

Co-Design of Dual-Band Low Noise Amplifier Operating in 900MHz/1800MHz Bands for Multi-standard Wireless Receiver

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Abstract—In this paper the design of a fully concurrent dual-band (900/1800MHz) low-noise amplifier (LNA) is presented, the main aim is to bring the noise figure below 3dB to improve the performance of modern receivers. Two single band LNAs operating at GSM 0.9GHz and Digital Cellular System (DCS) 1.8GHz are separately designed using traditional method first then both single-band matching networks are merged, one dual-band matching network (MNs) of the dual band LNA is designed at (900MHz and 1800MHz). This is a single stage amplifier. The dual band LNA is designed to provide low noise figure. The fully concurrent LNA circuit designed using BFG520 Transistor technology, and simulated in Advance Design System (ADS) of version 2009A. For use in multi-standard wireless receiver frontend the proposed design is very useful because the noise figure obtained is suitable for the better performance. The simulation results show that single band LNA at 900 MHz gives the Noise figure of 1.2dB while at 1800MHz it is increased to 2.6dB, the dual band design provides the Noise figure of 1.19dB and 2.71dB for 900MHz and 1800MHz respectively, using 100mA current from 9V power supply with the power consumption of 0.9 Watt.

Keywords—Low Noise Amplifier, Matching Network

I. INTRODUCTION

In the recent years the telecommunication sector is developing swiftly and this development provided growth in radio frequency (RF) operated systems. The demand for high performance and low noise communication circuits has been increased. The LNAs are widely used in the RF and microwave receivers. The LNA is an important component in the front-end of RF receivers [i]. New-generation radio receivers are capable of operating at different frequency bands. Low noise Amplifiers (LNAs) working at wide frequency band and with multi operating standards are required. It is important to design Low Noise Amplifiers operating at different frequency bands. In the receiver chain LNA is the first active element so the overall noise figure

(NF) of the receiver depends on the noise figure (NF) of LNA, which controls output Signal to noise ratio (SNR) and sensitivity of receiver [ii]. LNAs are a frontend device of any receiver system used in wireless communications and normally LNAs are inserted just after the antenna [iii, iv]. The wireless communication input signal is weak and unprotected against noise so the primary task while designing the Low Noise Amplifier is to enhance the signal power and minimizing the introduction of noise. In designing circuits for Low Noise Amplifier the major problem is to reduce noise figure as well as to provide a stable 50Ω input match for maximum power transfer [v].

Initially, two single band LNAs operating at 900MHz and 1800MHz are designed separately. One dual-band matching network (MNs) of the dual band LNA is designed at 900MHz and the other at 1800MHz finally both the networks are combined. This is a single stage amplifier [vi]. The results indicate that the co-design version has a performance similar to that of the cascade version, with the number of passive components reduced to nearly half. In this method, no separate mode control switch is required for channel selection. The values of passive devices in the dual-band Matching Network are determined by the formulae given in this manuscript.

II. BACKGROUND

Key elements in LNA are Noise figure, return loss and the gain, the performance of the system is strongly affected by low NF without adequate gain, and with high gain without low NF [vii, viii].

In the modern receivers, the power of the signal received is usually very low and needs to be properly amplified for further processing like base band operation, so the purpose to design LNA at the frontend is to amplify the signal received and to reduce the noise Fig. 9.

Overall noise figure of the receiver depends on the noise figure of LNA [x], output Signal-to-noise ratio (SNR) and sensitivity of the receiver is controlled by noise figure of LNA [xi], because of these reasons

LNA is considered the most important element of any wireless receiver. To optimize the gain and noise figure number of topologies have been used to implement LNAs, for example single stage LNA in CMOS processes for a standard wireless receiver and for multistandard wireless receivers concurrent and non-concurrent dual band LNAs are developed [xii].

In a dual band non-concurrent topology anyone of the single band is operated at specific operating frequency [xiii], in another topology two or more single bands working in parallel mode can consume more power in concurrent configuration. Wide band amplifiers are another topology but unwanted signals are also amplified with the input frequency band of interest which degrades the overall performance of the receiver [xiv].

14dB of Voltage gain has been achieved with noise figure of around 2dB for concurrent LNA operating at 900MHz/2.4GHz for multi-standard wireless receiver [v]. To implement multiband LNA there are number of approaches available like wide band, switch mode, parallel mode and concurrent mode LNA [ix, xv].

In this paper the approach followed is concurrent LNA using band pass filter in which the signal is fed to the LNA through band pass filter where the input and output impedance matching is specially considered, when compared with parallel LNA, concurrent LNA topology reduces the chip area or the module area as there would be only one driver circuit for all the frequency bands of choice, and could save the power consumption by reducing the number of passive components on chip. In wide band LNA, strong undesirable blockers are amplified together with the desired frequency bands and receiver sensitivity is significantly degraded [v, xiv].

III. PROCEDURE FOR CO-DESIGN

A. Primary matching network design

Suppose that ω_1 and ω_2 are the two operating angular frequencies for target Band pass filter BPF and LNA where ($\omega_1 < \omega_2$). First, according to method in [iv], BPF is designed, then single band input and output Matching Network(MN) are designed for two single band LNAs.

