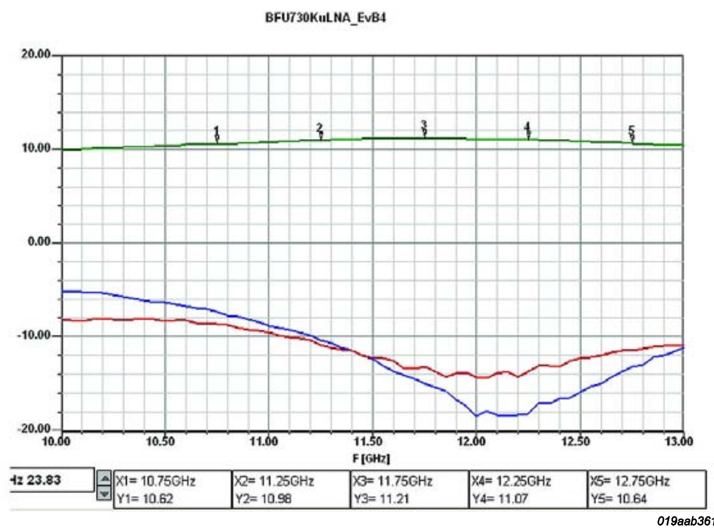
Fig 8. BFU730F Ku LNA EvB

4.5 Measurement results

4.5.1 Gain and match – typical values

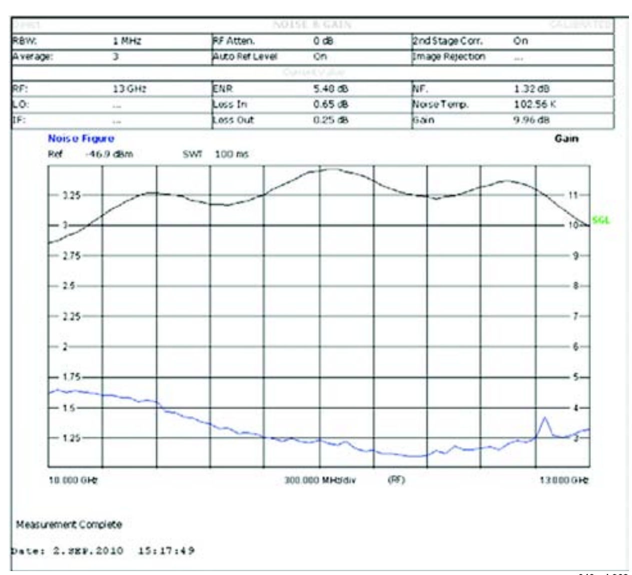


(1) No gain correction has been applied / see § 5.3 to apply correction

(2) Blue – S11, red – S22

Fig 9. BFU730F Ku band LNA – Gain and match measurement plots

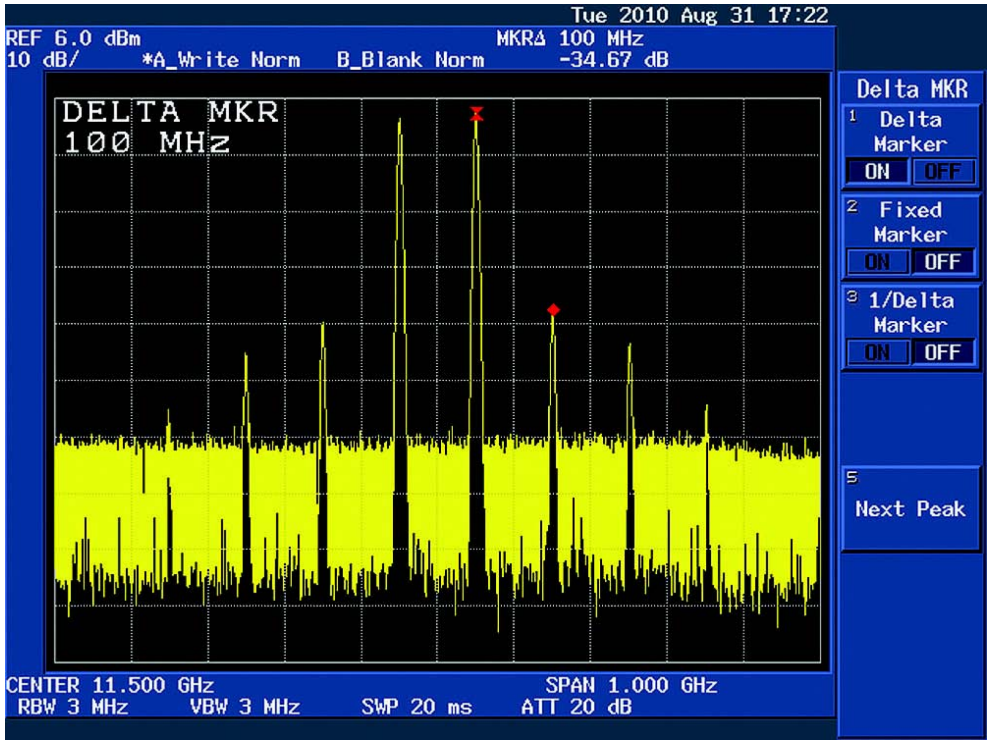
4.5.2 NF and Gain – typical values



(1) NF and Gain correction applied / see § 5.3 for value

Fig 10. BFU730F Ku band LNA – NF and Gain measurement plots

4.5.3 Linearity / OIP3 – typical values



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$OIP3 = P_{f1} + (P_{f1} - P_{2f1\_f2})/2 = 4.2dBm + (4.2 + 30)/2dB = 21.3dBm$

$IIO3 = OIP3 – Gain = 21.3dBm – 11dB = 10.3dBm$

Fig 11. BFU730F Ku band LNA – Linearity measurement plot

4.5.4 Gain, NF, Current vs temperature

BFU730F Ku LNA exhibits less than 1dB gain variation for temperature varying in the range of: -40ºC to +85ºC

Table 3. Gain / NF vs Temp

BFU730F EvB4 tested for Gain and NF variation over temperature[1]

Temperature (ºC)	Icc (mA)	NF (dB)	Gain (dB)
+25	11.6	1.45	10.7
+50	11.4	1.6	10.65
+70	11.1	1.75	10.6
+85	11.0	1.8	10.55
-10	11.8	1.2	11.2
-25	11.9	1.15	11.2
-40	12	1.1	11.25

[1] Measurements have been focused on relative variation of the Gain and NF vs. temperature, however the absolute numbers might not be accurate. NF and Gain plots are available by request.

