AN11144

Universal Single LNB with TFF101x FIMOD IC

Rev 1.0 — 16 January 2012 **Application note**

Document information

Info	Content
Keywords	DNC, TFF101x, Ku Band, LNB
Abstract	The document provides circuit, layout, BOM and performance information for Ku Band Universal Single LNB equipped with NXP's TFF101x integrated DNC.

Revision history

Rev	Date	Description
1.0	20120116	First revision

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1. Introduction

TFF101x means a series of integrated Down-Converters (DNC) for Low Noise Block (LNB) at Ku band (10.7 GHz to 12.75 GHz) satellite receiver system. The family includes TFF1014, TFF1015, TFF1017 and TFF1018, in which the only difference is conversion gain.

TFF101x integrates most parts of Ku Band Universal Single (US) LNB, including pre-amplifier, mixer, buffer amplifier and PLL synthesizer, and the LO frequency (9.75GHz or 10.6GHz) can be easily switched by a logical level, so for a full US LNB, only an LNA, a 25MHz crystal and a biasing ICs are needed as the external circuits (As shown in Figure 1).

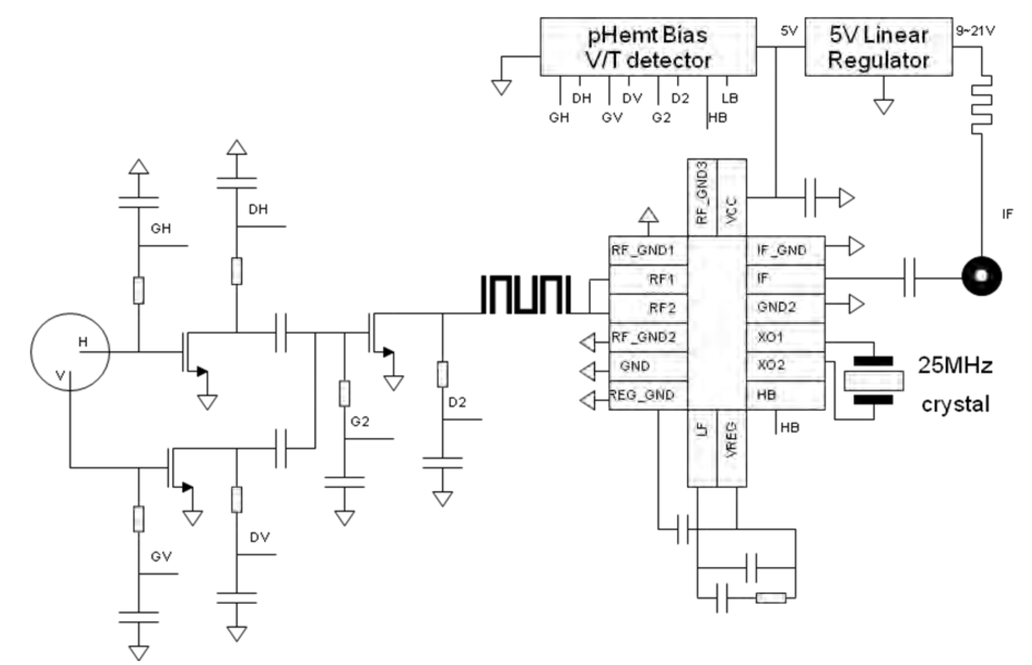


Fig 1. Typical US LNB diagram using the FIMOD IC (TFF101x)

TFF101x has excellent performance: Low noise figure (typ. 7dB), flat conversion gain (full band 1.4dB), low phase noise (1.5˚RMS integrated from 10 kHz to 13 MHz), low power consumption (5V/52mA), good input (RF) and output (IF) return loss (>10dB). Since the DNC uses PLL synthesizer instead of DRO as the LO generator, the frequency accuracy utterly depends on the resonance frequency of crystal circuits, the LNB based on TFF101x is free of tuning, so both design and production become much easier.

This paper intends to describe a Ku band universal single LNB design which is used to evaluate the final performance when TFF101x is used in a real US LNB. It is well known that the LNA contributes the most NF (Noise Figure) of a total LNB, and the DNC contributes a smaller part of NF. To evaluate the final NF of a TFF101x LNB, a typical LNA with the popular transistor NE3503M04 is designed, and the relevant circuit parameters are given. The layout for TFF101x is discussed in detail, which is very important for NF, gain, phase noise and spurious suppression. The design files includes the schematic, layout, BOM, mechanical design are all presented then. To evaluate the reference design, both RF performance and signal quality are measured and compared with some discrete US LNBs in the market.

2. General Description

To evaluate the performance of TFF101x in a real US LNB, the design should be close to a real US LNB as much as possible. For convenience in RF measurement, the target prototype only differs from real US LNB in two points:

- The input interface is a circular waveguide (CWG) instead of a feed horn.
- The output interface is a 50Ω SMA connector instead of a 75Ω F type connector.

The LNA implemented in the LNB is a typical two-stage LNA based on NE3503M04, and in which, the power supply for the first stages are used for switching the polarization of vertical or horizontal.

Some performance like LO offset, phase noise and output power mainly depend on the performance of TFF101x, which has been well solved in single TFF101x EVB. The other performance like NF, gain flatness and image rejection mainly or partly depend on the external RF front-end. To make sure that the TFF101x LNB is satisfied with the current applications, the performance should be comparable with the available discrete LNBs in the market. The desired performance is shown in Table 1.

Table 1. Target Performance

Parameter		Value	Unit	Comments
Input Frequency	Low Band	10.70 to 11.70	GHz	
	High Band	11.70 to 12.75	GHz	
Output Frequency	Low Band	950 to 1950	MHz	
	High Band	1100 to 2150	MHz	
Local Oscillator Frequency	Low Band	9.75	GHz	
	High Band	10.6	GHz	
Phase Noise	At 10 kHz offset	-75	dBc/Hz	
Conversion Gain		55 to 70	dB	Depends on which TFF IC used
Gain Ripple		3	dB	
Noise Figure	Low Band	1.1	dB	Comparable with the discrete US LNB in the market
Image Rejection		40	dB	
1dB Compression Point		0	dBm	
3rd Order Intermodulation		10	dBm	
Output Return Loss (50 Ω)		10	dB	
Cross Polar Rejection		20	dB	
Current Consumption		75	mA	

3. Design

The LNB consists of a base with CWG input, a cover for shielding, a PCBA with probes soldered. A fixture is made to assemble them precisely.

Since the Ku band LNB operates at very high frequency, the dimension of the base, cover, the probes and the assembly accuracy affect the NF and gain significantly. This information is given before the introduction of the circuits design.

The circuits design starts from the schematic design, after that, the simulation of the LNA and the Band Pass Filter (BPF) is presented. The layout for TFF101x is discussed in detail then, and in the end, the final PCB and the BOM are given.

3.1 Mechanical Design

The dimension of the CWG and the CWG to microstrip adapter (the probe) are very sensitive to the NF of the LNB. The impedance of the probes, including the input circuits of the LNA, are obtained by 3D EM simulation (the model is shown in Figure 2), and will be implemented in the simulation of LNA in Section 3.3. The PCB material is Rogers 4003 with 20mil thickness, which has similar property with the special LNB laminates Rogers 4233, but more popular in PCB manufacturer.