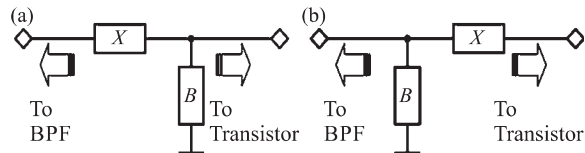


Fig.1. Two types of L-type Matching Networks [vi]

The schematic shown in Fig. 1 (a) and Fig. 1 (b) shows the series reactance and shunt susceptance values at ω_1 and ω_2 as X_1 , B_1 and X_2 , B_2 , respectively. Identical types of single-band Matching Networks MNs for both ω_1 and ω_2 will be used. The

next step is to combine these matching networks into dual band MNs. The general form of dual band matching network is shown in Fig.2.

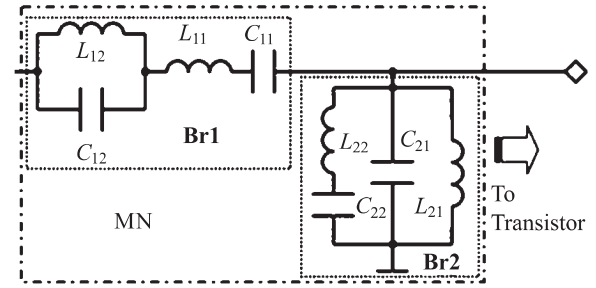


Fig. 2. Two branches of dual-band Matching Network [vi]

If the basic elements of X and B in Fig. 1 have the structure of branches (Br1) and (Br2) depicted in Fig.2, respectively, it can replace both circuits in Fig. 1 as a dual-band MN in Fig. 2 for the dual-band LNA. The value of each element of branches 1 and 2 in dual-band MN shown in Fig. 2 can be calculated using the following procedure [vi].

B. Translation of single band MNs into Dual band MN

Two single band matching networks designed for ω_1 and ω_2 can be converted into one dual band matching network having structure of Fig. 1 by using the following formulas.

First of all, find out values of each element in the series branch (Br1) of the dual-band MN, the elements are L_{11} , C_{11} , L_{12} and C_{12} . Equation 1 and equation 2 give the relationship of these elements with a single band MNs series branch [xvi].

$$\omega_1 L - \frac{1}{\omega_1 C_{11}} + \frac{\omega_1 L_{12}}{1 - \omega_1^2 L_{12} C_{12}} = X_1 \quad (1)$$

$$\omega_2 L_{11} - \frac{1}{\omega_2 C_{11}} + \frac{\omega_2 L_{12}}{1 - \omega_2^2 L_{12} C_{12}} = X_2 \quad (2)$$

Taking further combination and resolving the expressions the current through L_{12} can be given as

$$C_{12} L_{12} = \frac{1}{\omega_1 \omega_2} \quad (3)$$

The values of L_{11} , C_{11} and C_{12} are dependent on L_{12} once it is calculated we can determine L_{11} , C_{11} and C_{12} from Equation 1-3. For L_{11} , C_{11} and C_{12} to be non-negative L_{12} should be minimum, L_{12min} can be given as;

$$L_{12min} = \max\left[0, \frac{(\omega_2 - \omega_1)(X_1 \omega_1 - X_2 \omega_2)}{\omega_1 \omega_2 (\omega_1 + \omega_2)}, \frac{(\omega_2 - \omega_1)(X_1 \omega_2 - X_2 \omega_1)}{\omega_1 \omega_2 (\omega_1 + \omega_2)}\right] \quad (4)$$

L_{12} is located to the smallest possible value. By putting value of L_{12} in equation (3) it can be able to calculate C_{12} which can be used to calculate L_{11} and C_{11} from equation (1).

In the same way, for the shunt branch (Br2) in the dual-band MN, the equations used to conclude L_{22} , C_{22} , L_{21} and C_{21} can be acquired as [xvi]

$$\omega_1 C_{21} - \frac{1}{\omega_1 L_{21}} + \frac{\omega_1 L_{22}}{1 - \omega_1^2 L_{22} C_{22}} = B_1 \quad (5)$$

$$\omega_2 C_{21} - \frac{1}{\omega_2 L_{21}} + \frac{\omega_2 L_{22}}{1 - \omega_2^2 L_{22} C_{22}} = B_2 \quad (6)$$

$$C_{22} L_{22} = \frac{1}{\omega_1 \omega_2} \quad (7)$$

$$C_{22} \min = \max\left[0, \frac{(\omega_2 - \omega_1)(B_1 \omega_1 - B_2 \omega_2)}{\omega_1 \omega_2 (\omega_1 + \omega_2)}, \frac{(\omega_2 - \omega_1)(B_1 \omega_2 - B_2 \omega_1)}{\omega_1 \omega_2 (\omega_1 + \omega_2)}\right] \quad (8)$$

Above formulas provide mathematical background for the design of dual band LNA, this is implemented in circuit designing and the theory is used to obtain our results [vi]

IV. BIASING NETWORK DESIGN

The approach is implemented in Advance Design System (ADS) to obtain the simulation results [xvii]. DC Voltage of 9V is applied to the transistor BFG 520 which is used in circuit. Biasing network is shown in Fig 3, with appropriate plan of biasing resistors, desired operating voltage and current were accomplished.

