Design of Highly Integrated Single to Balanced Bandpass Low Noise Amplifier at 900MHz for Cognitive Radio Applications

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Abstract—A highly integrated radio frequency front end with three functions such as RF Filter, Balun and Low noise amplifier (LNA) is proposed in this paper. Input matching for LNA will be accomplished using band pass filter and output matching will be done using micro strip Balun. Single to differential low noise amplifier with two functions together will be best suited for RF front end architecture and can be used directly with double balanced mixer. The integration of the blocks will reduce the size. The noise figure of the whole integrated design is 0.47 dB, very less and gain is high at the same time. Bandpass LNA can be used for the cognitive radio applications. To demonstrate the performance and effectiveness of the proposed design method, a 900MHz single-to-balanced bandpass LNA with Microstrip Balun will be implemented on printed circuit board using packaged E-pHEMT transistor.

Keywords—balun, bandpass filter, cognitive radio, Low noise amplifier.

I. INTRODUCTION

Low noise amplifier is used to amplify the incoming weak signals without affecting them by noise, and to improve the signal parameters. The low noise amplifier is placed at the radio receiver RF front end. Receiver receives the radio waves and converts their information to a suitable form. It consists of major blocks as switch, band pass filter, low noise amplifier, balun and mixer. The information carried by the radio waves is affected by the noise. Noise which acts as an unwanted signal degrades the quality of information. So the noise parameter is of prime importance [1]. The low noise amplifier needs to have low noise figure, high gain and good stability to avoid oscillations.

Microwave circuit has functions such as low noise amplification, power amplification, mixing etc. In the early technology tubes structure was used for amplification in microwave. In the present technology the FET’s and transistors are used for amplification purpose. All the signal parameters are improved due to the use of transistors. In this design of low noise amplifier low noise figure, high gain, good stability and input output matching all these parameters should work together hand in hand [2].

Advanced cellular base stations have the requirement of low noise figure, high gain and good linearity from the amplifier. The low noise amplifier at the receiver of base station should fulfill all these needs. For the base stations the noise figure is preferred around 0.5dB [3]. LNA have wide area of applications in the ISM radios, GSM/WCDMA base stations and cognitive radio [2]-[3]. Next generation is influenced by compact design and products. The size of the circuit and design should be as small as possible. At the radio receiver, RF front end should be very compact for better and efficient design. Integration of all the available blocks is necessary. Therefore highly integrated circuit is much preferred for the receiver. The functional blocks should integrate in the single circuit so that the circuit size is reduced. The RF transceiver blocks can be integrated into a single circuit so that design becomes less bulky and of low cost. The main aim of the paper is to highly integrate the receive blocks. Blocks like band pass filter, LNA, balun and mixer can be integrated by making them work on the extended functionality. In this proposed work the single to balanced band pass filter is designed so that the filter block is reduced from the front end and also the balun due to the balancing technique [1].

In the field of wireless communication, research is being done on the cognitive radio and the spectrum sensing due to the spectrum scarcity. The principle of cognitive radio is to utilize the licensed spectrum without disturbing the primary user. The
way in which the spectrum is allotted for secondary user and utilization of band comes under the spectrum sensing and allocation. There are various applications in the cognitive radio field. The RF front end receiver used for the spectrum sensing and allocation consist of the filter, amplifier as discussed above [4]. The LNA used here needs to have low noise figure, high gain at the same time. The proposed LNA is in the ISM band and can be used for the cognitive radio applications.

II. PROPOSED BLOCK DIAGRAM

The single to balanced bandpass LNA is designed by using the following blocks.

![Block diagram](image)

The band pass filter act as the input matching network, band pass balun as the output matching network. So the required frequency selective small signal gain response can be achieved.

Band pass filter- it is an important block of communication system, it’s the essential part of the superhyterodyne receiver. The filter can be implemented by using lumped components, microstrip etc. the design style of the filter depends on the requirement of the size of filter and the frequency of operation.

Low noise amplifier- the amplifier amplifies the weak signals received by the antenna. The LNA needs to have high gain, low noise figure, low power dissipation. Here the LNA can be designed by using any type of topology. The DC biasing is applied to the amplifier circuit. The DC voltage depends on the transistor’s voltage requirement being used for the amplifier design.

Bandpass balun- it’s a three port device. Balun stands for balanced unbalanced. Has a matched input and differential outputs. The differential output is equal and opposite. The balun can be implemented using the flux coupled transformers and microstrip. They both are interchangeable at lower frequencies.

III. CIRCUIT IMPLEMENTATION

The circuit simulation is done in the ADS (Advance Design System) software by the Agilent Company. The design using the lumped components and the Microstrip components is done, so it’s a mixed designing called as hybrid design.