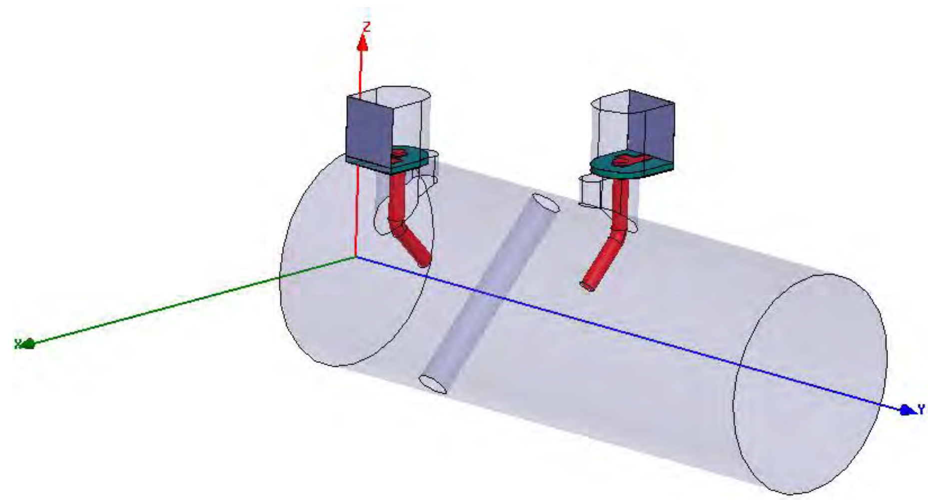
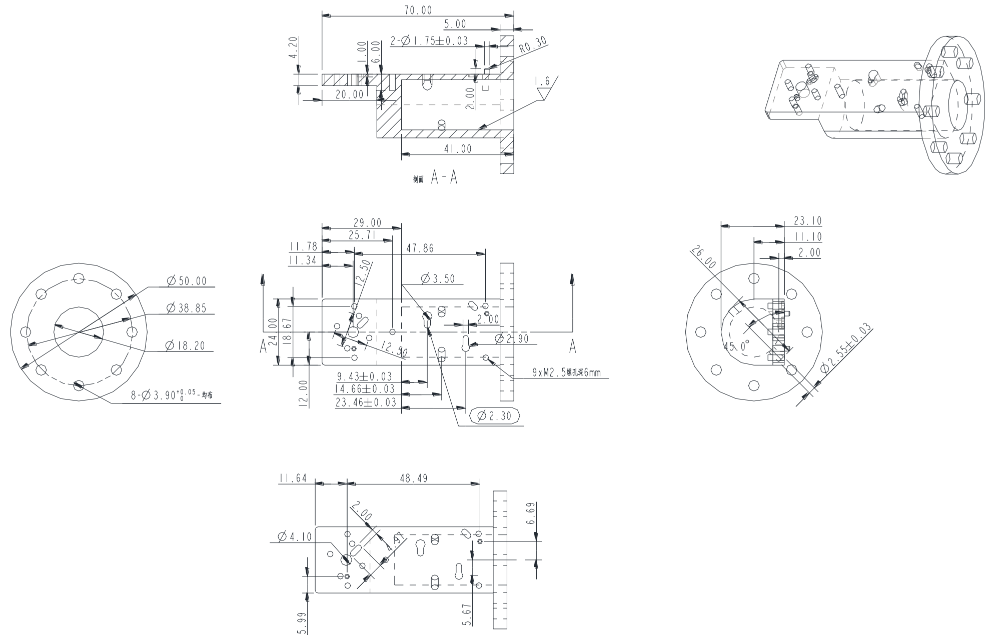
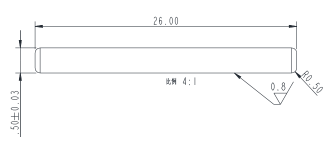


Fig 2. CWG to microstrip adapter

The drawing of the base (including a short stick) and probes are shown in Figure 3 and Figure 4 respectively, and the dimensions of the CWG, probe and probe holes are based on the dimension in the model in Figure 2. It is also important to assemble the probe with right direction and position. To solder the probes precisely, a fixture is designed to position the probes during soldering, and the assembly process is shown in Figure 5.



(1) Base



(2) Short stick

Fig 3. LNB base

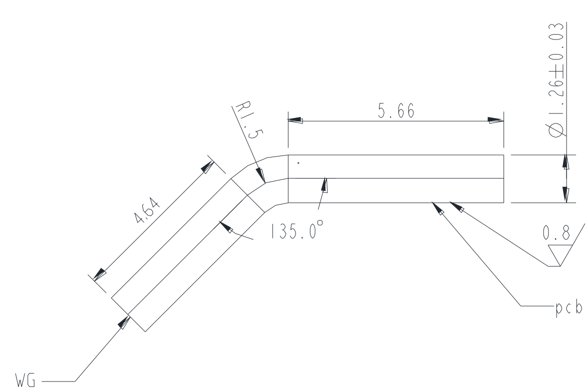


Fig 4. Probe

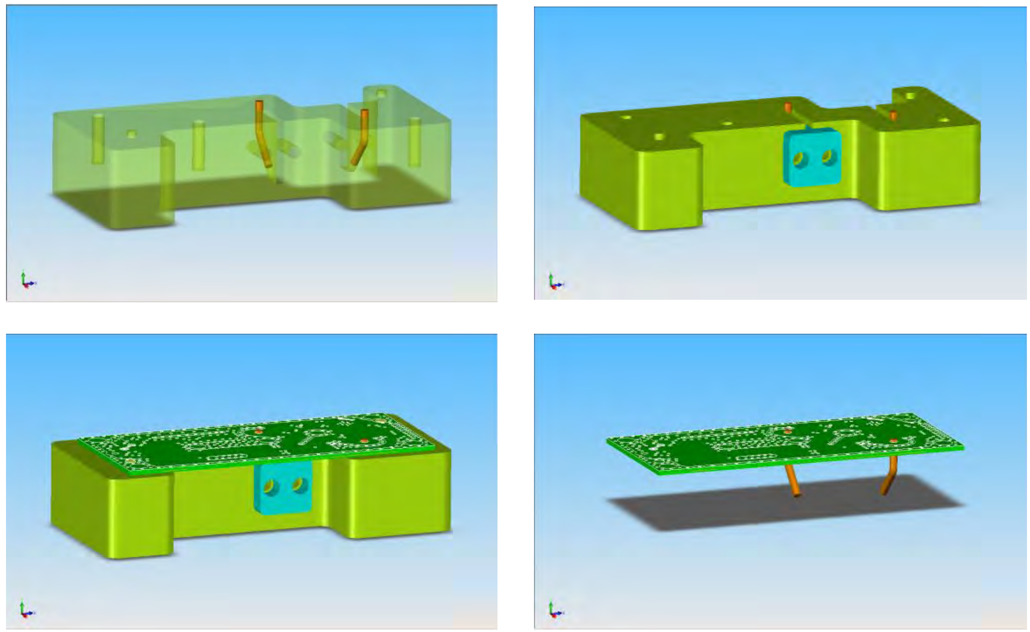


Fig 5. Probe assembly process

3.2 Schematic

The Schematic of the reference Ku band US LNB is shown in Figure 6.

Three pieces of NE3503M04 are used as the two-stage LNA for both vertical and horizontal polarization. ZXNB4202 is chosen as the voltage regulator and bias IC.

A JFVNY's 25MHz crystal is selected for the reference of the PLL. The overtone order is fundamental for stable temperature performance and the load capacitance is 8pF for accurate LO frequency.