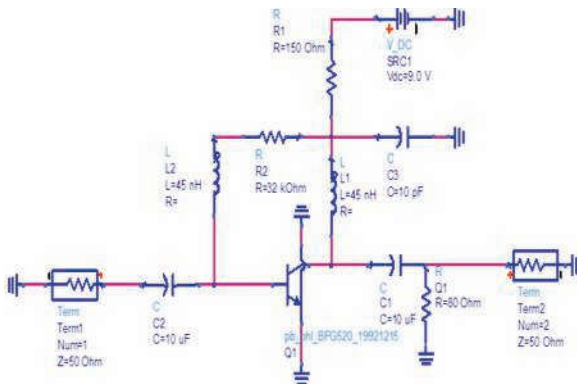


Fig 3. Schematic of biasing network

In this circuit the capacitors C1, C2 force that no direct current travels to the input and output portion of RF path. The C3 capacitor is used as a filter which prevents the unwanted noise and high frequency ripple signals from the direct current power supply, a capacitor of 10uF capacitance is more suitable in this circuit for blocking the DC. Two inductors L1 and L2 prevent the radio frequency signals travelling into the biasing network of circuit. These inductors L1 and L2 chokes are used to separate the radio frequency from the biasing network circuit. After analyzing the results, it was analyzed that to increase the maximum gain it is possible to set all the reactive components.

V. SINGLE BAND LNAS

First step in circuit of dual band low noise amplifier design is to design two single band low noise amplifiers at 900MHz and 1800MHz.

A. LNA design at 900MHz

Fig 4. Depicts the circuit diagram of LNA at 900MHz. Design includes a shunt capacitor of 4.43pF and a series inductor of 5.19nH as input matching network. Output matching network contains a shunt inductor of 55.5nH. These components make the proposed LNA design perfectly matched at 50Ω at both input and output ports.

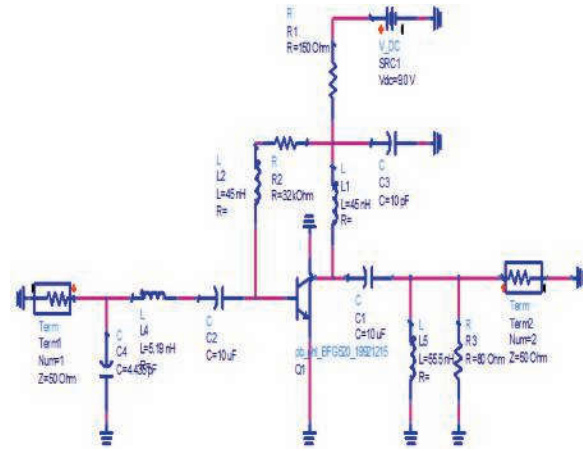


Fig 4. Matching Network Design of LNA at 900MHz

B. LNA design at 1800MHz

The circuit diagram of LNA at 1800 MHz is depicted in Fig 5. Design includes a shunt inductor of 3.35nH and a series capacitor of 2.82pF as input matching network. Output matching network contains a shunt inductor of 14.93nH. These components make this LNA design perfectly matched at 50Ω at both input and output ports at the desired operating frequency i.e. 1800MHz.

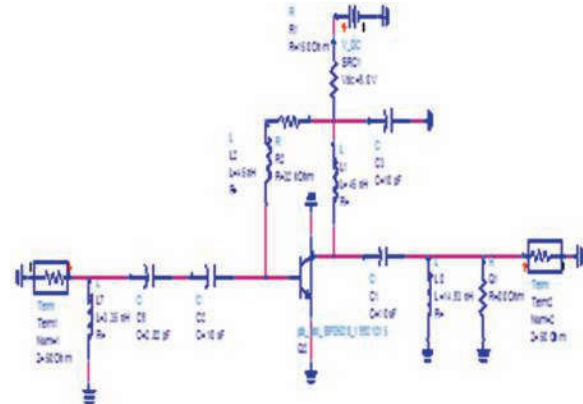


Fig 5. Matching Network Design of LNA at 1800MHz

C. Results of 900MHz LNA

In order to analyze the behavior of the RF devices or networks at a given frequency we need scattering parameters or S-parameter. Fig. 6 describes the curve of S-Parameter S (2, 1) it is the forward transmission of input at port1 and output at port2. Marker indicated the results of S (2, 1) at 900MHz. Forward transmission is taken in dB, in the biasing network and set the all values of components for high gain result, low noise and stability of the circuit. Fig. 6 shows that the gain of 14.138dB at 900MHz is obtained.

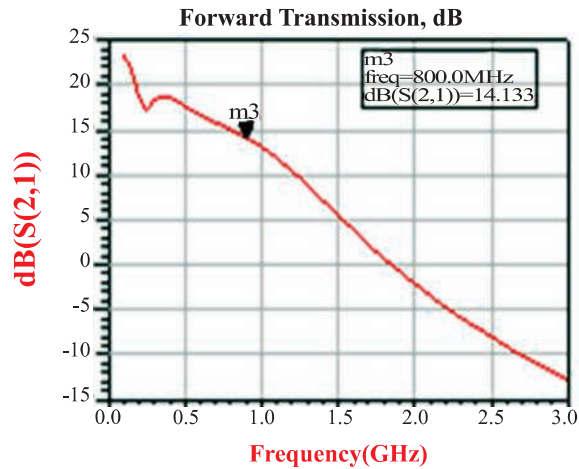


Fig. 6. Graph showing Forward transmission at 900MHz

Fig. 7. Shows the result of S-Parameter S (1, 2), which is the input transmission at port2 and output is port1. Marker M2 shows the result of S (1, 2) at 900MHz, which is around -27dB.