4.5.5 Summary

Measurements results averaged over nine EvBs are presented in Table 4

Table 4. Typical results measured on the BFU730F Ku band LNA Evaluation Boards
Operating frequency is f=11.5GHz unless otherwise specified; Temp = 25 °C

Parameter		Symbol	Min	Typ	Max	Unit
Supply Voltage		V_{CC}	4.75	5	5.25	**V**
Supply Current		I_{CC}	10.8	11.5	12.1	**mA**
Power gain	10.75GHz	G_p [2] [3]		10.55		**dB**
	11.25GHz			10.9		**dB**
	11.75GHz			11.15		**dB**
	12.25GHz			11		**dB**
	12.75GHz			10.4		**dB**
Noise Figure	10.75GHz	NF[4] [5]		1.4		**dB**
	11.25GHz			1.25		**dB**
	11.75GHz			1.2		**dB**
	12.25GHz			1.2		**dB**
	12.75GHz			1.35		**dB**
Input Return Loss		RL_{in}		12		**dB**
Output Return Loss		RL_{out}		12		**dB**
Input 1dB Gain Compression		P_i1dB		0.5		**dBm**
Input third order intercept point		$IP3_i$		10		**dBm**

[2] No gain correction has been applied. To apply gain correction see § 5.3

[3] Average Gain = 10.85dB

[4] NF correction applied, see § 5.3

[5] Average NF = 1.3dB

5. NF and Gain measurement corrections

There are two types of errors and losses that have been taken into account to correct the NF and Gain measurement results: (1) Own system error for NF measurement and (2) insertion losses accounted to RF IN and RF OUT connectors, microstrip feed lines and the DC block used at the output of the LNA in NF measurements.