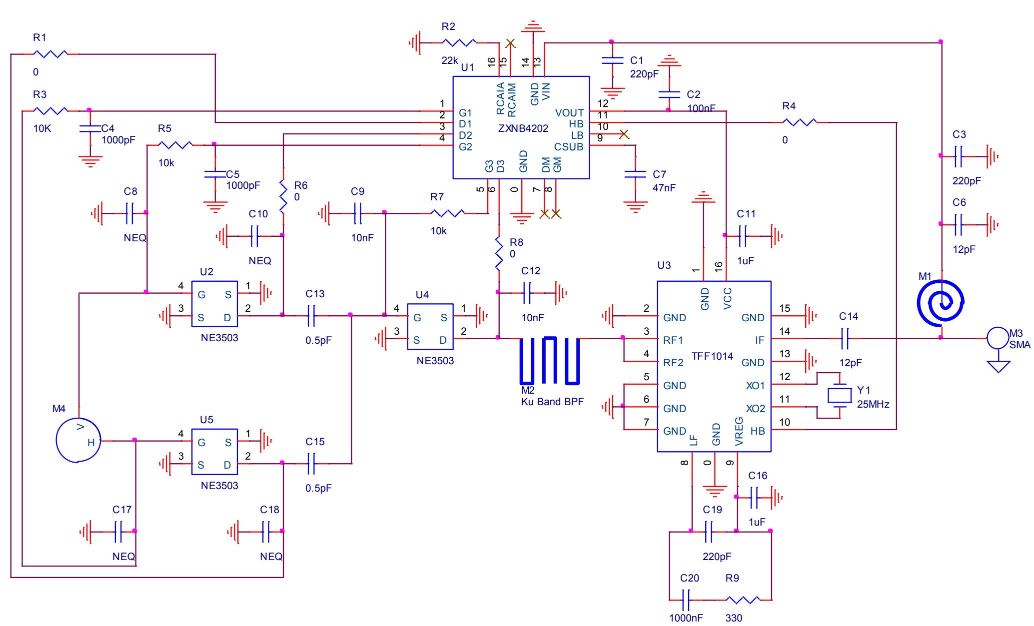


Fig 6. Ku band US LNB schematic

3.3 LNA and BFP Simulation

The LNA and BPF in Figure 6 is simulated and optimized for excellent NF, gain flatness and image rejection. The Simulation model is shown in Figure 7. SNP1 is the S parameters of the CWG to microstrip adapter, which is mentioned in Section 3.1. SNP2 and SNP3 is the de-embedding model to remove the effect of the overlapped parts in SNP1 and the NE3503 Model. The intermediate matching network, output matching network and the BPF are modeled by Momentum for better accuracy.

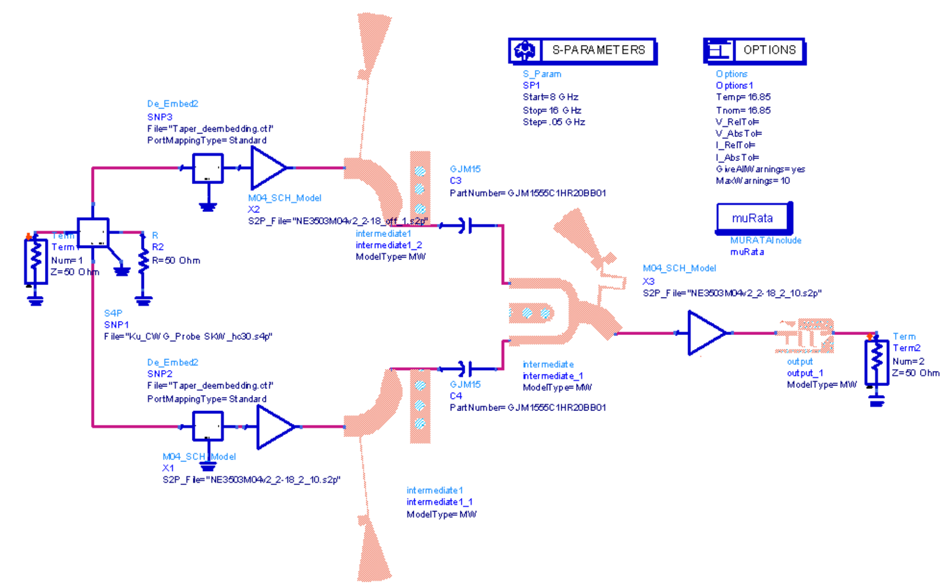
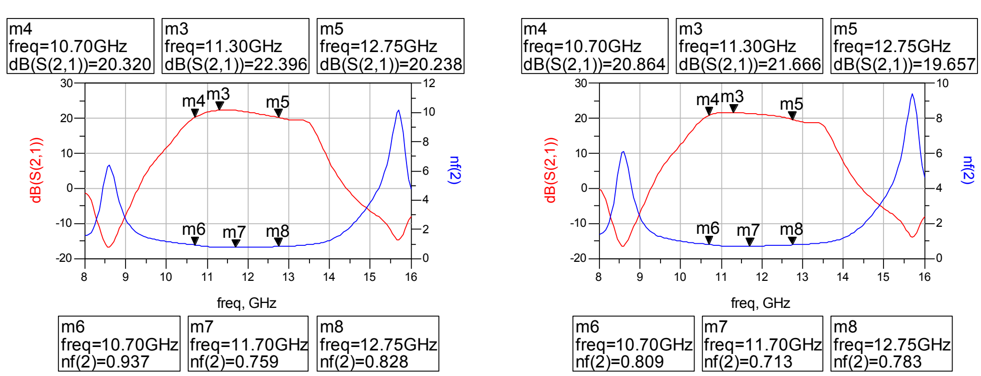


Fig 7. LNA and BPF ADS model

According to the simulation (the result is shown in Figure 8), the NF of both polarization paths, not taking account of the contribution of the DNC, is about 0.8dB. The total gain including the probe, the 2-stage-LNA and the image rejection BPF is about 20dB.



a. Vertical

b. Horizontal

Fig 8. LNA and BPF ADS simulation result

3.4 Layout

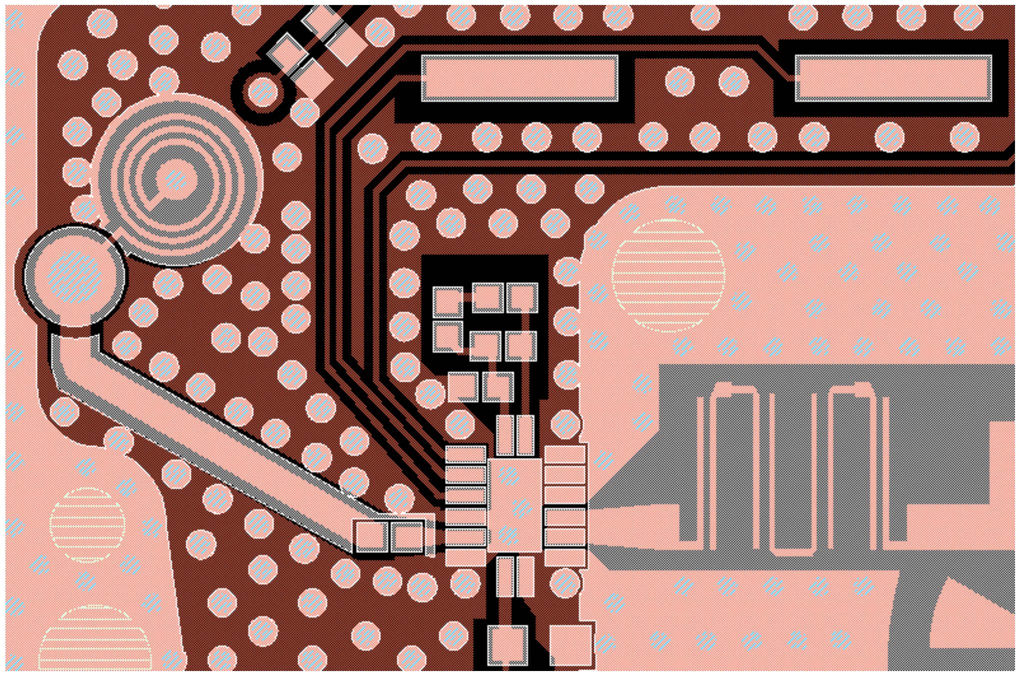


Fig 9. The footprint of TFF101x and surrounding circuits

The layout for TFF101x is zoomed and shown in Figure 9. There are some important points highlighted as follow.