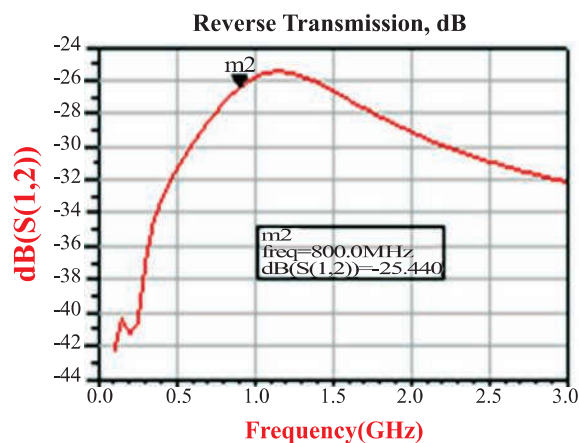


Fig. 7. Graph showing Reverse Transmissions at 900MHz

Input and output Coefficients of reflection are important for the maximum power transfer, Fig 8 shows the plots of input reflection coefficient on smith chart. The Marker (M1) in Fig. 8 shows that amplifier is

matched at 900MHz, since it has no imaginary part at the output port.

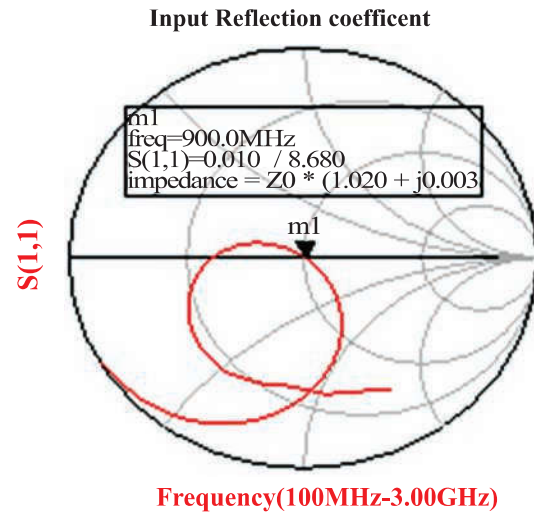


Fig. 8. Input reflection coefficient smith chart at 900MHz

Fig. 9 shows the plot of output reflection coefficient on smith chart. Marker shows that amplifier is matched at 900MHz, since it has no imaginary part at output port.

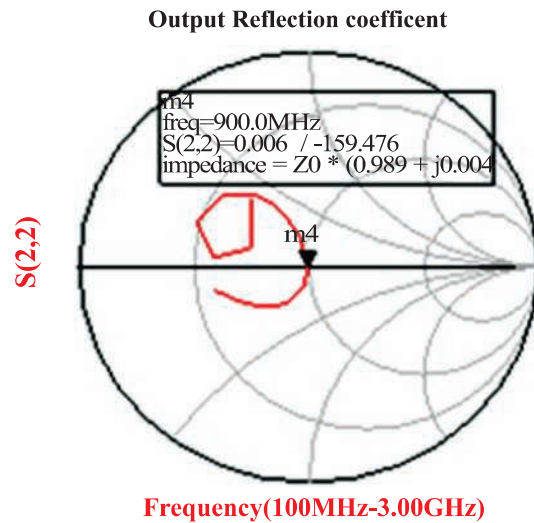


Fig. 9. Output reflection coefficient on smith chart at 900MHz

As depicted in Fig. 10, is the curve of minimum noise figure and the actual noise figure of design at 900MHz. The two curves blue and red shows the curve of minimum noise figure for the frequency between of 100MHz to 3.0GHz and the actual noise figure of the designed circuit network for the same frequencies respectively. Values of minimum noise figure and the actual noise figure at 900MHz is 1.01 and 1.208 respectively are also shown.

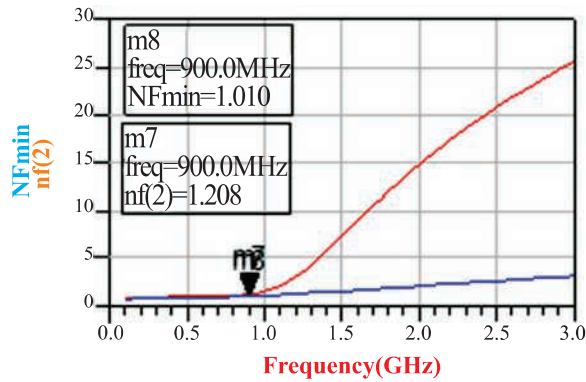


Fig. 10. Showing minimum and actual noise figure at 900MHz

The curve of stability function 'μ' after designed the matching network is shown in Fig 11. The red and blue lines in the plot stand for Stability Factor 'μ' (Load) and 'μ' (Source).

$$\mu > 1$$

is the condition for unconditional stability as shown in the graph represents that amplifier is stable.

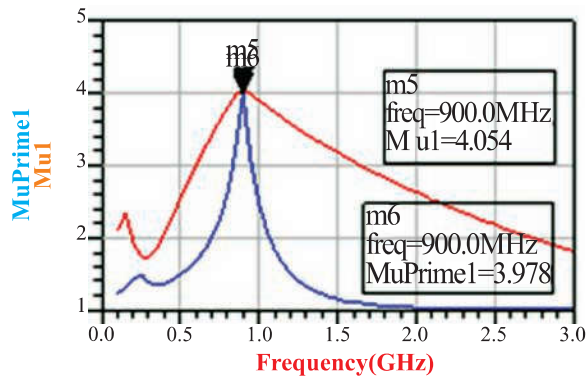


Fig. 11. Unconditionally stable at 900MHz

Fig. 12 demonstrates the plot for input reflection coefficient in the linear scale region below 10dB from 700MHz to 1.050GHz. These are the two boundary points of bandwidth; it is observed that frequency ranges of input and output return losses are less than -10dB.