5.1 NF measurement system error

A Miteq professional amplifier, rated as NF=1dB, Gain=24dB, has been used as reference for NF measurement system correction. Its manufacturer data is in Fig 12:

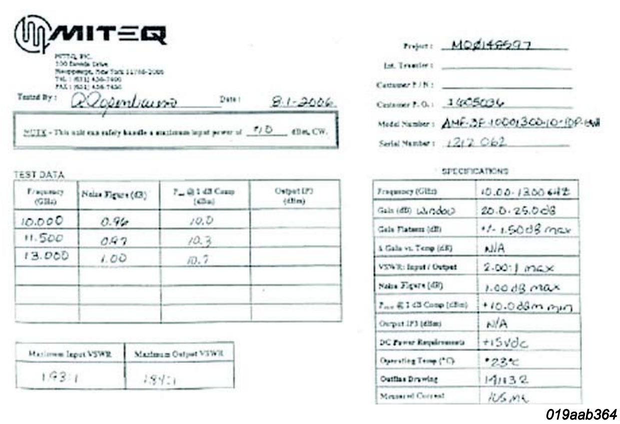

Fig 12. Miteq amp 062

Miteq 062 amplifier measured with the NF setup used to qualify the BFU730F Ku band LNA has the NF performances listed in Fig 13. The system correction factor, NFsys, is the difference between the measured NF and the 1dB reference value from the catalog

Direct		NOISE & GAIN			CALIBRATED
RBW:	1 MHz	RF Atten.	0 dB	2nd Stage Corr.	On
Average:	3	Auto Ref Level	On	Image Rejection	...
		Current Value			
RF:	10 GHz	ENR	5.29 dB	NF.	1.47 dB
LO:	...	Loss In	0 dB	Noise Temp.	116.84 K
IF:	...	Loss Out	0 dB	Gain	23.46 dB

Frequency List Results

RF	NF	Noise Temp	Gain
10.000 GHz	1.470 dB	116.045 K	23.464 dB
10.250 GHz	1.500 dB	119.623 K	23.809 dB
10.500 GHz	1.510 dB	120.626 K	24.469 dB
10.750 GHz	1.539 dB	123.332 K	24.663 dB
11.000 GHz	1.540 dB	123.445 K	24.427 dB
11.250 GHz	1.557 dB	125.018 K	24.138 dB
11.500 GHz	1.535 dB	122.920 K	24.126 dB
11.750 GHz	1.552 dB	124.553 K	24.437 dB
12.000 GHz	1.570 dB	126.271 K	24.902 dB
12.250 GHz	1.538 dB	123.270 K	24.992 dB
12.500 GHz	1.572 dB	126.448 K	24.500 dB
12.750 GHz	1.535 dB	122.929 K	23.952 dB
13.000 GHz	1.570 dB	126.280 K	23.682 dB

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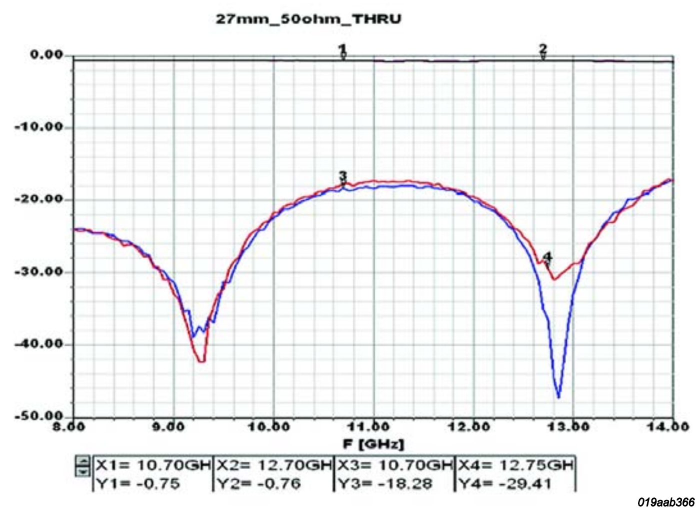
(2) **NFsys**= NFtable13 – 1dB represents the NF system correction factor: average value = 0.5dB