- Grounds.
  - The die pad MUST be well grounded. There are three via, with 0.5 mm diameter, mapped directly on the die pad.
  - GND via should be put as close as possible to the other GND pins.
  - It is strongly recommended to copy all the GND via in and surrounding TFF101x to any practical design.
- Footprint.
  - Die pad size: 2x1 mm. And soldering mask is 0.1mm larger for each side.
  - Other pads 0.85x0.3mm, slightly bigger than the pins for easier soldering. And the soldering mask is 0.05mm larger for each side.
  - It is strongly recommended to copy the footprint of TFF101x to any practical design.
- RF input.
  - 50 Ω transmission line which has been used in TFF101x EVB before is used here again.
- IF line.
  - 50 Ω Coplanar Waveguide with Ground (CPWG) line for good matching and anti-inference. The width of the CPWG line is 20mil, which is identical with the width of a 0402 capacitor.

- Decoupling capacitors.
  - There two decoupling capacitors for TFF101x: one is for VCC and the other is for VREG. Both should be placed as close as possible to the power pins.
- Loop filter.
  - The area of the loop filter (LF) should be as small as possible.
  - There is a GND ring surrounding the LF, for shielding the interference.
- 25MHz crystal.
  - The pair of 25MHz lines goes parallel like differential lines for better anti-interference.
  - The gap between the 25MHz lines, as well as their width, should be as thin as possible (both are 0.15mm actually).
  - As much as GND on both side of the 25MHz lines

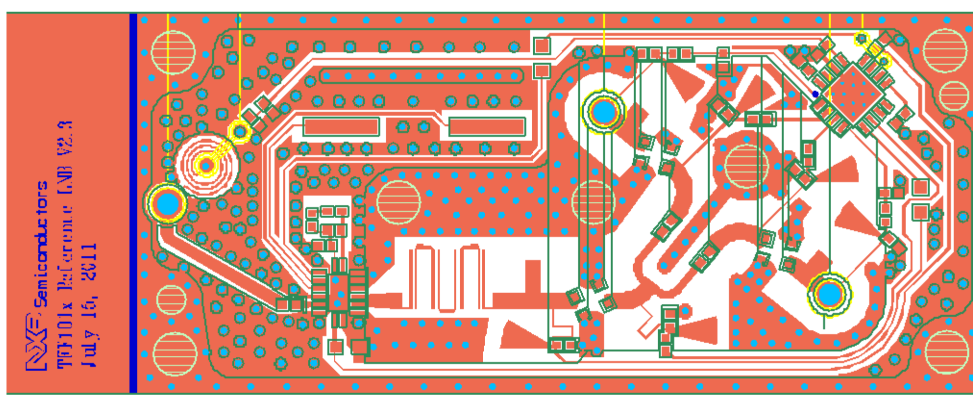


Fig 10. Final PCB

The final PCB layout is shown in Figure 10. The maroon filled patterns are the top layer, the golden outlines are the bottom layout, the light blue filled circles are plated via, the white shadowed circles are non-plated holes for mounting, and the white outline is the soldering mask layer.

3.5 Bill of Materials

Table 2. Bill of materials

Designator	Description	Footprint	Qty	Value	Supplier Name/type
U1	Bias IC	QFN1644	1		ZETEX -ZXNB4202JB16TC
U2,U4,U5	HJFET	SOT343	3		Renesas-NE3503M04
U3	FIMOD	DHVQFN16	1		NXP -TFF1014N1
C1,C3,C19	Capacitor	0402	3	220pF	Murata-GRM1555C1H221J

Designator	Description	Footprint	Qty	Value	Supplier Name/type
C2,C20	Capacitor	0402	2	0.1uF	Murata-GRM155R71C104K
C4,C5	Capacitor	0402	2	1000pF	Murata-GRM155R71H102K
C6,C14	Capacitor	0402	2	12pF	Murata-GRM1555C1H120J
C7	Capacitor	0402	1	47nF	Murata-GRM155R71E473K
C9,C12	Capacitor	0402	2	10nF	Murata-GRM155R71H103K
C11	Capacitor	0603	1	1uF	Murata-GRM188R61A105K
C13,C15	Capacitor	0402	2	0.5pF	Murata-GJM1555C1HR50B
C16	Capacitor	0402	1	1uF	Murata-GRM155R61A105K
R1,R6	Resistor	0402	2	0	Ralec-RTT02000J
R2	Resistor	0402	1	22k	Ralec-RTT022202F
R3,R5,R7	Resistor	0402	3	10k	Ralec-RTT021002F
R4,R8	Resistor	0603	2	0	Ralec-RTT03000J
R9	Resistor	0402	1	330	Ralec-RTT023300F
Y1	Crystal	HC-49XA	1	25MHz	JFVNY-HC-49XA-C08TTA-25.000MHz

3.6 LNB View

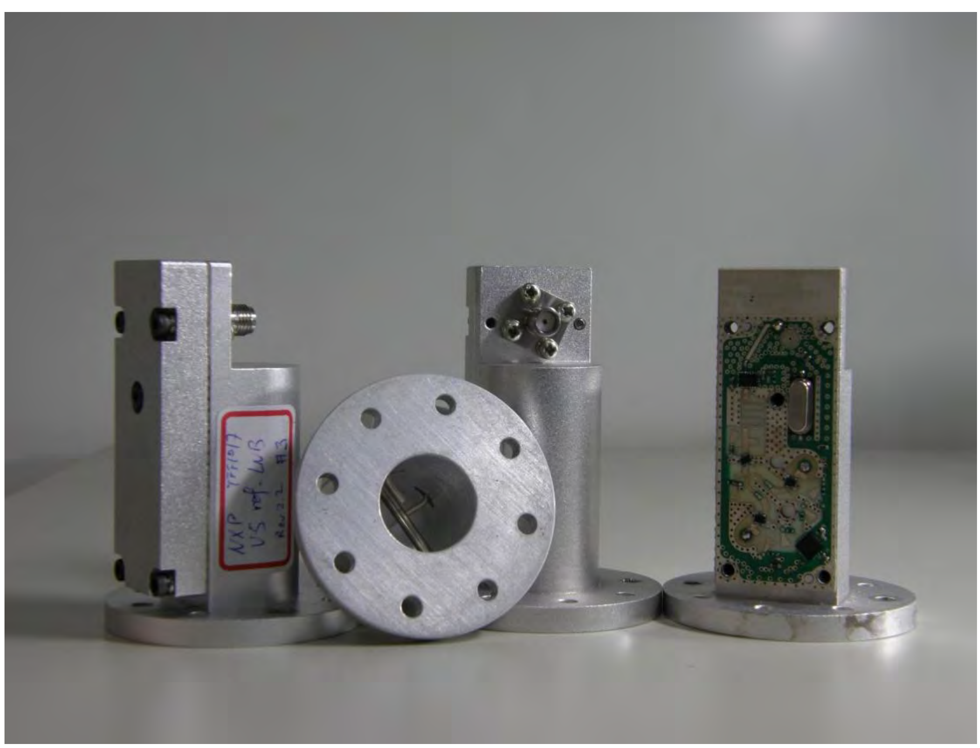


Fig 11. LNB view

4. Measured Results

The items in Table 1 are measured and given in Section 4.1, while the live signal test has also been implemented and results is shown in Section 4.2.