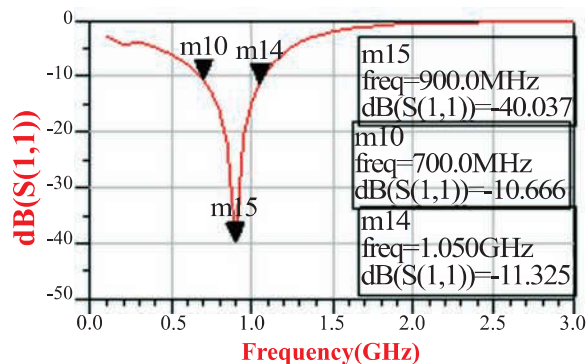


Fig. 12. Bandwidth at 900MHz

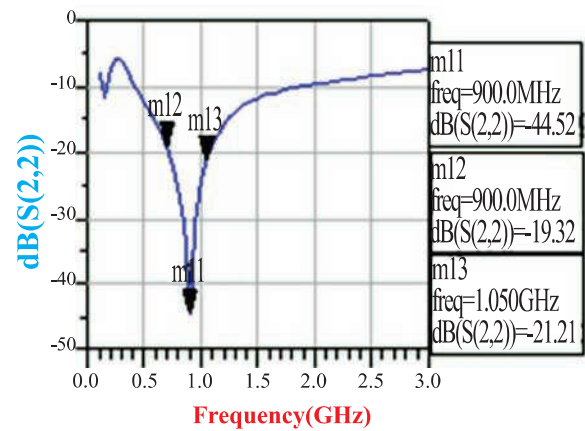


Fig. 13. Output reflection coefficients at 900MHz

The result of Output Reflection Coefficient (ORC) is demonstrated in Fig 13. The markers are positioned at the required points of bandwidth.

D. Results of 1800MHz LNA

Fig 14 represents the curves of S-Parameter S (2, 1). It is the Forward Transmission (FT) input at port1 and output is port2. Marker indicates the result of S (2, 1) at 1800MHz. Design the biasing network and set all the values of components for high Gain, Low noise and Stability. Fig 14 shows that the gain at 1800MHz is 8.577dB.

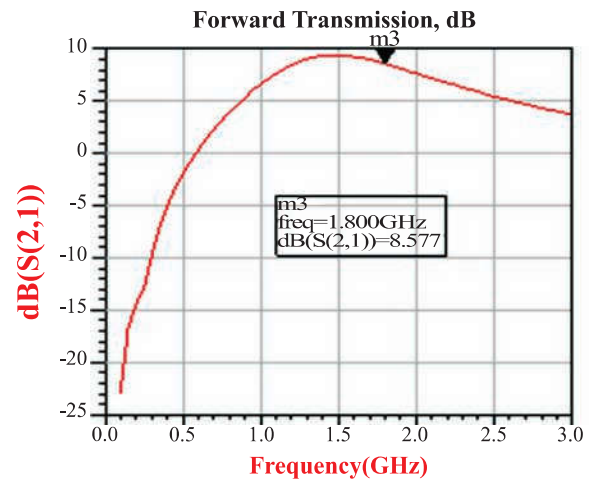


Fig. 14. Graph showing Forward transmission at 1800MHz

The Fig. 15 depicts the curve of S-Parameter S (1, 2) It is the transmission of input at port2 and output at port1. Marker(M4) shows the result of S (1, 2) at 1800MHz. Reverse transmission (RT) is taken in dB. The designed biasing network and all the set values of passive components the reverse transmission at port 1 is -20.324 dB at 1800MHz.

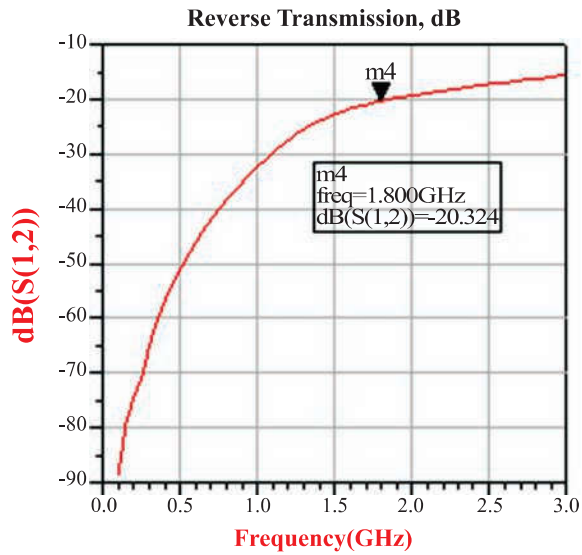


Fig. 15. Graph showing Reverse Transmissions at 1800MHz

The plots shown in Fig. 16 and 17 are the input reflection and output reflection coefficient on smith chart at 1800MHz respectively. Markers indicate that the amplifier is matched at 1800MHz as it has no imaginary part at input as well as output port.