A. Band pass filter:

RF input is applied to the band pass filter which will accept only the signals within selected band. In this design the filter is designed for 900MHz and the frequency band taken is from 800 MHz to 1GHz. Filter can be designed by using the lumped components if there is no size constraint. Here the filter size becomes crucial due to the overall integration of the circuit. Microstrip filters are compact and essential part in many RF applications. Hairpin filter is a popular micro strip filter configuration. It’s designed by folding back the ends into ‘U’ shape. Due to this folding technique the size of the filter is reduced. Parallel coupled filter size is greatly reduced by the hairpin filter due to the folding mechanism. The parameter as width, length and spacing are decided for designing. Spacing is kept same for all the parallel lines in the filter. Width of the coupled lines is larger than the gap between them.

![Schematic of hairpin filter](image)

The figure 2 above is implemented in the ADS software. The S11 (input return loss), S21 parameters are plotted. The S11 is the input return loss and S21 is for insertion loss. The insertion loss should be ideally zero.

B. Low noise amplifier:

For the design of the single stage low noise amplifier the BJT transistor is used. LNA designing has various topologies such as common source, common gate topology. Here in the proposed design the band pass balanced LNA with common source architecture with inductive source degeneration is selected for the active stage. This architecture is decided by considering the constrain between low noise figure and high gain at the same time. In this inductive degeneration method the inductor which has the voltage series topology is responsible for the stability of the circuit. BJT transistor used is the ATF 54143 of Avago Company. ATF 54143 is a low noise enhancement mode PHEMT transistor. Features of this transistor are the high linearity, low noise figure and 800 um gate width [6]. Biasing voltage for the amplifier is 2V and current is 30 mA. The input impedance and output impedance matching to the amplifier circuit is provided through the inductor. The microstrip line is used as an inductor by setting the length and width for the active stage topology.
The above design, fig. 3 is implemented in the ADS. The S11 (input return loss), S22 (output return loss) and S21 (gain) are plotted. The stability is checked of the overall circuit which is 1.2 i.e. above 1, and the noise figure is calculated.

C. Balun:

Balun is used to connect balanced circuit to unbalanced circuit. They have 180° phase shift and equal balanced impedance. There are many ways in which balun can be designed such as with lumped components (L, C) and the transmission line balun made using the co-axial cable from a λ/4 length of wire. Here we are using the microstrip balun. Methods of designing the balun are Ruthroff balun, Guanella and Marchand balun. Design of the Marchand balun consist of the λ/4 length of wire. There is unbalanced port at the input and a balanced port at the output. It provides the isolation from primary [5].

\[ S_{11} = 0 \] \hspace{1cm} (1)
\[ S_{21} = -S_{31} \] \hspace{1cm} (2)

\[ Z_{a} = \text{unbalanced port impedance} \]
\[ Z_{b} = \text{balanced port impedance} \]

The marchand balun is designed using the microstrip transmission line. The \( S(2, 1) \) and \( S(3, 1) \) are plotted to measure the output ports 2 and 3.

IV. SIMULATION AND RESULT

ADS (Advance Design System) software is used for the simulation of the circuit. It is software developed by the Agilent Company. The simulations of the band pass filter, low noise amplifier and balun is done in the ADS. EM simulation is carried out for all the 3 blocks in the integrated form. Co simulation is done of all three blocks together. The parameters such as S11, S21, S31, noise figure and stability are plotted for the whole integrated circuit.

The noise related parameters are the noise factor (F) and the noise figure. The noise figure is defined as the difference between the SNR in and SNR out. Noise figure is required to be very less; in the proposed design the overall noise figure is 0.479 dB which is less than 0.5 dB so can be used for base stations.

\[ \text{Fig. 5. Schematic of the marchand balun} \]

\[ \text{Fig. 6. Stability Vs frequency} \]

Input return loss (S11) is measured at the same port to calculate loss due to incident and the reflected signal. The ideal value of S11 should be below -10 dB. It shows signal reflected at port 1 for the incident signal at port 1. Similarly the S22 at the output port also should be below -10 dB.
Figure 7 shows the input return loss S (1, 1) measured at the input port 1. The S11 value is below -10 dB, it is -13 dB at 900 MHz. The figure 8 below shows the gain S (2, 1) of the overall integrated circuit. Gain is 15.4 dB at 900 MHz of all the 3 stages integrated together.

The figure 9 below shows the balanced output from balun. S(2, 1) and S(3, 1) are the output at the port 2 and port 3 with respect to port 1. There is a small difference between the two outputs.

The figure 10 shows the phase angle. The phase difference between the balanced outputs at port 2 and port 3 should be 180 degree. In the figure, the phase difference is 178.4.

ACKNOWLEDGMENT

The designs and simulations were done in ADS (Advanced Design System) at SM wireless solutions, Hadapsar, Pune. The authors would like to thank R. Wekhande for making the resource available.

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