Fig 13. Miteq 062 amplifier NF and Gain

5.2 Insertion losses

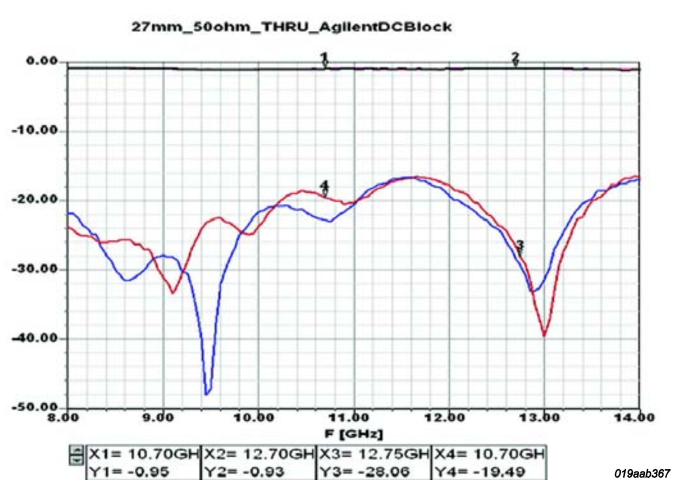
The losses that have to be taken into account are: (1) RF connectors and micro strip lines for Gain-match measurement and RF connectors and microstrip lines plus output DC block for the NF-Gain measurement.

Fig 14 and Fig 15 below plot the two losses:



(3) **RF_IL** = 0.75dB represents the total on board loss of the LNA (RF connectors and 50Ω line)

Fig 14. Insertion loss for 2 RF connector and 27mm uStrip line on Rogers4003 PCB

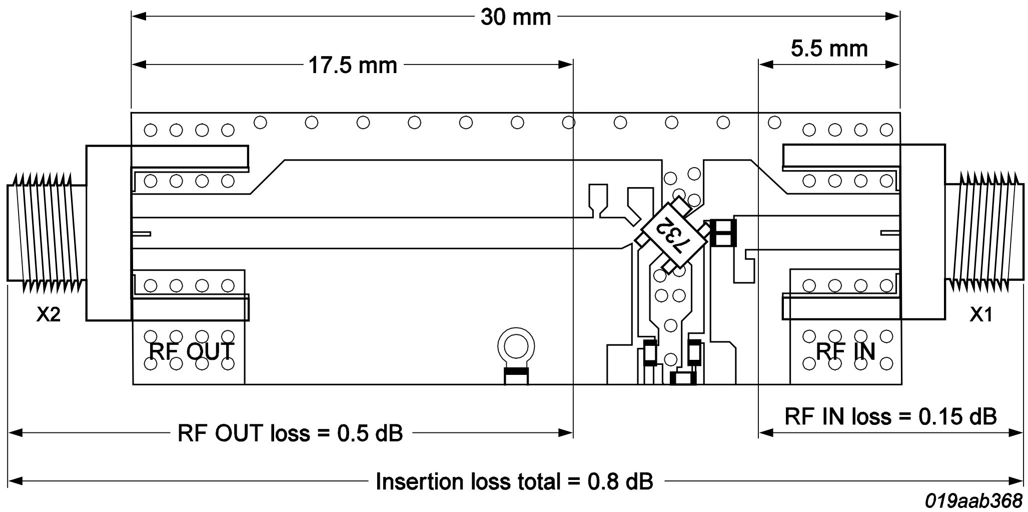


(4) **RF_IL_DC**=0.95dB represents the on board loss + output DC block loss

(5) **DC block loss** ≈ 0.2dB

Fig 15. Insertion loss for a RO4003 27mm SMA_SMA thru + Agilent DC block

Fig 16 shows the on board loss spitted between the input and the output:



(6) RF input loss = 0.15dB / RF output loss = 0.5dB

Fig 16. Insertion loss distribution

5.3 Correction factors for Gain-match and NF-Gain measurements

Table 5. Correction factors / values

Measurement type	Correction on	Corrected for	Correction value	Correction applied
Gain-match on Network Analyzer	Gain	RFin + RFout total loss	RF_IL=RFin + RFout = 0.75dB	N
NF-Gain on NF Analyzer	NF	NF System error + RFin loss	NFsys+RFin = 0.5dB+0.15dB ≈0.65dB	Y
	Gain	RFout loss + DC block loss	RF_IL_DC –NFsys-RFin=0.95dB-0.65dB = 0.3dB	Y

6. Abbreviations / explanations

Table 6. List of abbreviation within text

Abbreviation	Stands for
LNA	Low Noise Amplifier
LNB	Low Noise Block
Ku band LNB	LNB in the frequency band of 10.7 ~ 12.75GHz
NF	Noise Figure
PCB	Printed Circuit Board
BOM	Bill of materials
ABS-S LNB	LNB for China Satellite System
MW	Microwave
EM	Electromagnetic

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