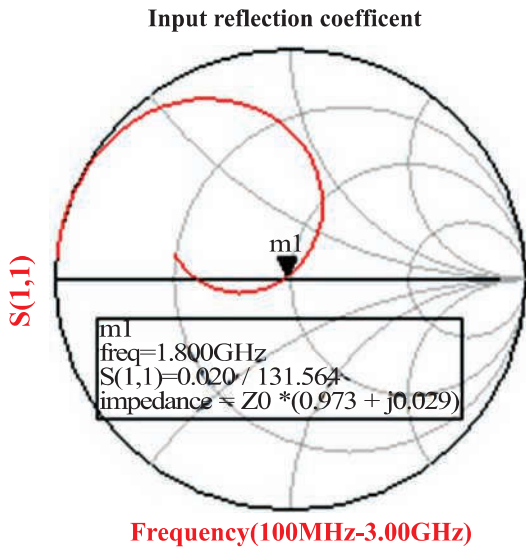


Fig. 16. Shows Input reflection coefficient smith chart at 1800MHz

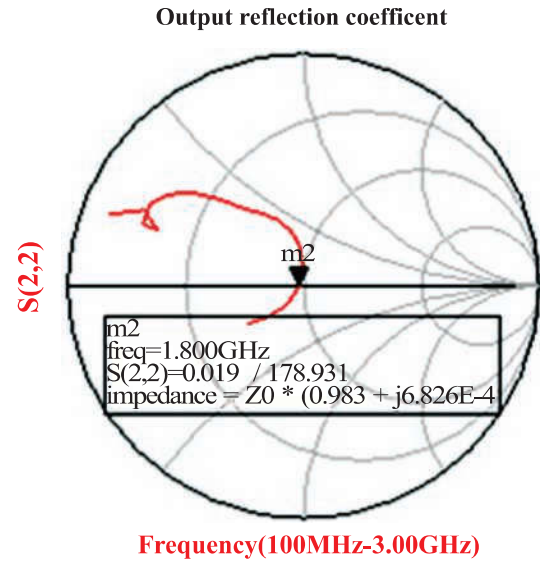


Fig. 17. Shows Output reflection coefficient on smith chart at 1800MHz

In Fig. 18 the curve of minimum noise diagram and the actual noise diagram of design at 1800MHz are depicted. Two curves in blue and red color show the range of minimum noise diagram in the frequency range from 0GHz to 3.0GHz and the actual noise diagram of designed network for the same frequencies, respectively. Values of min noise diagram and the actual noise diagram at 1800MHz are 1.847 and 2.625 dB, respectively.

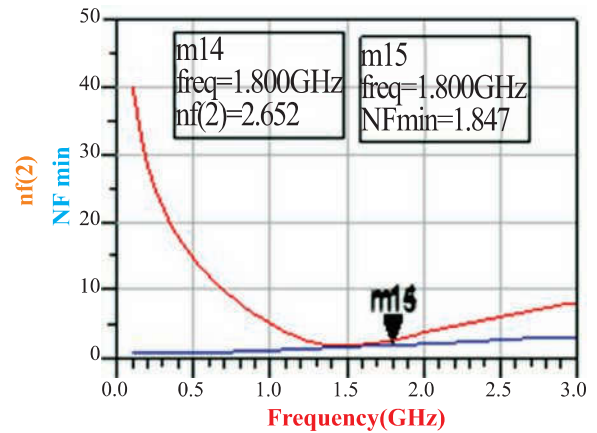


Fig. 18. Noise Figure at 1800MHz

Fig. 19 shows the condition for unconditional stability, graph shows that amplifier is stable.

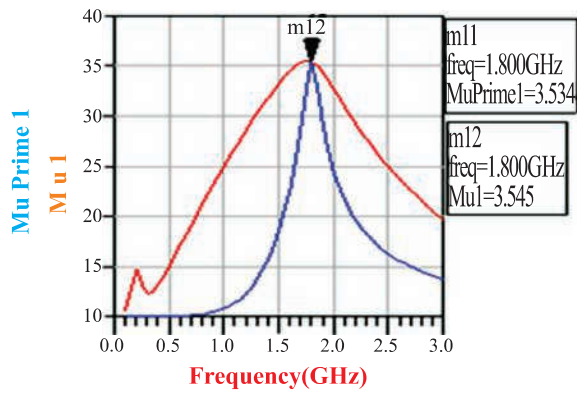


Fig. 19. Unconditionally stable at 1800MHz

Fig. 20 demonstrates the plot of input reflection coefficient in the linear scale in region below 10dB from 1.550GHz to 2.250GHz. These are the two boundary points for bandwidth. For these results both input and output return losses are less than -10dB.

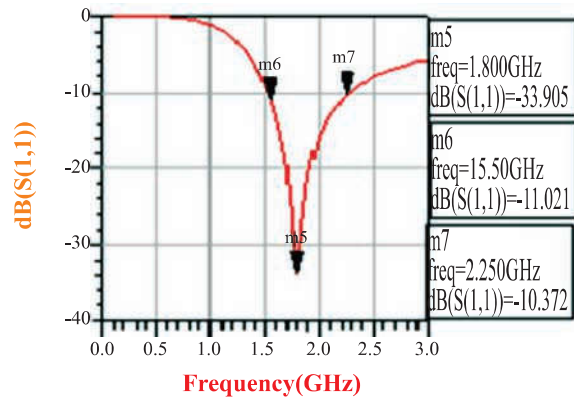


Fig. 20. Shows Bandwidth at 1800MHz

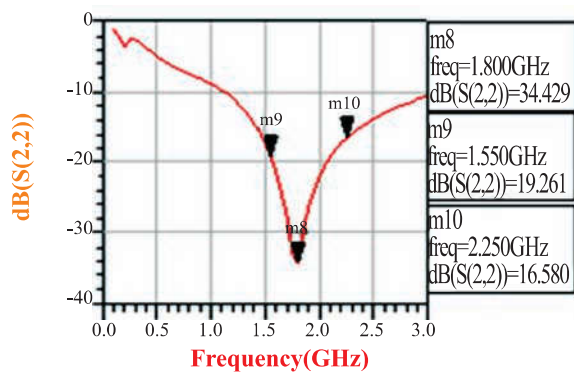


Fig. 21. Shows Output reflection coefficients at 1800MHz

The result of Output Reflection Coefficient is demonstrated in Figure 21. Markers positioned at required bandwidth and preferred frequency.