4.1 General Performance

Five US LNBs have been made. LNB #1 and #2 are based on TFF1015, #3 is based on TFF1017, #4 is based on TFF1014, and #5 is based on TFF1018. The conversion gain of different type of DNC is compared in Section 4.1.1. And in Section 4.1.2, The NF curves of all the LNBs, as well as that of two discrete LNBs from W Company and S Company as the benchmark, are given. The plots of the phase noise and output return loss are shown in Section 4.1.3 and Section 4.1.4 respectively. All the measured specifications are summarized in Section 4.1.5.

4.1.1 Conversion Gain

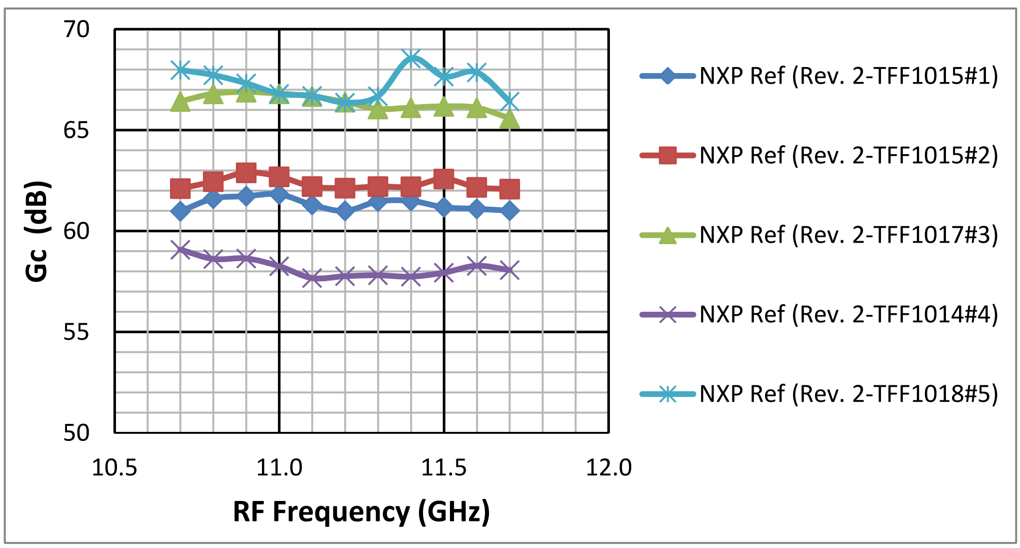


Fig 12. Conversion gain measurement results (Low band/Vertical)

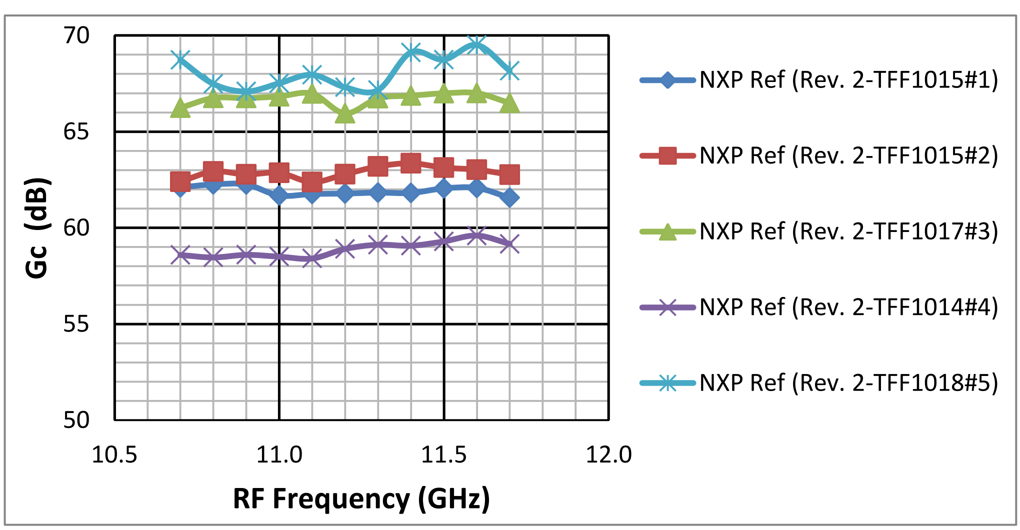


Fig 13. Conversion gain measurement results (Low band/Horizontal)

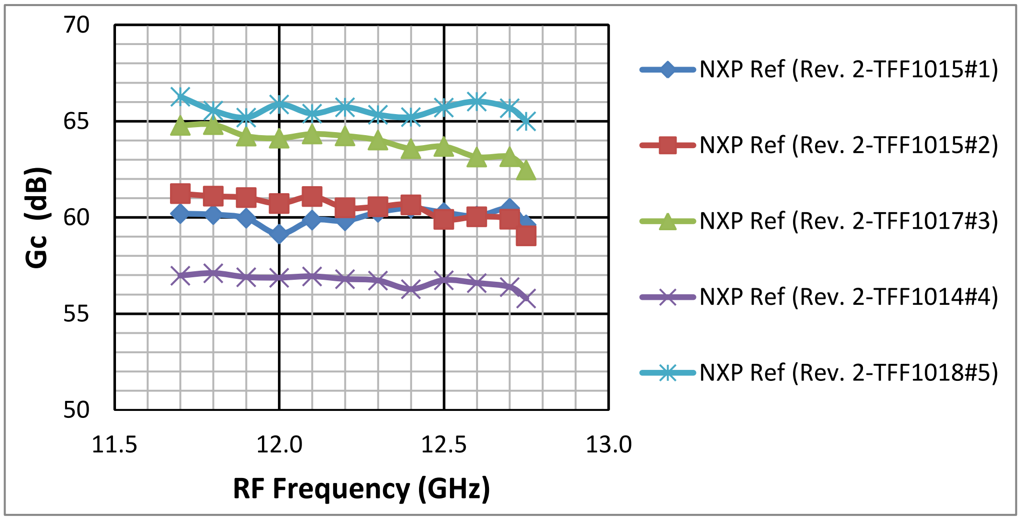


Fig 14. Conversion gain measurement results (High band/Vertical)

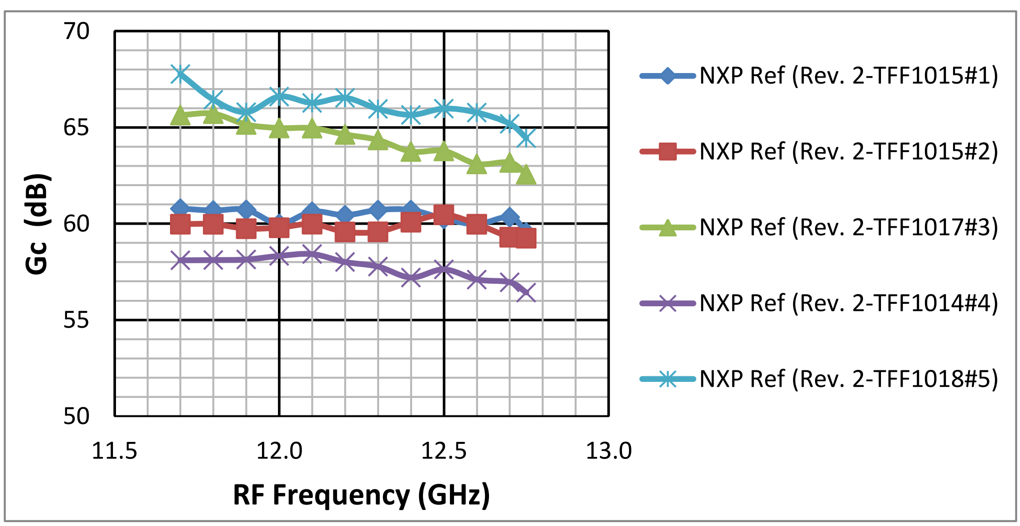


Fig 15. Conversion gain measurement results (High band/Horizontal)

As shown in Figure 12 to Figure 15, the conversion gain of LNB with TFF1014 is 58dB and 57dB at low band and high band respectively; for TFF1015 LNB, these values are 62dB and 60dB respectively; for TFF1017 LNB, they are 66db and 64dB; and for TFF1018 LNB, they are 68dB and 66dB.

4.1.2 Noise Figure

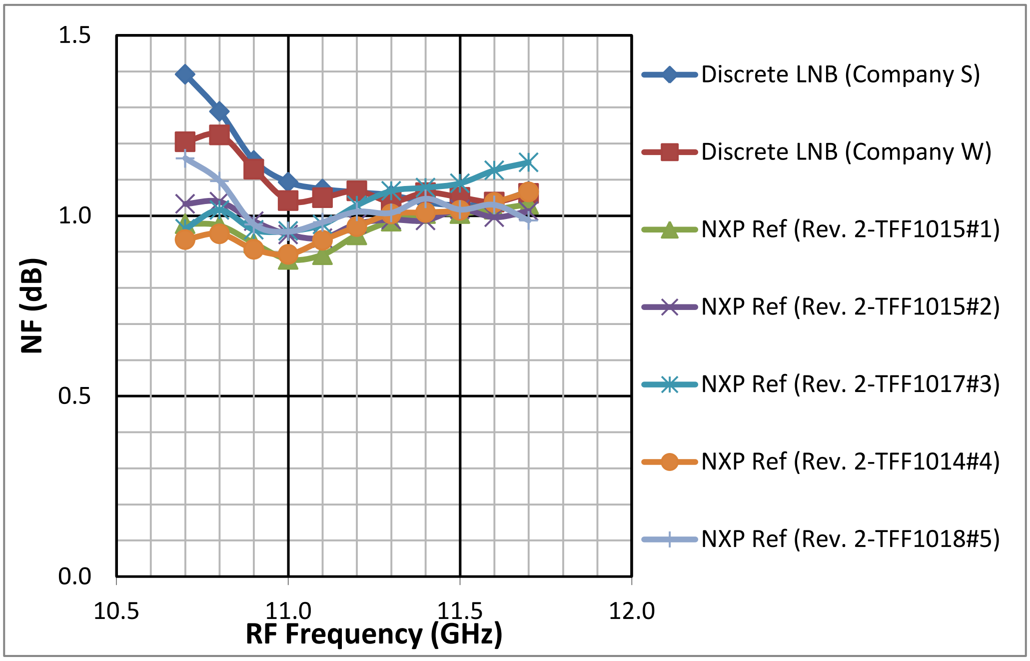


Fig 16. Noise figure measurement results (Low band/Vertical)

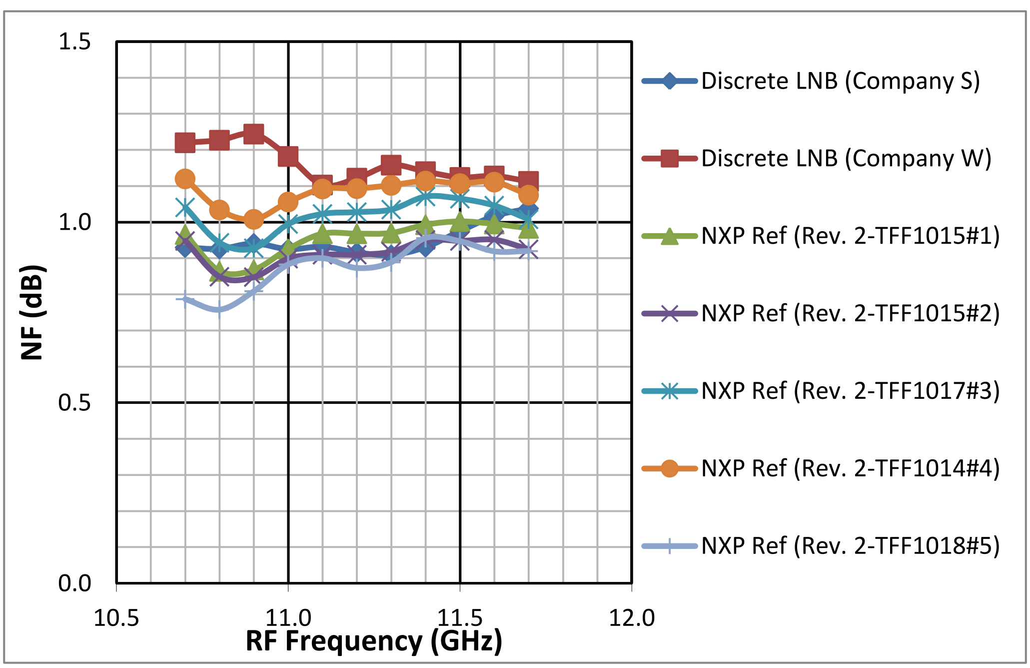


Fig 17. Noise figure measurement results (Low band/Horizontal)