VI. DUAL BAND LNA

As discussed earlier, we designed the Dual Band matching network from the two single Band matching network circuits with operating frequencies at 900MHz and 1800MHz. This describes the results of the final Dual Band Low Noise Amplifier working at both 900 MHz and 1800MHz concurrently. The circuit diagram shown in Fig. 22 is used for making Dual Band Low Noise Amplifier.

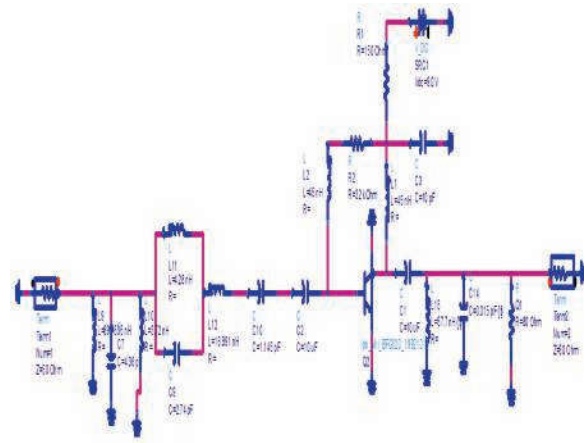


Fig. 22. Circuit diagram for Dual Band LNA

A. Results of dual band LNA

Output and input transmission of dual band LNA is depicted in figures 23 and 24 respectively. LNA has a forward gain of 14.13dB and 8.52 dB at 900MHz and 1800MHz respectively.

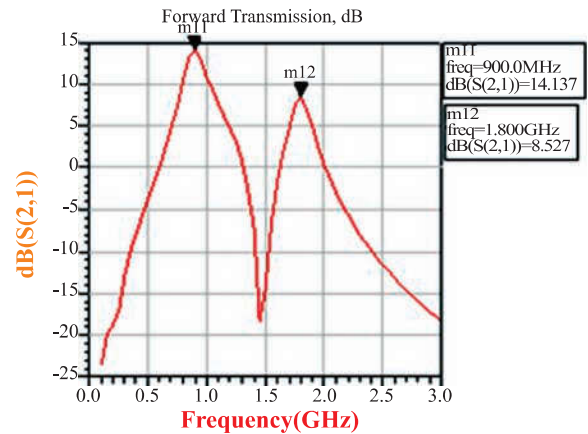


Fig. 23. Graph showing Forward transmission

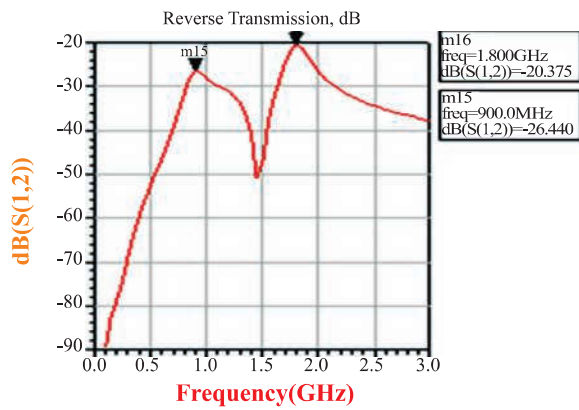


Fig. 24. Graph showing Reverse transmission

Fig. 24 shows Reverse Transmission (RT), by designing the biasing network and setting all the values of components for Low noise amplifier, the values of RT obtained are -26.44 dB and -20.375 dB at 900MHz and 1800MHz respectively.

Figures 25 and 26 depict the results of output reflection and input reflection coefficients respectively on Smith Chart at 900MHz and 1800MHz.

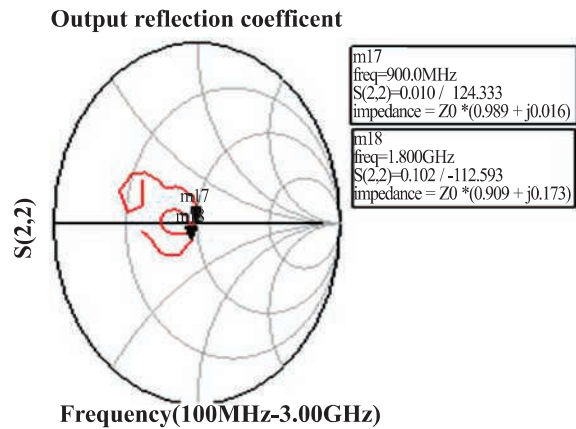


Fig. 25. Output reflection coefficient on smith chart

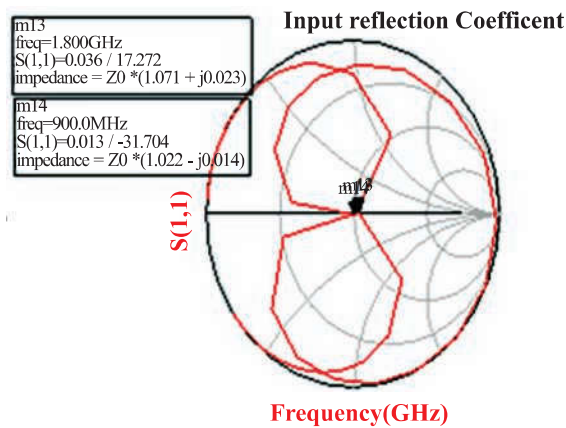


Fig. 26. Input reflection coefficient on smith chart

Fig. 27 shows the curve of minimum noise and the actual noise of dual band design at 1800MHz and 900MHz. Two curves (blue and red) show the curve of minimum noise in between frequency ranges of 0GHz to 3.0GHz and the actual noise of designed network of similar frequency ranges, respectively. Value of minimum noise figure and the actual noise figure at 1800MHz is 1.847 and 2.717 respectively and values of minimum noise and the actual noise at 900MHz is 1.01 and 1.195 respectively.

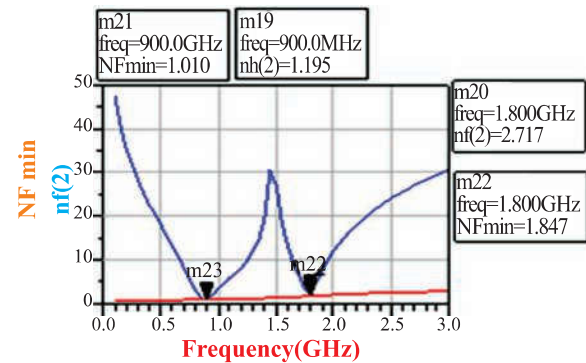


Fig. 27. Graph shows Noise Figure

For the stability check following plot in Figure 28 shows that the LNA is stable for desired frequency range.

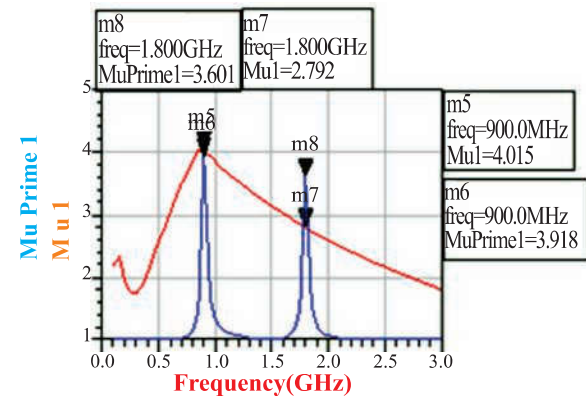


Fig. 28. Graph shows unconditionally stable

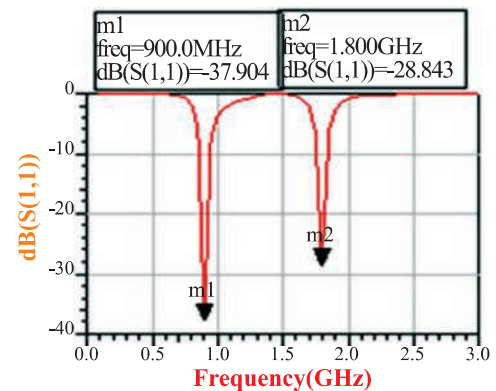


Fig. 29. Shows Bandwidth

Fig. 29. Shows the two operating bands of dual band LNA marked at 900MHz and 1800MHz.

VII. RESULTS AND DISCUSSIONS

The results obtained are summarized in table I and II respectively, the single band LNA at 900 MHz achieved the noise figure of 1.2dB while at 1800MHz it is 2.6dB and our dual band design has provided the noise figure of 1.19dB and 2.71dB for 900MHz/1800MHz respectively drawing 100mA current from 9V power supply with power consumption of 0.9 Watt. Signal gain for 900MHz/1800MHz achieved the values of 14.13dB and 8.52 dB.

The results clearly elaborate performance of dual band single stage LNA, the appropriate input and output matching network for the given amplifier has provided efficient gain and minimum noise figure. The design of Low Noise Amplifier is completed using ADS simulations.

Moreover, an RF dual band LNA with working frequency of 900MHz and 1800MHz was designed, simulated, and built. The results suggest that the amplifier have a comparatively high gain which keeps the amplifier intrinsically stable at all the frequencies.

TABLE I
SUMMARY OF VOLTAGE GAIN AND NOISE FIGURE

Frequency	0.9 GHz	1.8 GHz
Voltage Gain	14.138dB	8.577dB
Noise Figure	1.19dB	2.71dB
DC Current	100mA	100mA

TABLE II
SUMMARY OF CONCURRENT DUAL BAND LNA PERFORMANCE

Specification Name	LNA at 900 MHz	LNA at 1800MHz	Dual Band LNA at 900MHz and 1800MHz	
Center Frequency	900 MHz	1800MHz	900 MHz	1800MHz
Bandwidth	>300MHz	>300MHz	100MHz	100MHz
Small signal Gain	14.13 dB	8.57 dB	14.13 dB	8.52 dB
Return loss (input, output)	-40 dB	-34 dB	-37.9 dB	-28.8 dB
Noise Figure	1.2 dB	2.6 dB	1.19 dB	2.71 dB
Supply Voltage	9V			
DC current	100mA			

VIII. CONCLUSIONS

Aim of this research is to model a conventional design for the Low Noise Amplifier, which is efficient

Co-design procedure for Dual-band Low Noise Amplifier.

Small signal gain is achieved above 14 dB with the noise figure of 1.19 dB and 2.71 dB for 900MHz and 1800MHz respectively.

If the less lossy RF substrate and high quality factor (Q) inductors are available, it will be possible to design true concurrent LNAs with better performance.

We plan to extend this design for tunable multi-band LNAs with more selective load filter using high quality factor (Q) inductors and minimizing the power consumption.

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