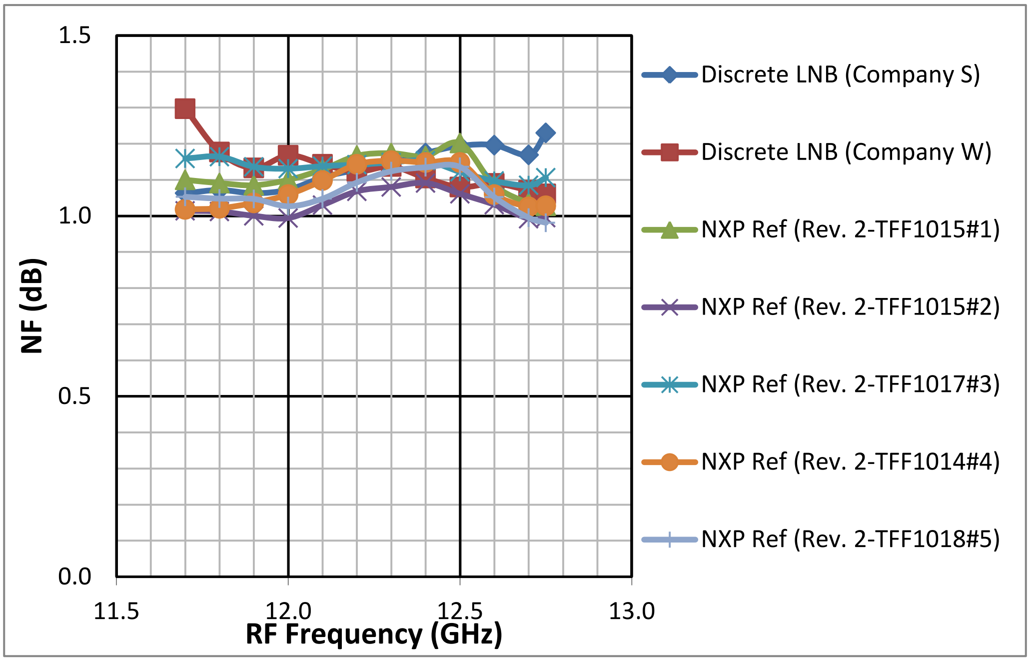


Fig 18. Noise figure measurement results (High band/Vertical)

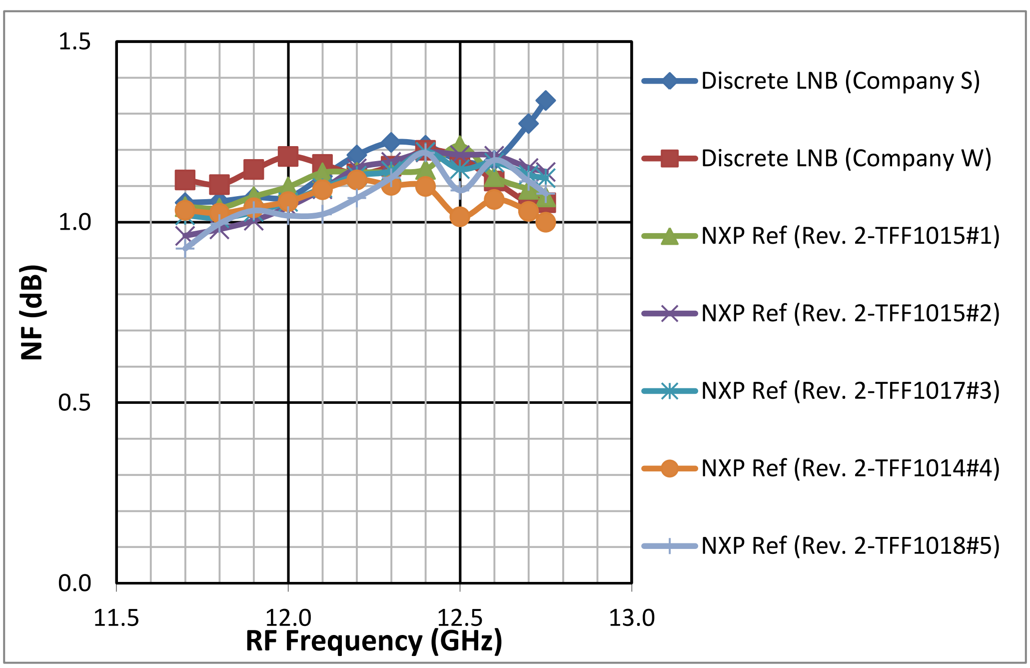


Fig 19. Noise figure measurement results (High band/Horizontal)

The NF of all the NXP US LNBs are plotted in Figure 16 to Figure 19 for low band and high band respectively, and as a reference, the NF of discrete LNBs of S Company and W Company, measured in the same system, is also given for comparison.

The NF of all the LNB based on TFF101x is comparable with that of discrete LNB. The NF is about 1.0dB at low band and 1.1dB at high band. The worst NF in the full band is no worse than 1.2dB.

4.1.3 Phase Noise

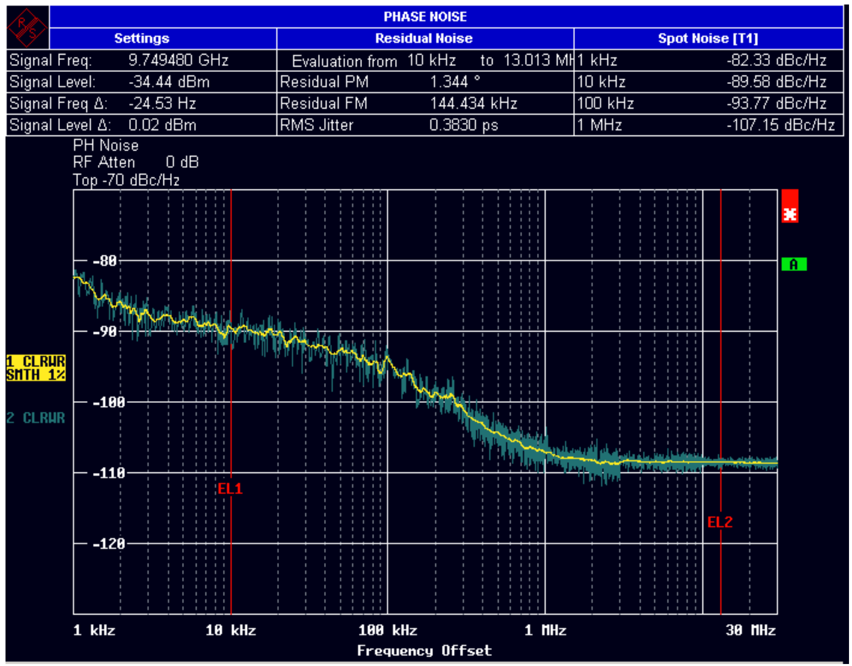


Fig 20. Phase noise measurement results (LNB #3, low band)

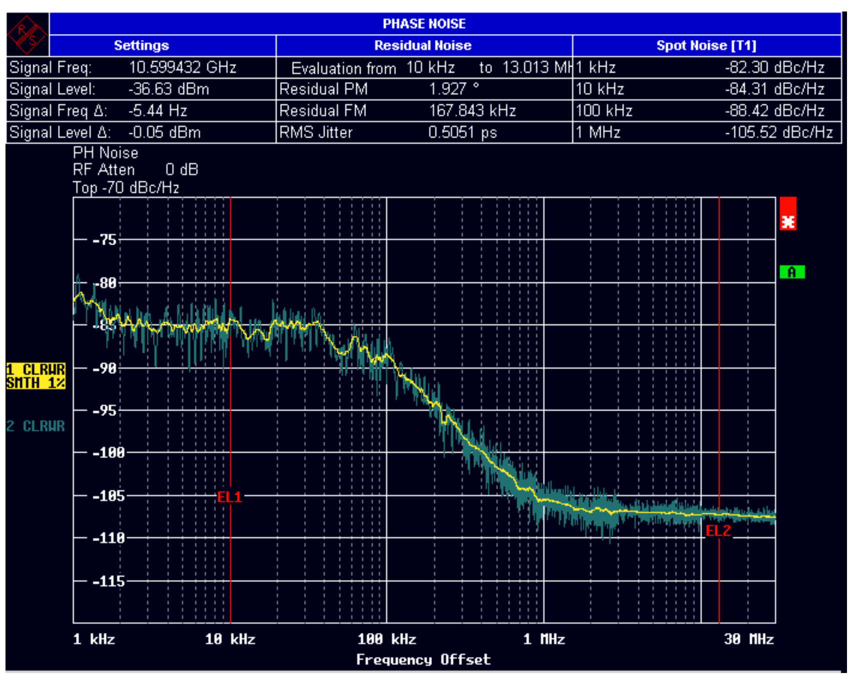


Fig 21. Phase noise measurement results (LNB #3, high band)

The #3 LNB based on TFF1017 is selected for the phase noise test, because the LO (Local Oscillator) magnitude leakage to IF port of the other LNBs is too small to measure the far end phase noise accurately. The phase noise (Figure 20) of 9.75GHz LO is -82, -90, -94, and -107dBc/Hz at 1k, 10k, 100k, 1MHz respectively, and those for 10.6GHz LO (Figure 21) is -81, -84, -88, -106dBc/Hz. The LO offset is about -500kHz.

4.1.4 Output Return Loss

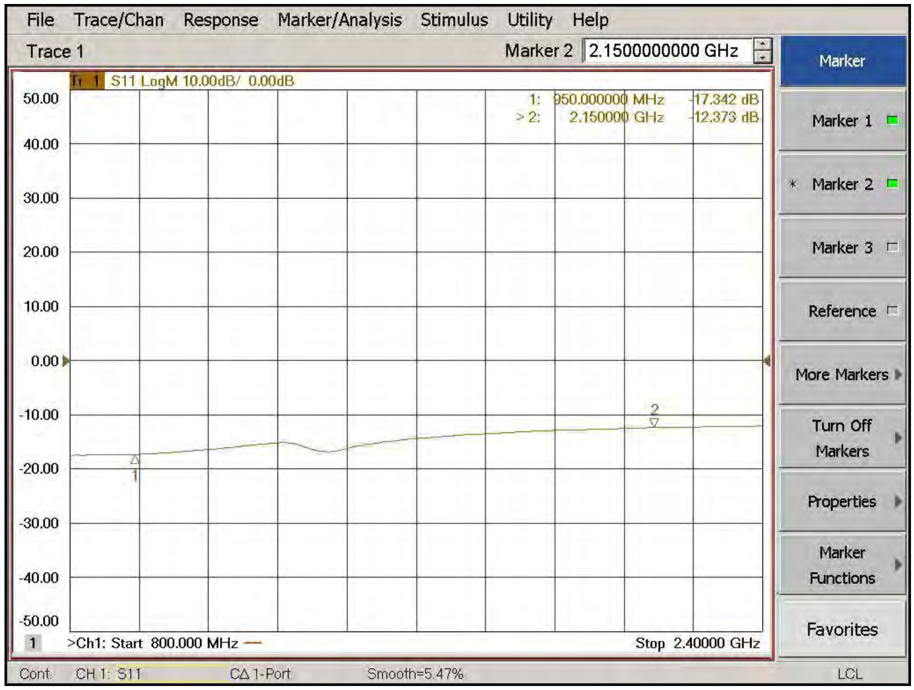


Fig 22. Output return loss measurement results (LNB #1)

As shown in Figure 22, the worst output return loss (for 50 Ω, only for reference) is -12dB.

4.1.5 Summary

Corresponding to the specification in Table 1, the items are measured and filled into Table 3. All the specifications reach the targets, or even better.

Table 3. Expected and Measured Results

Parameter			Expected	Measured	Unit	Comments
Local Oscillator Frequency	Low Band		9.750000	9.749499	GHz	500kHz offset
	Low Band		9.750000	9.749499	GHz	
Phase Noise	At 10 kHz offset		-75	-90 to -85	dBc/Hz	
Conversion Gain	TFF1014	LB	55 to 70	58	dB	
		HB		57		
	TFF1015	LB		62		
		HB		60		
	TFF1017	LB		66		
		HB		64		
	TFF1018	LB		68		
		HB		66		
Gain Ripple			3	3 (Max.)	dB	
Noise Figure	Low Band		1.1	1.0	dB	Comparable with the discrete US LNB in the market
	High Band		1.3	1.1	dB	

Parameter	Expected	Measured	Unit	Comments
Image Rejection	40	~56	dB	tested at 9.5GHz (image of 11.7GHz for HB)
1dB Compression Point	0	4.1	dBm	IF=2150 MHz
3rd Order Intermodulation	10	18 (Min.)	dBm	IF=2000 MHz
Output Return Loss	10	12	dB	For 50 Ω
Cross Polar Rejection	20	20	dB	at 12.75GHz
Current Consumption	75	75 (Typ.)	mA	

4.2 Signal Quality

The #2 NXP reference LNB is mounted on a Rover (approx 2 meters) 60cm triax parabolic antenna to receive the signal from satellite of Astra 19.2^{E}, and the Modulation Error Ratio (MER) is measured (the weather condition of almost blue sky, temperature approximately 5˚C) and shown in Figure 23. The MER of 8PSK and QPSK are both around 14dB, which meets Astra's requirement.

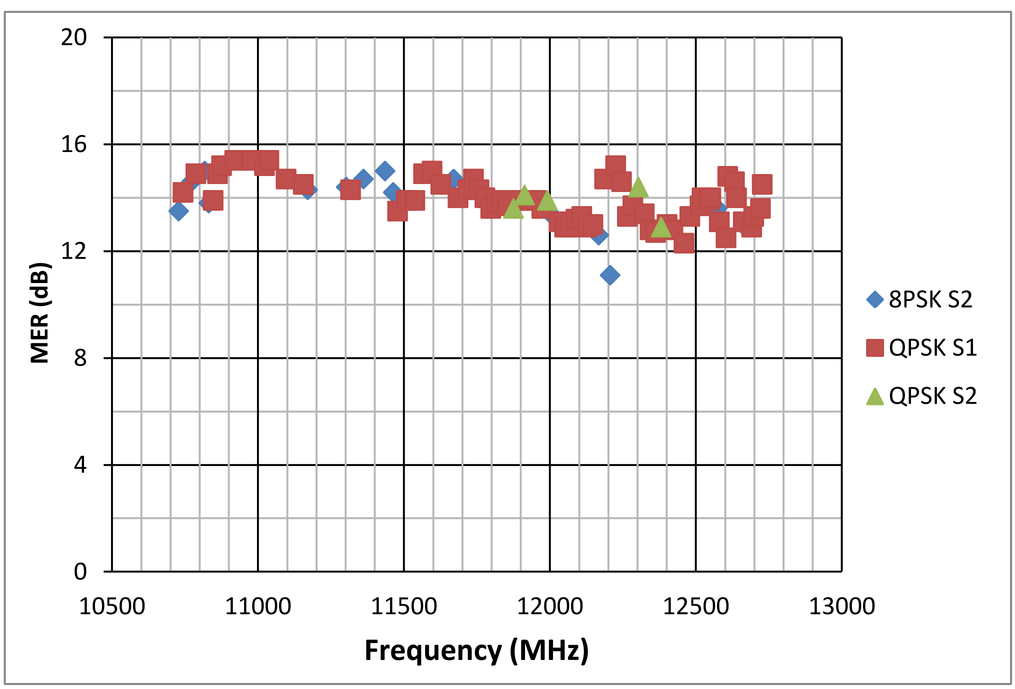


Fig 23. MER for N-PSK signal with NXP LNB #2 (TFF1015)

5. Conclusions

A design of Ku band universal single LNB based on TFF101x has been made, and all specification match the requirement for DVB-S application.

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7. List of figures

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